EXPERIMENT 4

Force & Newton's Laws of Motion

OBJECTIVE:
To examine the concepts of FORCE and NEWTON'S THREE LAWS OF MOTION; to understand the relationship between force and acceleration, the vector nature of force, and the concept of NET FORCE.

INTRODUCTION:

Acceleration, mass, and force often seem confusing to students as they begin the study of physics. This set of demonstration experiments has been designed to clear up some of this confusion by examining each concept and showing how all are related. The relationships among these concepts are summed up simply enough in the words of Newton's three laws of motion.

In this experiment, you will take a look at the concept of INERTIA in a laboratory setting. Newton's First law of motion is often called the Law of Inertia, and you will see why this is the case after doing the first study. You'll also contemplate the relation of inertia to MASS.

By FORCE we simply mean a push or a pull. A force is quantified in terms of numbers and units, but it must also be specified with a DIRECTION. That is, forces are described using VECTORS. (You may wish to review your class notes on vectors and how to add them.) The Second Law of motion beautifully relates the net force on an object and its acceleration. If one were to investigate the roles of cause and effect regarding physical phenomena, this law is the place to start!

In this experiment, we look at the general concept of force. In the next few experiments (including this one, actually) we'll look at some specific forces such as gravity, the normal force, tension, friction, and the spring force. But all of these forces require one thing: a system of two or more objects interacting with each other. There are no isolated forces in nature, and this is the gist of Newton's Third Law.

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DEMONSTRATION STUDIES:
1. Inertia and Mass
2. Acceleration and Force
3. Rolling along
4. Force Table
5. Action and Reaction

EQUIPMENT NEEDED
1. Ball and Card
2. Data from Experiment 2
3. Inclined plane
4. Force Table
5. Spring Balance

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STUDY #1 - THE BALL AND CARD

1. Find the Ball and Card set-up. The idea is to dislodge the card without tipping the ball over. It may take some practice to get it to work properly, but first try dislodging it with the spring launch attached to the stand. Hold down the stand with one hand and pull back on the spring launch with the other hand.

![Fig. 4.1](image)

2. Next, try removing the card from beneath the ball by rapidly pulling the card with your hand. This usually takes more practice!

**OBSERVATION QUESTION 1**

a) Describe briefly what you observed when the spring launch was used and when you used your hand to remove the card: did the ball remain on the stand?

b) From your class notes or textbook, state Newton’s First Law of Motion.

c) Suppose you have (i) an object at rest, (ii) an object moving with constant velocity, and (iii) an object moving with a changing velocity. How are (i) and (ii) the same while both differ from (iii)?

d) Again from your class notes or textbook, define *inertia*. How does this concept relate to the concept of *mass*?

e) Suppose you took a pencil and rolled it across a horizontal surface. If the pencil eventually slows to a stop, what physical quantity must be acting on the pencil, as inferred from Newton’s First Law?

f) Suppose you have a ball attached to a string, and you swing the ball around in a circle. Now suppose the string breaks. Would the ball continue in a circular path, or would it tend to travel in a straight line? Explain your answer using the concept of inertia.
STUDY #2 – ACCELERATION IMPLIES FORCE

You will take NO new data in this study, but rather use the data from EXPERIMENT 2, STUDY #2.

If an object is accelerating, Newton’s Second Law says that there is a non-zero NET FORCE acting on the object. The net force could be a single force (like the ones mentioned in the Introduction of this lab) or the sum of individual forces. In the latter case, each force acting on the object may have a different magnitude and different direction, but the result of adding the individual forces involves a single number (the magnitude) and a direction (often expressed in terms of angles). Looking at the Second Law expressed in mathematical (vector) form, one sees that the magnitude of the acceleration is proportional to the magnitude of the net force, and the direction of the acceleration is the SAME as the direction of the net force.

Forces are most commonly expressed in terms of Newtons: 1 Newton = 1 kg · 1 m/s². That is, if you have an object with a mass of one kilogram traveling with an acceleration of 1 meter per (second)², then it must be experiencing a net force of 1 Newton. Another unit of force is the dyne. One dyne = 1 gram · 1 cm/s².

Since there are $10^3$ grams in a kilogram and $10^2$ cm in a meter, there are $10^5$ dynes in a Newton, or 1 dyne = $10^{-5}$ Newtons.

1. Recall Experiment 2, Study #2. You recorded the mass of the glider and calculated the magnitude of acceleration. Use those results to calculate the net force that must have been acting on the glider to produce that acceleration.

**OBSERVATION QUESTION 2**

a) State Newton’s Second Law in terms of vectors.

b) Calculate and record the magnitude of the net force acting on the glider.

c) What was the direction of the acceleration? What was the direction of net force? (Possible answers: parallel to the air track, perpendicular to the air track, ...)

d) Identify the forces $\vec{F}_1$ and $\vec{F}_2$ acting on the glider below. Note that the net force is the vector sum of the two forces.

$$\vec{F}_{\text{net}} = \vec{F}_1 + \vec{F}_2$$
STUDY # 3 – ROLLING ALONG

1. First, find a couple of balls that have the same size, with one ball heavier than the other (the ones you used in Experiment 3 will do).

   Place the balls at the same height above the floor and drop them.

   **OBSERVATION QUESTION 3**

   (a) Which ball had the greater acceleration?

   (b) Write an expression for the force experienced by a ball of mass \( m \) in free-fall. Use this expression to indicate which ball experienced the greater force.

2. Take one of the balls over to an inclined plane with a groove in the middle. Set the angle of the plane at about 15° and let the ball roll down the plane. Then set the angle of inclination at 30° and repeat.

   ![Diagram](image)

   (c) At which angle did the ball take the longest time to reach the bottom of the plane? Which angle gave rise to the greater acceleration (and hence the greater net force)?

