Newton’s First Law

Introduction

One version of Newton’s First Law states:

> An object at rest stays at rest, or travels in a straight line with constant speed, unless impelled by a force to do otherwise.

The law consists of three phrases, separated by commas. In this activity, we will try to understand what this law means by examining these three parts.

Part One: An object at rest

Place a golf ball on a smooth flat surface at a point where it is at rest. Observe the ball for about half a minute.

What does the ball do? Record your observations on the answer sheet. Do your observations verify the first part of the law?

Part Two: An object in motion

Give the golf ball a quick push and observe it’s motion immediately after the push. Record your observations on the answer sheet. Do your observations support *both* conditions of the second part of the law?

Part Three: Unless

Repeat Part Two, only now place a piece of cloth or carpet a few feet in front of the ball. Observe the ball’s motion on the carpet and record your observations on the answer sheet.

What caused the ball to change from initially at rest to moving?

What explanation can you give for the ball’s behavior on the carpet?

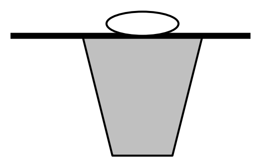
Why was the ball’s behavior on the carpet different from the ball’s behavior on the smooth floor?

The ball's motion on the smooth floor was probably not ideal. To what can you attribute the imperfect motion of the ball on the smooth floor?

Applications

1. Place an index card on top of a glass or cup, and a coin on top of the index card. With your finger, quickly flick the edge of the card, causing it to move horizontally.

On the answer sheet, record the behavior of the index card, the coin, and the cup. Carefully explain the behavior of each object separately in terms of Newton's First Law of motion.



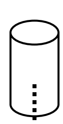
2. Get two pieces of a light cotton string and a heavy (at least 200 gram) mass with two hooks or loops on it. Tie one string to each loop and hang the mass from one of the two strings.

When performing the next two tasks, be careful to keep your feet or other body parts out of the way of the falling mass.

Quickly pull the lower string until one of the two strings breaks. What do you observe?

Reattach the broken string to the mass. Slowly pull the lower string until one of the two strings breaks. What do you observe?

Carefully explain both observations using Newton's First law.



Newton's Second Law

Introduction (long explanation)

Newton's Second Law states:

> The acceleration of an object is proportional to the net force acting on the object and inversely proportional to its mass.

Proportional means as one variable increases then so does the other by the same factor. For example, if the force is doubled, then the acceleration also doubles; if the force is cut to a tenth of its previous value, then the acceleration is also a tenth of what it used to be. Of course, these results assume that the value of the mass has not changed in the meantime – the mass is constant.

Inversely proportional means that as one variable increases, the other decreases by the same factor. For example, if the mass is tripled, then the acceleration is only one third of its previous value, assuming the same force is applied.

Newton's second law can be stated as an equation: $F = ma$, where F is the applied force, m is the object's mass, and a is the object's acceleration.

Newton's second law states that the product of an object's mass and acceleration is proportional to the applied force. If we choose to measure acceleration in m/s^2, mass in kilograms, and force in the unit of the Newton, then the proportionality constant is 1. (Think about converting between feet and inches; it is necessary to multiply or divide the measurement by 12 to get the new correct value. The unit of force, the Newton, is defined as 1 Newton = 1 $kg\text{-}m/s^2$, so the conversion factor between the unit of force and the product of mass and acceleration is 1.)

The second law does not mean that force *is the same thing* as mass times acceleration. Forces exist independently of the accelerations they cause. Forces still exist even when there is no acceleration.

If the relationship between two variables is proportional, then a graph of one versus the other is a straight line.

The general form of a straight line is

$$y = mx + b$$

Compare this to

$$F = ma$$

If force is plotted on the Y-axis and acceleration is plotted on the X-axis while the mass is held constant, then we expect the graph to be a straight line with the slope of the straight line equal to the mass of the object. Note that the y-intercept is zero. This makes sense, since according to Newton's first law, if there is no net force, then the acceleration is zero.

