EXPERIMENT 2. VECTORS

LABORATORY PROTOCOL

OBJECTIVES:

Verify the methods of vector algebra using experimental, graphical, and analytical techniques.

PRINCIPLES:

A vector is a mathematical entity having magnitude and direction. An arrow in space may geographically represent it, with its length proportional to the vector's magnitude.

Vectors obey certain rules of combination (such as addition and multiplication) that are similar to that of ordinary algebra. These combinations also follow distributive and commutative axioms. However, two vectors are equal only if they have equal magnitudes and direction and division by a vector is meaningless. It is also worthwhile to mention that the negative of a vector is a vector with the same magnitude but opposite in direction.

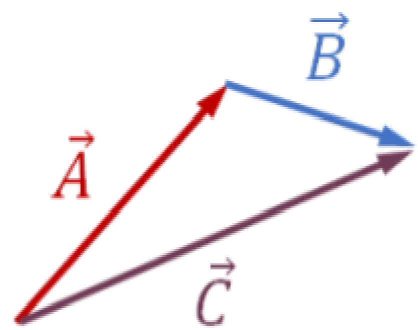

Figure 2.1. Tail tip method of determining the vector sum of vectors

Figure 1 shows vectors A and B and illustrates how the vector sum (or resultant) C is obtained. The tail of the second vector is placed at the head of the first vector and the resultant is determined by drawing a vector from the tail of A to the head of B. Physically, A and B can be the scaled representations of consecutive displacements of a particle. Say A represents displacement from point a to b and B from b to c. The resultant vector C can then be interpreted as the scaled representation of the effective displacement that gives the same effect (i.e, transfer of the particle from point a to point c). Thus we see that

$$\mathbf{C} = \mathbf{A} + \mathbf{B} \qquad \text{(Eq 2.1)}$$

The actual displacement represented by vector C can be determined graphically by measuring the direction of the displacement relative to some reference orientation and length of the vector C relative to a scale. From Eq 1, we see that we can set A and B to be perpendicular to each other. Thus, we can always choose any two perpendicular vectors that sum to any vector. Fixing these perpendicular directions is equivalent to choosing an x- and y-axis in a plane. Any vector lying in an x-y plane can therefore be represented as the resultant of a vector parallel to the x-axis and a vector parallel to the y-axis. These vectors are called x- and y-component vectors, respectively. This is illustrated for vectors A, B, and C in figure 2. The component vectors can completely describe a vector. Given the components, the magnitude and direction of a vector can be determined by,

$$|A| = \sqrt{A_x^2 + A_y^2} \qquad \text{(Eq 2.2)}$$

$$tan\theta = \frac{A_y}{A_x} \qquad \text{(Eq 2.3)}$$

The components can also be used to determine the resultant vectors. Let's illustrate this for vectors A and B discussed above: Since $A = A_x + A_y$ and $B = B_x + B_y$, the resultant of A and B can be expressed as the sum of the component vectors.

Rearranging the terms (commutatively), as well as grouping terms together (associatively) we obtain:

$$C = (A_x + B_x) + (A_y + B_y) \qquad \text{(Eq 2.4)}$$

The sum (Ax + Bx) is parallel to the x-axis while the sum (Ay + By) is parallel to the y-axis. Therefore, they are the components of the resultant C

$$C_x = A_x + B_x \qquad \text{(Eq 2.5)}$$

and

$$C_y = A_y + B_y \qquad \text{(Eq 2.6)}$$

The equilibrant of a set of forces is the single force that must be combined with the set of forces to maintain the system in equilibrium. The equilibrant (sometimes called antiresultant) must be equal in magnitude but opposite in direction to the resultant vector.

