Forces and Static Equilibrium - Worksheet

1. Given the apparatus in front of you, What are the forces acting on the paper clip?

2. Draw a free body diagram of the paper clip and plot all the forces acting on it. Remember forces are vector quantities, i.e. they have both magnitude and direction!

3. Are the forces acting on the paper clip in one, two or three dimensions?

4. A body accelerates under the influence of force. Why is the paper clip not accelerating? Discuss the effect of each force on the paper clip individually and their collective effect.

5. Using the information you collected in step 2, what is the net force on the paper clip? Use vector analysis in this step.

6. When a body is not moving nor rotating we say that this body is at static equilibrium. Is the paper clip in static equilibrium?

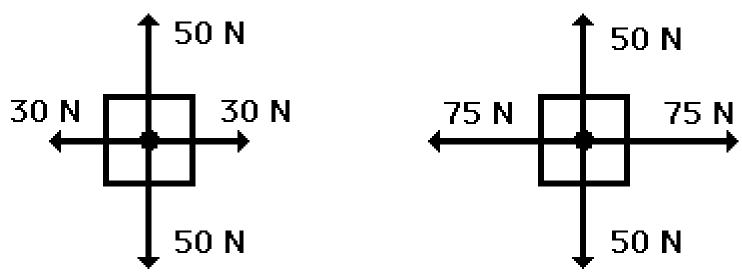
7. Using the results you obtained from step 5 and the statement in step 6 can you deduce the physics law of static equilibrium?

8. Suggest another method to calculate the net force.
   "Drawing is deception." ~ Maurits Cornelius Escher.

9. From the knowledge you gained in this lab session. Determine the mass of the unknown object in front of you.

Forces and Static Equilibrium

When all the forces that act upon an object are balanced, then the object is said to be in a state of **equilibrium**. The forces are considered to be balanced if the rightward forces are balanced by the leftward forces and the upward forces are balanced by the downward forces. This however does not necessarily mean that all the forces are *equal* to each other. Consider the two objects pictured in the force diagram shown below. Note that the two objects are at equilibrium because the forces that act upon them are balanced; however, the individual forces are not equal to each other. The 50 N force is not equal to the 30 N force.

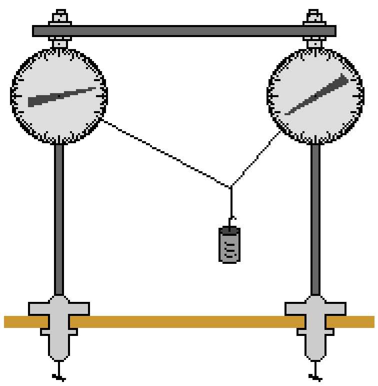


If an object is at equilibrium, then the forces are balanced. *Balanced* is the key word that is used to describe equilibrium situations. Thus, the net force is zero and the acceleration is 0 m/s^2. Objects at equilibrium must have an acceleration of 0 m/ s^2. This extends from Newton's first law of motion. But having an acceleration of 0 m/ s^2 does not mean the object is at rest. An object at equilibrium is either ...

- at rest and staying at rest, or
- in motion and continuing in motion with the same speed and direction.

This too extends from Newton's first law of motion.

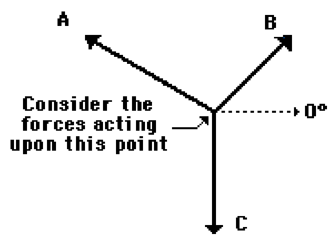
If an object is at rest and is in a state of equilibrium, then we would say that the object is at "static equilibrium." "Static" means stationary or at rest. A common physics lab is to hand an object by two or more strings and to measure the forces that are exerted at angles upon the object to support its weight. The state of the object is analyzed in terms of the forces acting upon the object. The object is a point on a string upon which three forces were acting. See diagram below. If the object is at equilibrium, then the net force acting upon the object should be 0 Newton. Thus, if all the forces are added together as vectors, then the resultant force (the vector sum) should be 0 Newton. (Recall that the net force is "the vector sum of all the forces" or the resultant of adding all the individual forces head-to-tail.) Thus, an accurately drawn vector addition diagram can be constructed to determine the resultant.