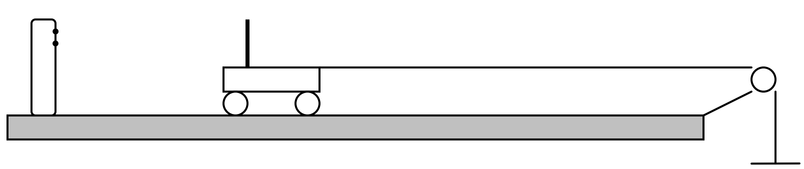
Experimental Design

We will measure the acceleration of a system under six different applied forces and plot the data. If the data suggests a straight line on a graph of force vs. acceleration, then we have reason to believe that Newton's was correct and acceleration is proportional to the applied force. We will also be able to compare the slope of the line to the value of the constant mass.

We will also check Newton's second claim, that acceleration is inversely proportional to mass, by doubling the mass of the system for one of the six applied forces and seeing if the acceleration is approximately halved.

Equipment and Set Up

Our system will consist of a cart attached to a weight hanger by a sting. The weight hanger will be suspended in the air by passing the string over a pulley. The weight hanger will provide the applied force to cause the system to accelerate. Adding more mass to the weight hanger will increase the applied force.



We will measure the acceleration of the cart using a motion detector and the computer-based data collection system

Procedure

The weight hanger has a mass of 50 grams. We will add ten grams to it at a time (60, 70, 80, 90, 100) until the total mass is 100 grams, or twice the initial value. (What do you predict the acceleration should be in that case, compared to the first measured acceleration?)

If the *mass* is 50 grams, then the *weight* is approximately 0.5 Newtons. A 100 gram mass has a weight of approximately 1.0 Newtons.

The cart is being accelerated by the hanging mass. But the weight hanger (plus any extra mass on it) is also being accelerated at the same rate. Therefore, to keep the mass of the system constant, we will start with two 20-gram masses and one 10-gram mass on the cart, and transfer 10 grams at a time to the weight hanger for each trial. This means that the total mass of the accelerating system is the mass of the cart plus 100 grams.

The total, constant mass can be measured. The applied force can be calculated from the known mass on the weight hanger. The acceleration will be measured using a motion detector.

Set up the computer-based data collection system with a motion detector attached. Place the motion detector at the far end of the track, away from the pulley. Be sure to start the cart at least 40 cm away from the detector. It may be helpful to tape an index card to the back of the cart to create a larger target.

Each run will be only a few seconds, so it will be possible to wait a few moments after the clicking has started before letting go of the cart. Be sure to <u>catch</u> the cart at the other end of the track, before it smashed through the pulley and off the track.

Measure the acceleration for each trail by finding the slope of the velocity vs time graph created by the motion detector. Highlight the straight-line section of the graph and choose the R= button. The slope of the line will be reported. Round the value to the closest 0.01 m/s/s.

Record the data in the data table. After all data is collected, make a graph of force vs. acceleration. Use the R= function again to find the slope of the straight mine, and compare the slope to the total mass of the system (about 600 g = 0.600 kg).

Make one more run, this time adding a 500 gram mass to the cart, and using 100 grams hanging from the pulley. Compare the measured acceleration to the value for Trial 6. Does the data support Newton's contention that mass and acceleration are inversely proportional?

Newton's Third Law

Equipment

Two spring scales – one for each partner.

Part One: Spring scales at rest

Hook the two spring scales together, hold them horizontally, and zero them. Each partner should be holding one spring scale.

Pull on the scales, but keep them at rest. How do the two scale readings compare?

Pull harder, stretching the springs more. How do the two scale readings compare?

Part Two: Spring scales moving at constant speed

Move the spring scales back and forth at a constant speed. How do the two scale readings compare?

Move faster back and forth, but at a greater speed. How do the two scale readings compare?

Part Three: Spring scales accelerating

Now accelerate the spring scales as they are hooked together. *At any given instant of time*, how do the two scale readings compare?

Challenge

Is there any way you can move the spring scales while they are hooked to each other so that the magnitude of one scale reading is different than the magnitude of the other scale reading at any single instant of time? If so, demonstrate to the instructor how it may be done.