MATERIALS

- Force Table
- Set of weights
- Block of wood
- Platform Balance
- Graphing Paper

- Ruler
- Bubble Level

PROCEDURE:

Let's play "Keep The Ring At The Center'
(a.k.a KTRATC)

Your objective is to keep the ring at the center (a.k.a. KTRATC) by pulling at different directions around the ring so that you maintain equilibrium. You can vary the pulling magnitude by changing the hanging mass. You can vary the pulling direction by adjusting the position of the pulley.

- Before starting the experiment, use the bubble level to check if the force table is in level. If it is not, adjust the legs of the force table until it is at level.
- Connect a thread to the ring. Attach a 200 g mass (including the mass of pan) to the other end of the string; this is your hanging mass 1. Attach the pulley at 210 degrees and let the thread pass through the pulley. Do not disturb the hanging mass unless you are told to do so.

CASE 1: Add another pulley and mass. Adjust the magnitude (mass) and position (angle) of this hanging mass to KTRATC. Record the angle and mass to table 2.1. (Total Masses Hanging = 2)

CASE 2: Use two different pulleys to KTRATC (i.e., two different masses at different positions). Record the magnitudes and positions. (Total Hanging Masses = 3)

CASE 3: From the set up in case 2, change the position of one of the pulleys by at least 10 degrees. Once adjusted, DO NOT MOVE THE PULLEYS ANYMORE. (Total Hanging Masses = 3)

A. Try to KTRATC by adjusting only the magnitude of this hanging mass. Were you able to KTRATC?
B. If it is not possible to KTRATC by just changing the magnitude of the hanging mass, try adjusting its position by at least 10 degrees as well.

CASE 4: Set the two added hanging mass to be perpendicular with each other. Try adjusting the magnitude of both hanging masses to KTRATC. (Total Hanging Masses = 3)

CASE 5: Use three different pulleys to KTRATC. Vary the magnitudes and positions to KTRATC. (Total Hanging Masses = 4)

The analytical column in table 2.2 is filled out by computing for the resultant of hanging mass 1,2, and 3 for each case then taking the equilibrant of the resultant. The theoretical equilibrant is the hanging mass 1.

Graph all the hanging masses' magnitude and direction for each case as accurately as possible. Indicate your scale. From the graphs, determine the resultants and equilibrants. No calculations will be done. The data will come from purely with the use of a pen, paper, protractor, and ruler. Input the equilibrant for each case under the graphical column in table 2.3.

Now, remove all the hanging masses and replace hanging mass 1 with a block of wood of unknown mass.

TRIAL 1: Add two hanging masses with equal magnitude and try to KTRATC by adjusting the position of both the hanging masses. If you can't, adjust the hanging masses' magnitudes (but keep them equal) and try again.

TRIAL 2: Once you were able to KTRATC, increase the hanging masses' magnitude (but keep them equal) and adjust the position to KTRATC again.

Measure the actual mass of the block using the platform balance. Then, from your data, calculate the mass of the block of wood.

WORKSHEET

Table 2.1. Experimental Data

CASE	Hanging Mass 1		Hanging Mass 2		Hanging Mass 3		Hanging Mass 4	
	M(g)	P(°)	M(g)	P(°)	M(g)	P(°)	M(g)	P(°)
1	200	210	200	30				
2	200	210	200	90	200	330		
3	200	210	220	100	250	330		
4	200	210	70	100	200	10		
5	200	210	200	120	200	30	200	300

Table 2.2. Percentage Error of Equilibrant (through calculation)

CASE	THEORETICAL		ANALYTICAL		ERROR	
	M(g)	P(°)	M(g)	P(°)	M(g)	P(°)
1	200	210	200	210	0	0
2	200	210	200	210	0	0
3	200	210	200	207	0	1.4
4	200	210	212	209	6	0.5
5	200	210	200	210	0	0

Table 2.3. Percentage Error of Experiment Equilibrant (through graphing)

CASE	THEORETICAL		GRAPHICAL		ERROR	
	M(g)	P(°)	M(g)	P(°)	M(g)	P(°)
1	200	210	200	210	0	0
2	200	210	200	210	0	0
3	200	210	200	207	0	1.4
4	200	210	212	210	6.0	0
5	200	210	200	210	0	0