   (d) What force(s) is acting on the ball that was not present in the first part of this study?

   (e) Suppose an object slides down an incline plane (like the glider in Experiment 2). Which expression best describes its acceleration along the plane: \( g \sin \theta \), \( g \cos \theta \), or \( g \tan \theta \)? (Hint: Imagine what happens when \( \theta = 0^\circ \) and when \( \theta = 90^\circ \).)
In the previous study, the same force was responsible for the acceleration of the ball down the inclined plane, i.e., the force of gravity was producing the acceleration in each case. As the angle changed, the acceleration changed. From Newton's Second Law, we must infer that the magnitude of the net force also changed. The gravitational force on the ball actually did NOT change, but the amount of force parallel to the plane (which is in fact the net force) DID change. We call this the COMPONENT of the gravitational force which is parallel to the plane. There is also a component of the gravitational force which is perpendicular to the plane.

In the present study you will use the FORCE TABLE to explore the components of force vectors. It consists of a circular platform with degree markings from 0 to 360°. In the center of the platform there's a small metal ring with a thin rod pegging the ring to the center. (See Figs. 4.3 and 4.4.) Attached to the ring are strings; these strings drape over pulleys on the side of the table and support 50-g mass hangers. One can adjust the angle position of the pulleys as well as the mass on the hangers.

The weight on each hanger exerts a TENSION (a basic pull) in the string which is transmitted to the metal ring at the center of the table.

Like any vector, a force has a MAGNITUDE and a DIRECTION. In this situation, the direction is specified by the angle indicated by the pulley, and the magnitude is given by the amount of weight on the hanger. Remember that

\[ \text{Weight} = \text{Mass} \times \text{Gravitational Acceleration} \]

or, symbolically, \( w = mg \). It is very important to distinguish between weight, which is a force expressed in Newtons or dynes, and mass, which has units of kilograms or grams.

In this experiment, however, the gravitational acceleration cancels out during the calculations, so (just this time!) we can take the mass of the weights as the force.
1. Attach one pulley at 0° and put a mass hanger on the free end of the string. Add a mass of 150 g to the hanger; the total mass is 200 g. Attach a second pulley at 180° and put the same mass (50 g + 150 g) on a string draped over the pulley. The situation should look like Fig. 4.4. Now remove the rod from the center of the ring.

**OBSERVATION QUESTION 4**

a) Compare the magnitude and direction of the force acting on the ring at the 180° with the magnitude and direction of the force acting at 0°.

b) What is the NET FORCE acting on the ring now?

When two vectors are added, their sum is called the RESULTANT vector. In the above situation, the resultant vector is zero, and the acceleration of the ring is also zero.

2. Replace the rod through the center of the ring. Add 100 g to the mass hanger at 0° (for a total of 300 g) and move the other pulley from 180° to 210°.

If you remove the rod now, the ring will accelerate toward the side of the table because the net force on the ring is obviously non-zero. In fact, according to Newton’s 2nd law the ring will accelerate in the direction of the new resultant. So we need to calculate the magnitude and direction of the new resultant vector, \( \vec{F} = \vec{F}_1 + \vec{F}_2 \). The vector \( \vec{F}_1 \) has a magnitude of 300 g and has a direction of 0° while the vector \( \vec{F}_2 \) has a magnitude of 200 g and a direction of 210°. The first thing we have to do when adding vectors is to resolve the vectors into Cartesian components, say \( x \) and \( y \). Then we sum the respective \( x \)- and \( y \)- components:

\[
F_x = F_1 \cos \theta_1 + F_2 \cos \theta_2 \\
F_y = F_1 \sin \theta_1 + F_2 \sin \theta_2
\]

c) Using the numbers in the previous paragraph for \( F_1, F_2, \theta_1, \) and \( \theta_2 \), find \( F_x \) and \( F_y \).

d) Find the magnitude of the resultant vector by finding
\[
F = \sqrt{F_x^2 + F_y^2}
\]

e) Find the direction of the resultant vector by finding
\[
\theta = \tan^{-1} \frac{F_y}{F_x}
\]

Next we want to find the EQUILIBRANT vector. This vector is the force added to the first two forces in order to balance the system. In other words, the equilibrant is just the weight of the previous resultant vector in a direction 180° opposite the resultant vector.
f) Take the amount of weight you found in part d) and place it over a third pulley in the direction you found in part e) plus or minus 180°. With all the weights in place, remove the rod holding the ring. Did the ring remain in the center of the table?

STUDY # 5 – Newton’s Third Law

1. Find the Hooke’s Law apparatus. Add a 50-g weight and note the distance reading, which will be in centimeters. Then add a second 50-g weight on top of the first mass, again noting the force reading. Add one more mass and note its distance.

OBSERVATION QUESTION 5

a) Record the distance measurement for each weight in centimeters. Does the spring stretch the same amount after a 50-g weight is placed on it? (If so, then the force exerted by the spring is proportional to the amount of stretch. This is known as Hooke’s law.)

b) What is the resultant force acting on the set of three masses after letting them hang from the spring? (Assume that the masses aren’t bouncing around!)

c) Now let’s consider the three masses individually. We want to identify the forces on each mass. For example, the top mass experiences its own weight by the force of gravity (downward) and a normal force from the middle mass (upward). The bottom mass experiences its own weight plus that of the middle and top masses – this is balanced by the upward pull of the spring.

What forces act on the middle mass?

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1/1/1/1/1/1/

-50 g
-50 g
-50 g
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* SUMMARY:

There were FIVE studies with a total of FIVE observation questions. Don’t forget to take your belongings with you when you leave the lab. Please clean up when finished.