Advanced Physics
Advanced Physics Sample Lab Report

Atwood's Machine Demonstrates Newton's Second Law

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Abstract

Everyone is affected by the laws of physics. Everywhere people go they accelerate, decelerate, sway, and fall. These forces are described by Newton's Second Law which tells how objects respond to force with acceleration. In this experiment two masses were hung off different sides of a pulley system. They responded to gravity and showed that the sum of the forces on an object is equal to the object's mass multiplied by its acceleration.

Introduction

Gravity, more or less, affects anything that has mass. Its pull is such that it attracts different masses with different forces. Yet it does this evenly so that if the masses were in free fall they would accelerate at the same rate. What would happen if two masses were set up so that they pulled against each other? One type of a system that does this is the Atwood's Machine. This is a setup invented by mathematician George Atwood in 1784 ("George Atwood") that hangs two objects of different mass from a pulley. As the masses fall or rise to their positions one can learn about the forces that act on those masses.

Isaac Newton's Second Law, published in his Principia in 1686, (Encyclopedia Britannica, 13:19) states that, "When an object is acted on by one or more outside forces, the sum of those forces is equal to the mass of the object times the resulting acceleration" (Wile, 84).

The forces in an Atwood's Machine can be examined and used to demonstrate Newton's Second Law. Forces come in multiple forms, in an Atwood's Machine the primary forces are gravity and tension. Tension is pulling force, it pulls on one object in one direction and another object the opposite direction. By nature it cannot push (the contact force pushes). When an object is hanging from a pulley which has another object hanging from the other side it pulls on that object to make it go up while the other object pulls back on it to make it go up. The objects are of course pulling on each other because they have weight which is decided by multiplying the object's mass by the gravitational acceleration.

These pieces of information and Newton’s Law can be used to put together a complete force equation for an object, such as:

T = ma (1)

And,

T – P + mg = ma (2)

These equations use negative signs where forces are subtracting from each other. When objects are exerting force on each other these equations can be combined to form an equation about a system such as an Atwood’s Machine. Since Forces are being applied, Newton’s Second Law should be able to predict what happens. If Newton’s Law was to affect the system, the acceleration would be less than that of gravity’s. This experiment was performed in order to examine the operation of an Atwood’s Machine, discover the acceleration of the system, and compare it to the theoretical calculation using Newton’s Second Law. When objects of different masses are released from an Atwood’s Machine the measured acceleration of those objects should be significantly less than that of an object in free-fall and it should be comparable to the value calculated by Newton’s Second Law.

Materials & Methods

In this experiment a tower of k’nex™, was built about 1.8 meters high with two lightweight k’nex™ pulleys at the top. It was designed so two wells were be beneath these pulleys, one for each.

Then two plastic, zip lock bags of about the same size were filled with sand so that one measured 50 grams and the other measured 60 grams. A string about as long as the tower was tall was strung through a hole in the top of each bag and tied so that the bags could hang from the string if the string was held in the middle.

This string was then put on the pulleys so that one bag hung down one well and one bag hung down the other well. The string was adjusted so that while the top of one bag was touching its pulley, the bottom of the other bag was touching the ground. The tower with its pulley and strings was moved to a level floor so that the bags could move up and down without touching the sides.

The lighter 50 gram bag was pulled down to the bottom so that it touched the ground and the other bag went to the top. This was released at the same time a stopwatch was started and when the 60 gram bag hit the ground the stopwatch was stopped. This was repeated nine more times so that there was a measurement of the how long it took for the 60 gram bag to travel from the top to the bottom. These ten times were averaged. The result was used to calculate the acceleration of the bags.

Then the acceleration was calculated for the system. This theoretical analysis used the mass of both bags to find how they were acting in each other.

In this experiment, the control was the calculated acceleration of the 60g object in freefall. The independent variable was the pulley and the other mass that were placed as constraints on the motion of the 60g bag. The dependent variable in this experiment was the time it took for the 60g bag to hit the ground. This experiment was done only once.

Results

The distance from the bottom of the 60 gram bag to the bottom of the 50 gram bag when they were about to be released was 173 cm.

Table 1 shows the ten measured times it took for the 60g bag to hit the ground.

Trial	#1	#2	#3	#4	#5	#6	#7	#8	#	9
Time in seconds	5.075	4.383	5.018	4.069	4.507	5.869	3.928	3.636		3.652

The average of these times is 4.4040 seconds.

This information can be used to solve the acceleration, with x being displacement, vo being initial velocity, a being acceleration, and t being time.

$x=v_o t+1/2\times at^2$ (3)

Since vo is zero, that part of the equation can be ignored and it can be solved for a:

$(x\times 2/t^2) = (1.73\ m\times 2/(4.4040 sec)^2 = 0.178 m/s^2$ (4)

So the acceleration of the masses is 0.178m/s2.

Now the theoretical acceleration can be found out as follows while defining the 60 gram bag as m1, the 50 gram mass as m2, the gravitational acceleration g, and the tension of the string T.

$m1g - T = m1a$ (5)

$T - m2g = m2a$ (6)

Substituting (4) into (3):

$m1g - m2g - m2a = m1a$ (7)

$(m1g - m2g)/(m1 + m2) = a$ (8)

The theoretical acceleration is 0.89m/s2.

Discussion

The measured acceleration should be equal to the calculated acceleration and less than the earth’s acceleration It can plainly be seen that the measured acceleration and the calculated acceleration differ greatly. The measured acceleration is only about 20% of the calculated acceleration. It also obviously is less than the earth’s gravitational acceleration of 9.81m/s2. So this experiment satisfied the second part of the hypothesis.

It can reasonably be argued that experimental error accounted for the difference between the measured acceleration and the one calculated by Newton’s Law. For instance if the mass of one of the bags was a little bit off, (which is likely because a low precision scale was used) then then that difference would heavily effect acceleration because the masses are separated by only 10 grams. The disadvantages of having the masses so similar is that it enables friction to work with more success against the motion so that it could easily take make a huge difference like eliminating eighty percent of an object’s acceleration. To make this experiment better one could separate the masses by twenty or thirty grams to improve accuracy.

Newton’s Second Law was applied to the 60 gram mass in Equation 5 and the 50 gram mass in Equation 6. These equations were combined into Equation 7 which was solved for acceleration in Equation 8. Newton’s Law predicted that the acceleration would be significantly lower than the gravitational acceleration. Since the measurement was much less than the gravitation acceleration it shows that Newton’s Law has reliability (and would have more if friction was taken into account.

The subject of force and motion is so important that more experiments on it are a good idea. This kind of experiment could be performed with more than two masses with many more pulleys. The situation could still be broken into individual force equations through Newton’s Law. Instead of using gravity to create tension, someone could use springs and even friction.

This experiment has demonstrated Newton’s Second Law. Though error and friction took much of the accuracy out of the experiment it still showed that the Second Law predicts facets of objects in motion.

Works Cited

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