Table 2.4. Unknown Mass

TRIAL	HANGING MASS 1		HANGING MASS 2		$MASS_{CALC}$ (g)	$MASS_{ACTUAL}$ (g)	%ERROR
	M(g)	P(°)	M(g)	P(°)			
1	120	90	120	330	120	125	4.0
2	150	95	150	325	127	125	1.6

CALCULATIONS:

In Table 2.2, the analytical mass, or magnitude, of the equilibrant was determined by calculating the x and y components of the combined hanging masses using the following formula

$$A_x = A\cos\theta \quad \text{(Eq 2.7)}$$

$$A_y = A\sin\theta \quad \text{(Eq 2.8)}$$

where the components are determined based on the added hanging masses and the positions identified in Table 2.1.

Table 2.5 Calculations for the X and Y Components of the Hanging Masses

Case 1	X Component	Y Component
1	$A_{1x} = (200)cos(30)$ $A_x = 173.2$	$A_{1y} = (200)sin(30)$ $A_y = 100$
2	$A_{1x} = (200)cos(90)$ $A_{1x} = 0$ $A_{2x} = (200)cos(330)$ $A_{2x} = 173.2$ $A_x = A_{1x} + A_{2x}$ $A_x = 173.2$	$A_{1y} = (200)sin(90)$ $A_{1y} = 200$ $A_{2y} = (200)sin(330)$ $A_{2y} = -100$ $A_y = A_{1x} + A_{2x}$ $A_y = 100$
3	$A_{1x} = (220)cos(100)$ $A_{1x} = - 38.2$ $A_{2x} = (250)cos(330)$	$A_{1y} = (220)sin(100)$ $A_{1y} = 216.7$ $A_{2y} = (250)sin(330)$

	$A_{2x} = 216.5$ $A_x = A_{1x} + A_{2x}$ $A_x = 178.3$	$A_{2y} =- 125$ $A_y = A_{1x} + A_{2x}$ $A_y = 91.7$
4	$A_{1x} = (70)cos(100)$ $A_{1x} =- 12.2$ $A_{2x} = (200)cos(10)$ $A_{2x} = 197$ $A_x = A_{1x} + A_{2x}$ $A_x = 184.8$	$A_{1y} = (70)sin(100)$ $A_{1y} = 68.9$ $A_{2y} = (200)sin(10)$ $A_{2y} = 34.7$ $A_y = A_{1x} + A_{2x}$ $A_y = 103.6$
5	$A_{1x} = (200)cos(120)$ $A_{1x} =- 100$ $A_{2x} = (200)cos(30)$ $A_{2x} = 173.2$ $A_{3x} = (200)cos(300)$ $A_{3x} = 100$ $A_x = A_{1x} + A_{2x} + A_{3x}$ $A_x = 173.2$	$A_{1y} = (200)sin(120)$ $A_{1y} = 173.2$ $A_{2y} = (200)sin(30)$ $A_{2y} = 100$ $A_{3y} = (200)sin(300)$ $A_{3y} =- 173.2$ $A_y = A_{1y} + A_{2y} + A_{3y}$ $A_y = 100$

To calculate for the analytical mass, Eq 2.2 was used.

