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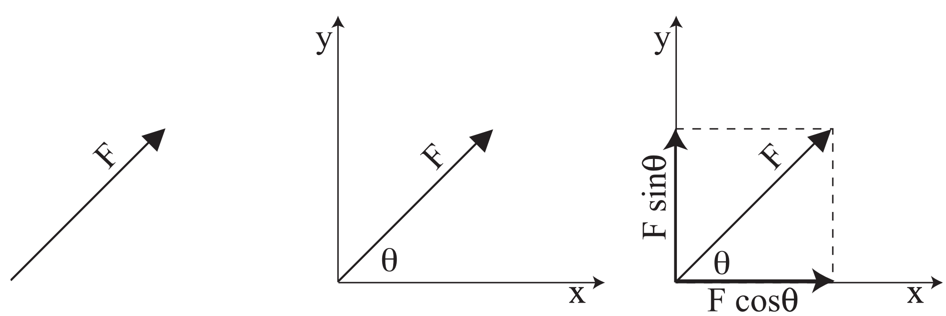
PHYS 231 Lab Exercise: The Vector Addition of Forces

Objective: The primary objective for this lab is to determine graphically, analytically, and experimentally the sum of several coplanar vectors. We'll do this by treating weight pulling in a given direction as a vector and adding the several weights pulling in different directions.

Introduction: While we have not discussed force in great detail yet, most of us would be comfortable to consider it to be the amount of pull or push an object feels. It turns out force is one example of a vector quantity, in that force has both magnitude and direction. In order to specify completely a vector quantity, like force, both magnitude and direction must be given.

If a number of non-parallel forces are acting at the same point on a body, it can be shown that a single force, equal to the vector sum of all the non-parallel forces, will produce the same effect on the body. Such a force is called the *resultant* of the original forces. The single force that holds a system of concurrent forces (forces acting through a common point) in equilibrium is called the *equilibrant* of the system. It is equal in magnitude to the resultant, but opposite in direction.

In today's lab, you will compute the sum of several force vectors, the *resultant* force, and then test that you have computed the sum correctly by trying to balance those original force vectors with an *equilibrant* force equal in magnitude but in the opposite direction as your computed *resultant* force.



Today you will find the sum of forces, the *resultant* force, by three methods:

1) **Graphical method:** A scale drawing is made on graph paper (included with this lab) in which the vectors to be added are placed head to tail. The resultant force (the sum of the forces) is obtained by drawing a vector from the tail of the first vector in the sum to the head of the last. The magnitude and direction of the resultant are obtained by measurement using a ruler and a protractor.

2) **Analytical method:** Using the laws of trigonometry, each vector in the sum is resolved into its components along the x and y axes:

$A_x = A \cos\theta$ and $A_y = A \sin\theta$

where A is the magnitude of the vector in question and θ is the direction of the vector relative to the x axis. These components are combined to find the components of the resultant. The magnitude and direction of the resultant force (the sum of the forces) is found using the Pythagorean Theorem and trigonometry, such that:

$$A = \sqrt{A_x^2 + A_y^2} \qquad \text{and} \qquad \theta = \tan^{-1}\frac{A_y}{A_x}$$

3) **Experimental method:** Masses corresponding to the magnitude and direction of each of the force vectors to be summed are arranged on a force table. These forces are balanced by an additional force, the *equilibrant* force, which is equal in magnitude to the vector sum of the forces in question, but in the opposite direction**.**

These three methods should give consistent results, we will see if they do today in lab.

Apparatus Used: Force table with four pulleys attached, set of slotted weights, v ruler, protractor.

Procedure:

Part I: Adding up Two Forces at Right Angles

What about units of force?
Since we have not discussed force due to gravity in detail, let us start with a simple (thus far untested) assumption. We will assume the force due to gravity will be proportional to the hanging mass: so 400g hanging will result in a force twice as big as a hanging mass of 200g. For units, we will simply invent a unit, equal to the force of gravity on a 1g mass, and call that a "U" (for "unit"). Thus, a 400g will result in a force of 400 U.

a) **Graphical Summation of 2 Force Vectors**
Let us initially consider two forces:

$\mathbf{F}_1$ = 400U @ 0˚
$\mathbf{F}_2$ = 300U @ 90˚

Compute the sum of these two force vectors graphically using the graph paper provided. ***In the space below, write down the length and direction of the sum of the 2 force vectors that you compute using this method.***

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b) **Analytical Summation of 2 Force Vectors**
Compute the sum of these two force vectors analytically (by components). ***Show your work below.***

c) **Determining the Sum of the Forces Experimentally**
Now let's test and see if the sum of the 2 force vectors you computed matches "reality." To do this, use the force table provided. For the 400U force in the 0˚ direction, hang a 400g mass from a pulley placed at 0˚. Similarly place a 300g mass hanging from a pulley at 90˚. Now determine the *equilibrant* force by pulling one of the other strings until you establish the required direction to balance the force of the other two weights. Place a pulley in this direction and then suspend the proper mass to bring the system into equilibrium (You are in equilibrium when the ring remains centered around the post in the middle of the force table).

Now, recall that the *equilibrant* force is equal in magnitude but in the opposite direction as *resultant* force, which is the sum of the two forces here. Given this statement, ***what is the magnitude and direction of the sum of the two forces?***

How does this sum you determined experimentally compare to your prediction based on your previously computed sum of the 2 force vectors?

Part II: The Sum of Two Forces not at Right Angles

Now find the sum of the two forces indicated below using each of the three methods:

$\mathbf{F_1}$ = 150U @ 50˚
$\mathbf{F_2}$ = 250U @ 125˚

Be sure to document your work clearly (you will likely have to use other sheets of paper).

Sum of these two forces via graphical method (use attached graph paper):

Sum of these two forces via analytical method:

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Sum of these two forces via experimental method:

Finally, compare your two predictions to the experimentally confirmed sum of the 2 force vectors.

Discussion: Please answer the following questions:

1. If $\mathbf{F} = \mathbf{F_1} + \mathbf{F_2}$ is F (the magnitude of **F**) necessarily greater than F_1 and/or F_2? Discuss.

2. Can the magnitude of a vector be equal to one of its components? Can it be less then magnitudes of both components?

3. For two forces whose magnitudes are 400 U and 300 U find the maximum and minimum magnitudes of their vector sum. How the forces $\mathbf{F_1}$ and $\mathbf{F_2}$ have to be directed to provide these magnitudes of the sum?

4. Can two vectors, of unequal magnitude, add up to give the zero sum? Can three or more coplanar unequal vectors have the zero sum?

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DATA SHEET

(You may record the data in an *Excel* spreadsheet if you prefer, but please record the same data)

Adding up Two Forces at Right Angles

Original Force			Graphical Summation of Forces		Analytical Summation of Forces	
Force	Magnitude (in U)	Direction	Horizontal	Vertical	Horizontal	Vertical
F_1	400	0˚				
F_2	300	90˚				

Experimentally Measured Equilibrant Force: __________ U @ _____˚

Summation of Force Vectors based on Equilibrant Force Vector: __________ U @ _____˚

Adding up Two Forces not at Right Angles

Original Force			Graphical Summation of Forces		Analytical Summation of Forces	
Force	Magnitude (in U)	Direction	Horizontal	Vertical	Horizontal	Vertical
F_1	150	50˚				
F_2	250	125˚				

Experimentally Measured Equilibrant Force: __________ U @ _____˚

Summation of Force Vectors based on Equilibrant Force Vector: __________ U @ _____˚

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