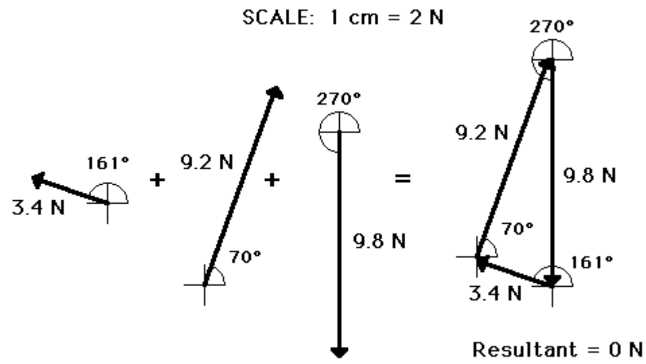


Sample data for such a lab are shown below.

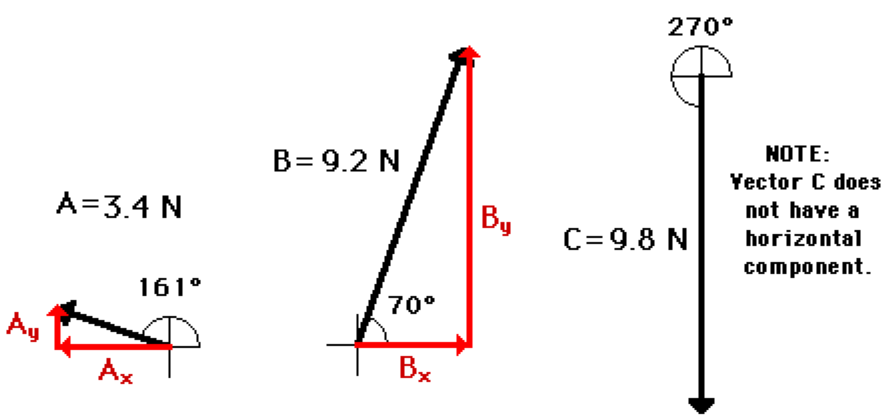
	Force A	Force B	Force C
Magnitude	3.4 N	9.2 N	9.8 N
Direction	161^o	70^o	270^o

These forces are presented as vectors in the diagram below. The net force should be 0 N or nearly 0N.





Another way of determining the net force (vector sum of all the forces) involves using the trigonometric functions to resolve each force into its horizontal and vertical components. Once the components are known, they can be compared to see if the vertical forces are balanced and if the horizontal forces are balanced. The diagram below shows vectors A, B, and C and their respective components. For vectors A and B, the vertical components can be determined using the sine of the angle and the horizontal components can be analyzed using the cosine of the angle. The magnitude and direction of each component for the sample data are shown in the table below the diagram.



Force	Horizontal Component	Vertical Component
A	A_x = 3.4 N*Cos (161°) A_x = 3.2 N, Left	A_y = 3.4 N*Sin (161°) A_y = 1.1 N, Up
B	B_x = 9.2 N*Cos (70°) B_x = 3.1 N, Right	B_y = 9.2 N*Cos 70°) B_y = 8.6 N, Up
C	C_x = 0 N	C_y = 9.8 N, Down

The data in the table above show that the forces nearly balance. An analysis of the horizontal components shows that the leftward component of A nearly balances the rightward component of B. An analysis of the vertical components show that the sum of the upward components of A + B nearly balance the downward component of C. The vector sum of all the forces is (nearly) equal to 0 Newton. But what about the 0.1 N difference between rightward and leftward forces and the 0.2 N difference between the upward and downward forces? Why do the components of force only nearly balance? The sample data used in this analysis are the result of measured data from an actual experimental setup. The difference between the actual results and the expected results is due to the error incurred when measuring force A and force B. We would have to conclude that this low margin of experimental error reflects an experiment with excellent results.

In conclusion, equilibrium is the state of an object in which all the forces acting upon it are balanced. In such cases, the net force is 0 Newton. Knowing the forces acting upon an object, trigonometric functions can be utilized to determine the horizontal and vertical components of each force. If at equilibrium, then all the vertical components must balance and all the horizontal components must balance.