Table 2.6 Calculations for the Analytical Mass of the Hanging Masses

CASE	Analytical Mass
1	$\lvert A\rvert = \sqrt{A_x^2 + A_y^2}$ $\lvert A\rvert = \sqrt{(173.2)^2 + (100)^2}$ $\lvert A\rvert = 200$

2	$$\lvert A \rvert = \sqrt{A_x^2 + A_y^2}$$ $$\lvert A \rvert = \sqrt{(173.2)^2 + (100)^2}$$ $$\lvert A \rvert = 200$$
3	$$\lvert A \rvert = \sqrt{A_x^2 + A_y^2}$$ $$\lvert A \rvert = \sqrt{(178.3)^2 + (91.7)^2}$$ $$\lvert A \rvert = 200$$
4	$$\lvert A \rvert = \sqrt{A_x^2 + A_y^2}$$ $$\lvert A \rvert = \sqrt{(184.8)^2 + (103.6)^2}$$ $$\lvert A \rvert = 212$$
5	$$\lvert A \rvert = \sqrt{A_x^2 + A_y^2}$$ $$\lvert A \rvert = \sqrt{(173.2)^2 + (100)^2}$$ $$\lvert A \rvert = 200$$

For the analytical position, or direction, of the equilibrant, Eq 2.3 was utilized for each case. To determine the direction of the equilibrant, an additional 180 degrees was incorporated. Based on the x and y components obtained, the following results are presented

Table 2.7 Calculations for the Analytical Position of the Hanging Masses

CASE	Analytical Position
1	$$tan\,\theta = \frac{A_y}{A_x}$$ $$tan\,\theta = \frac{100}{173.2}$$ $$\theta = 30^{\circ}$$ Position of the Equilibrant (P) = $30^{\circ} + 180^{\circ}$ P = 210°
2	$$tan\,\theta = \frac{A_y}{A_x}$$ $$tan\,\theta = \frac{100}{173.2}$$ $$\theta = 30^{\circ}$$ Position of the Equilibrant (P) = $30^{\circ} + 180^{\circ}$

	P = 210°
3	$tan\,\theta = \frac{A_y}{A_x}$ $tan\,\theta = \frac{91.7}{178.3}$ $\theta = 27^{\circ}$ Position of the Equilibrant (P) = $27^{\circ} + 180^{\circ}$ P = 207°
4	$tan\,\theta = \frac{A_y}{A_x}$ $tan\,\theta = \frac{103.6}{184.8}$ $\theta = 29^{\circ}$ Position of the Equilibrant (P) = $29^{\circ} + 180^{\circ}$ P = 209°
5	$tan\,\theta = \frac{A_y}{A_x}$ $tan\,\theta = \frac{100}{173.2}$ $\theta = 30^{\circ}$ Position of the Equilibrant (P) = $30^{\circ} + 180^{\circ}$ P = 210°

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To calculate the percentage error for the determined mass and position, the following equation was employed.

$$\%error = \left|\frac{analytical - theoretical}{theoretical}\right| \times 100\% \quad \text{(Eq 2.9)}$$

where, given the theoretical mass 200g and position 210°, we have

Table 2.8 Calculations for the Percentage Error Between Theoretical and Calculated Analytical Data

CASE	Percentage Error of Mass	Percentage Error of Position
1	$\%error = \left\|\frac{analytical - theoretical}{theoretical}\right\| \times 100\%$	$\%error = \left\|\frac{analytical - theoretical}{theoretical}\right\| \times 100\%$

