JoVE: Science Education

Force

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Overview: The goal of this experiment will be to understand the components of force and their relation to motion through the use of Newton's second law by measuring the acceleration of a glider being acted upon by a force.

Nearly every aspect of motion in everyday life can be described using Isaac Newton's three laws of motion. They describe how objects in motion will tend to stay in motion (the first law), objects will accelerate is acted on by a net force (the second law), and that every force exerted by an object will have an equal an opposite force exerted back onto the object (the third law). Almost all of high school and undergraduate mechanics is based on these simple conceptes.

Principles of Force and Motion: One of the most famous equations in all of physics is Newton's second law

$$\vec{F} = m * \vec{a} \text{(Equation 1)}$$

It states simply that the force on an object is equal to the mass of the object times its acceleration.

In the experiment to follow, a glider will be connected to a falling weight by a pulley. Because friction caused by the glider sliding along a track would result in an extra force that is difficult to measure the glider will be on an air track to reduce friction. The air track creates a cushion of air between the glider and track reducing any friction to approximately zero. The force of the weight will accelerate the glider according to Equation 1.

The force on the weight will be entirely due to gravity. Here Equation 1 becomes $\vec{F} = m * \vec{g}$ where $\vec{g}$ is the acceleration due to gravity ~(9.8 m/s^2). While the acceleration due to gravity will remain the same, the force can be increased by adding mass.

As the weight falls it creates tension in the string connecting the weight to the glider. The pulley changes the direction of the tension force from vertical to horizontal. With nothing else connected, the tension in the string is equal to the force of the falling weight which causes the same magnitude of force on the glider. To calculate the acceleration on the glider due to the pull of the weight the forces are equated.

$\overrightarrow{F_{glider}} = \overrightarrow{F_{weight}} = m_{glider} * \vec{a} = m_{weight} * \vec{g}$ Which can be solved for $\vec{a}$

$$\vec{a} = \vec{g} * \left(\frac{m_{weight}}{m_{glider}}\right) \text{(Equation 2)}$$

To measure the acceleration a photogate timer is placed 20 cm from the initial position of the glider. The acceleration can be calculated from the measured final velocity and distance traveled using the equation

$$\vec{a} = \frac{\overrightarrow{v^2}}{2d} \text{(Equation 3)}$$

where $\vec{v}$ is the final velocity and d is the distance traveled. The flag at the top of the glider will pass through the photogate which will record the amount of time the glider takes to pass through the gate. The flag is 10 cm long so the velocity of the glider is equal to the length of the flag divided by the time.

Procedure:

1. Initial setup

   1.1) The air track will have a pulley connected to one end. The string will be tied to one end of the glider and run through the pulley where it will be connected to the hanging weight.

   1.2) Place the glider at the 50 cm mark on the air track. Place the photogate timer at the 70 cm mark. The glider itself has a mass of 200 g. Hold onto the glider so that it does not move and add weights to the hanging end so that the total mass of the weight is equal to the mass of the glider.

   1.3) Once the weights are in place release the glider from rest and record the velocity of the glider for 5 runs and take the average value.

   1.4) Calculate the theoretical value for acceleration from Equation 2 and the experimental value from Equation 3. For example, if the glider has mass 200 g and the hanging weights have mass 200 g then the theoretical acceleration from Equation 2 is $\vec{a} = \vec{g} * \left(\frac{m_{weight}}{m_{glider}}\right) = 9.8\, m/s^2 * \left(\frac{200g}{200g} = 9.8\, m/s^2\right)$. If the velocity measured is 2.0 m/s then using Equation 3 the experimental value for acceleration is $\vec{a} = \frac{\vec{v^2}}{2d} = \frac{(2.0m/s)^2}{2*0.2m} = 10\, m/s^2$.

2. Increasing the mass of the glider

   2.1) Add four of the weights to the glider, which will double its mass.

   2.2) Release the system from rest and record the velocity of the glider for 5 runs and take the average value. Calculate the theoretical value for acceleration from Equation 2 and the experimental value from Equation 3.

3. Increasing the force on the glider

   3.1) Add more mass to the hanging weight so that it has a total mass of 500 g.

   3.2) Release the system from rest and record the velocity of the glider for 5 runs and take the average value.

   3.3) Calculate the theoretical value for acceleration from Equation 2 and the experimental value from Equation 3.

   3.4) Add more mass to the hanging weight so that it has a total mass of 800 g.

   3.5) Release the system from rest and record the velocity of the glider for 5 runs and take the average value.

   3.6) Calculate the theoretical value for acceleration from Equation 2 and the experimental value from Equation 3.

Representative Results:

m_{glider} (g)	m_{weight} (g)	$\vec{v}$ (m/s)	$\vec{a}_{THEORY}$ (m/s^2)	$\vec{a}_{EXPERIMENT}(m/s^2)$	% Difference
200	200	2.2	9.8	12.1	20
400	200	1.3	4.9	4.2	17
200	500	3.2	24.5	26.1	7
200	800	3.86	39.2	37.2	5

The results of this experiment confirm the predictions made by Equations 2 and 3. With increased mass of the glider in part 2 the acceleration was smaller due to the fact that with the increased mass a larger force would be needed to accelerate the glider to the same velocity as in part 1. In part three the increased mass of the hanging weight did indeed increase the force on the glider and the acceleration as a result. The acceleration increased with the increased mass as predicted.

Summary: In this experiment the components of force were examined. Newton's second law states that force is equal to the mass of an object multiplied by the acceleration. By adjusting the mass of the glider the the acceleration of the glider became less. With increased force on the glider the acceleration was increased confirming Newton's second law. The results should be accurate as long as there are no other forces acting on the glider. As mentioned, the friction should be reduced to nearly zero thanks to the air cushion between the glider and track. The pocket of air is not perfect and the air from the track might push the glider in a specific direction. This can be tested by allowing the glider to sit on the air track with no force on it. If the glider moves in either direction there might be some force on the glider from the track.

Applications:

Newton's second law is fundamentally linked to the motion people experience every day. Without any force an object will not accelerate and will remain at rest or continue to move at a constant rate. Therefore if someone wants to get something moving, like hitting a baseball a certain distance, they know they must apply force enough to accelerate a baseball of some mass and it can be calculated with an equation as simple as $\vec{F} = m * \vec{a}$.

Just as it takes a certain force to accelerate an object, it takes the same amount of force to bring an objects velocity down to zero. By looking at $\vec{F} = m * \vec{a}$it is clear that an abject with a lot of mass is much harder to stop than an object with a smaller mass. It is easier to stop a bike than a train! The faster something is going the more acceleration is required to bring it to a stop, so it takes much more force to stop a bullet than a basketball.

Newton's second law becomes a bit more complicated when the components of force are changing with time. For an object that is experiencing some kind of drag force, such as air resistance, its acceleration can change with time. A rocket is an example of an object which has mass changing with time. As the rocket burns fuel its mass gets smaller and it actually requires less force to accelerate as time passes.