	$\%error = \left\|\frac{200-200}{200}\right\| \times 100\%$ $\%error = 0$	$\%error = \left\|\frac{210-210}{210}\right\| \times 100\%$ $\%error = 0$
2	$\%error = \left\|\frac{analytical - theoretical}{theoretical}\right\| \times 100\%$ $\%error = \left\|\frac{200-200}{200}\right\| \times 100\%$ $\%error = 0$	$\%error = \left\|\frac{analytical - theoretical}{theoretical}\right\| \times 100\%$ $\%error = \left\|\frac{210-210}{210}\right\| \times 100\%$ $\%error = 0$
3	$\%error = \left\|\frac{analytical - theoretical}{theoretical}\right\| \times 100\%$ $\%error = \left\|\frac{200-200}{200}\right\| \times 100\%$ $\%error = 0$	$\%error = \left\|\frac{analytical - theoretical}{theoretical}\right\| \times 100\%$ $\%error = \left\|\frac{207-210}{210}\right\| \times 100\%$ $\%error = 1.4$
4	$\%error = \left\|\frac{analytical - theoretical}{theoretical}\right\| \times 100\%$ $\%error = \left\|\frac{212-200}{200}\right\| \times 100\%$ $\%error = 6.0$	$\%error = \left\|\frac{analytical - theoretical}{theoretical}\right\| \times 100\%$ $\%error = \left\|\frac{209-210}{210}\right\| \times 100\%$ $\%error = 0.5$
5	$\%error = \left\|\frac{analytical - theoretical}{theoretical}\right\| \times 100\%$ $\%error = \left\|\frac{200-200}{200}\right\| \times 100\%$ $\%error = 0$	$\%error = \left\|\frac{analytical - theoretical}{theoretical}\right\| \times 100\%$ $\%error = \left\|\frac{210-210}{210}\right\| \times 100\%$ $\%error = 0$

To solve for the percentage error in Table 2.3, Eq 2.9 was also utilized.

Table 2.9 Calculations for the Percentage Error Between the Theoretical and Graphical Data

CASE	Percentage Error of Mass	Percentage Error of Position
1	$\%error = \left\|\frac{analytical - theoretical}{theoretical}\right\| \times 100\%$ $\%error = \left\|\frac{200-200}{200}\right\| \times 100\%$ $\%error = 0$	$\%error = \left\|\frac{analytical - theoretical}{theoretical}\right\| \times 100\%$ $\%error = \left\|\frac{210-210}{210}\right\| \times 100\%$ $\%error = 0$
2	$\%error = \left\|\frac{analytical - theoretical}{theoretical}\right\| \times 100\%$ $\%error = \left\|\frac{200-200}{200}\right\| \times 100\%$ $\%error = 0$	$\%error = \left\|\frac{analytical - theoretical}{theoretical}\right\| \times 100\%$ $\%error = \left\|\frac{210-210}{210}\right\| \times 100\%$ $\%error = 0$

3	$\%error = \left\lvert\frac{analytical - theoretical}{theoretical}\right\rvert \times 100\%$ $\%error = \left\lvert\frac{200-200}{200}\right\rvert \times 100\%$ $\%error = 0$	$\%error = \left\lvert\frac{analytical - theoretical}{theoretical}\right\rvert \times 100\%$ $\%error = \left\lvert\frac{207-210}{210}\right\rvert \times 100\%$ $\%error = 1.4$
4	$\%error = \left\lvert\frac{analytical - theoretical}{theoretical}\right\rvert \times 100\%$ $\%error = \left\lvert\frac{212-200}{200}\right\rvert \times 100\%$ $\%error = 6.0$	$\%error = \left\lvert\frac{analytical - theoretical}{theoretical}\right\rvert \times 100\%$ $\%error = \left\lvert\frac{210-210}{210}\right\rvert \times 100\%$ $\%error = 0$
5	$\%error = \left\lvert\frac{analytical - theoretical}{theoretical}\right\rvert \times 100\%$ $\%error = \left\lvert\frac{200-200}{200}\right\rvert \times 100\%$ $\%error = 0$	$\%error = \left\lvert\frac{analytical - theoretical}{theoretical}\right\rvert \times 100\%$ $\%error = \left\lvert\frac{210-210}{210}\right\rvert \times 100\%$ $\%error = 0$

For Table 2.4, the equations Eq 2.7 and Eq 2.8 were used to calculate the x and y components of the combined hanging masses.

Table 2.10 Calculations for the X and Y Components of the Hanging Masses

Case 1	X Component	Y Component
1	$A_{1x} = (120)cos(90)$ $A_x = 0$ $A_{2x} = (120)cos(330)$ $A_{2x} = 103.9$ $A_x = A_{1x} + A_{2x}$ $A_x = 103.9$	$A_{1y} = (120)sin(90)$ $A_y = 120$ $A_{2y} = (120)sin(330)$ $A_{2y} = -60$ $A_y = A_{1x} + A_{2x}$ $A_y = 60$
2	$A_{1x} = (150)cos(95)$ $A_{1x} = -13.1$ $A_{2x} = (150)cos(325)$ $A_{2x} = 122.9$ $A_x = A_{1x} + A_{2x}$ $A_x = 109.8$	$A_{1y} = (150)sin(95)$ $A_{1y} = 149.4$ $A_{2y} = (150)sin(325)$ $A_{2y} = -86$ $A_y = A_{1x} + A_{2x}$ $A_y = 63.4$

To calculate the mass, Eq 2.2 was used.

Table 2.11 Calculations for the Calculated Mass of Trial 1 and 2

CASE	Analytical Mass
1	$\lvert A\rvert = \sqrt{A_x^2 + A_y^2}$ $\lvert A\rvert = \sqrt{(103.9)^2 + (60)^2}$ $\lvert A\rvert = 120$
2	$\lvert A\rvert = \sqrt{A_x^2 + A_y^2}$ $\lvert A\rvert = \sqrt{(109.8)^2 + (63.4)^2}$ $\lvert A\rvert = 126.8$

For the analytical position, or direction, of the equilibrant, Eq 2.3 was also utilized for each case. To determine the direction of the equilibrant, an additional 180 degrees was incorporated. Based on the x and y components obtained, the following results are presented

Table 2.12 Calculations for the Calculated Position of Trial 1 and 2

CASE	Analytical Position
1	$tan\,\theta = \frac{A_y}{A_x}$ $tan\,\theta = \frac{60}{103.9}$ $\theta = 30^{\circ}$ Position of the Equilibrant (P) = $30^{\circ} + 180^{\circ}$ P = 210°
2	$tan\,\theta = \frac{A_y}{A_x}$ $tan\,\theta = \frac{63.4}{109.8}$ $\theta = 30^{\circ}$ Position of the Equilibrant (P) = $30^{\circ} + 180^{\circ}$ P = 210°

To calculate the percentage error for the determined mass and position, Eq 2.9 was also employed, where the actual mass was 125g. We have,

Table 2.13 Calculations for the Percentage Error Between Calculated Mass and the Actual Mass

CASE	Percentage Error of Mass
1	$\%error = \left\lvert \frac{analytical - theoretical}{theoretical} \right\rvert \times 100\%$ $\%error = \left\lvert \frac{125 - 120}{120} \right\rvert \times 100\%$ $\%error = 4$
2	$\%error = \left\lvert \frac{analytical - theoretical}{theoretical} \right\rvert \times 100\%$ $\%error = \left\lvert \frac{125 - 127}{120} \right\rvert \times 100\%$ $\%error = 1.6$

GRAPHS:

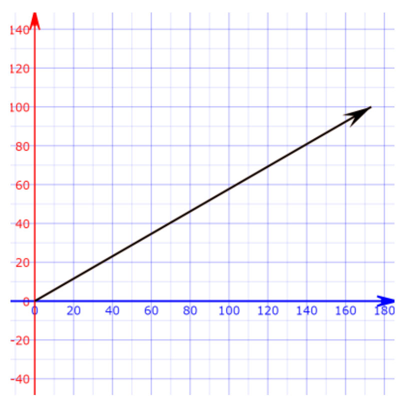

Figure 1. Graph of Case 1

Figure 1 shows the graph for case 1, with a vector of 200g magnitude at 30°. The equilibrant would simply be its anti-parallel, 200g at 210°.

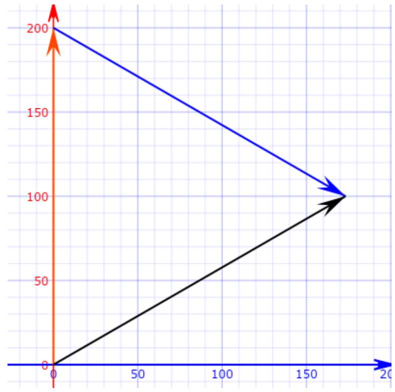

Figure 2. Graph of Case 2

Figure 2 shows the graph of case 1, with vectors 200g magnitude at 90° and 200g magnitude at 330°. This results in a resultant vector of 200g magnitude at 30° and an equilibrium of 200g magnitude at 210°.

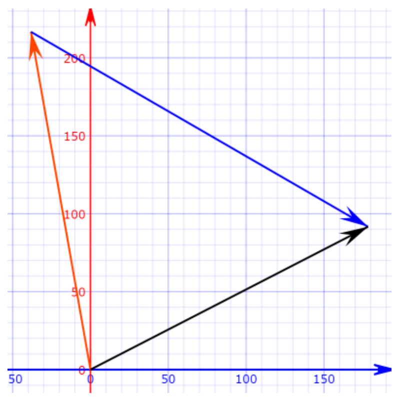

Figure 3. Graph of Case 3

Figure 3 shows the graph of case 3, with vectors 220g magnitude at 100° and 250g magnitude at 330°. This results in a resultant vector of 200g magnitude at 27° and an equilibrant of 200g magnitude at 207°.

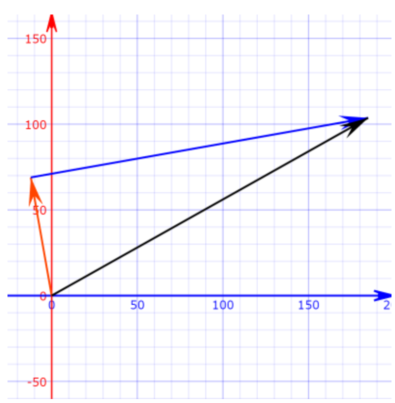

Figure 4. Graph of Case 4

Figure 4 shows the graph of case 4, with vectors 70g magnitude at 100° and 200g magnitude at 10°. This results in a resultant vector of 212g magnitude at 30° and an equilibrant of 212g magnitude at 210°.

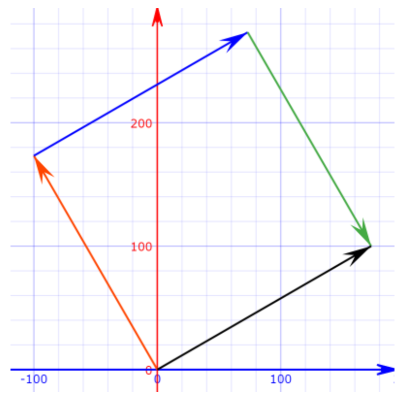

Figure 5. Graph of Case 5

Figure 5 shows the graph of case 5, with vectors 200g magnitude at 120°, 200g magnitude at 30°, and 200g magnitude at 300°. This results in a resultant vector of 210g magnitude at 30° and an equilibrant of 210g magnitude at 210°.

OBSERVATIONS:

Accordingly, components of a vector can determine its resultant and antiresultant through three ways namely; experimental, graphical, and analytical techniques using a force table. As such, this experiment aims to verify the different methods of vector algebra through KTRATC where direction, magnitude, and mass can be manipulated. Moreover, vector algebra is used to help determine the unknown mass of a block of wood.

Exposed to new things, various complications were met but were properly resolved. One problem however persists during data gathering where the ring was indeed at the center but not grounded on the table. Moreover, since it was being pulled in different directions, the ring was slightly tilted but nonetheless centered. Perhaps it is due to this that the force table was not entirely in equilibrium as proven mathematically and with respect to the percentage error. A small percentage but worth noting as this affects the result in case four.

On determining the magnitude and angles graphically, two methods were implemented namely hand-drawn using head-to-tail method and using software. It has been observed that proportional error, specifically scale factor error occurred to the hand-drawn vectors due to different rulers and protractors used. However, since the error is less than 10%, the data is still valid. Moreover, no specific software was mentioned so this was utilized and proven accurate as some critical values under percentage error corresponds to that of using analytical technique.

With careful experimentation, only two out of the five cases had less than 10 percent error through calculations. This is due to the fact that the two positions for case three were adjusted by at least 10 degrees because doing only option A wasn’t enough to KTRATC while case four involved adjusting the positions to be perpendicular with each other. Point is, the positions were adjusted based on the procedure and with no interferences for readjustment until it's in equilibrium. Balancing case three for example was a challenge due to its perpendicular positions so it's understandable why the magnitude is higher compared to theoretical. Even with those minimal errors, both techniques are almost similar and yet graphical technique has proven to be better only due to the fact that it has no error in angle in case four.

Lastly, vector algebra was used to determine the unknown mass. As can be seen in the calculations of two trials under the unknown mass (see table 2.2),the average analytical magnitude in terms of grams was 124 with less than 5% error. This further verifies the validity and accuracy of vector algebra in determining the analytical mass.

GUIDE QUESTIONS:

1. Is there a limit in the number of hanging masses that may be used to KTRATC? Explain.
    - Theoretically, there are simply no restrictions on the number of hanging masses; in other words, the number of vectors of all forces is equal to zero. The system can maintain equilibrium be it the forces applied are one, two, or more so far as the components of the forces sum up to zero. However, as a matter of practicality, there are limitations when all the physical space on the force table is used. It gets complicated when more hanging masses are involved because more pulleys are needed to handle them.
2. How were the graphical technique and the analytical technique related? Which is more accurate?
    - The analytical technique isolates equations mathematically to solve each force into its x and y components, and when these are summed, this is checked to see if they are balanced; the algebraic sum of the x component equals zero, while the algebraic sum of the y component also equals zero. The graphical technique involves drawing forces as vectors on a diagram, and unlike the analytical instances where vectors are summed algebraically, here we use a protractor and ruler to draw the vectors to scale and then sum. Both techniques are used to confirm vector equilibrium. However, in terms of accuracy, the graphical technique is generally more accurate compared to the analytical method based on the acquired data (table 2.3) since it has yielded a lower percentage of errors. The graphical technique simplifies the checking of vectors to enhance equity since one can visually find any mistake or inaccuracy when calculating vectors since it displays the force vectors and enables one to easily determine vector equilibrium.
3. Based on the experiment, why is hanging mass 1 considered the equilibrant?
    - Hanging mass 1 is considered the equilibrant since it balances the other forces applied to the system, making sure that the ring stays in the center of the force table. In vector equilibrium, the equilibrant is the force that counteracts the resultant of all other forces. By adjusting its magnitude and angle, Hanging Mass 1 ensures the vector sum of all forces is zero, maintaining the system in equilibrium.

4. Throughout this experiment, we have used the units “grams’ to express the magnitude of the forces acting, and yet we know grams measure mass and not force. How can we be sure that the law of vector addition is being validly tested?
    - In this experiment, "grams" were used as a substitute for the magnitude of the force. Since the acceleration due to Earth's gravity in F = ma is constant, we can assume that the varying masses can represent the force under a different unit (grams). The force is directly proportional to the mass, with a constant and unchanging acceleration due to gravity for all the hanging masses. This ensures that the relationship between each mass and the force is consistent. Therefore, using grams to represent the magnitude of the force does not invalidate the law of vector addition.
5. When the ring is at the center, what is observed when one of the hanging masses is disturbed?
    - When one of the hanging masses changes its magnitude (grams) and/or angle, the equilibrium of the system is disrupted, requiring the adjustment of one or more hanging masses in order for their resultant to be equal in magnitude but opposite to the designated hanging mass representing the equilibrant on the force table.