2nd Edition Physical Science

Student Manual

2nd Edition Physical Science Lab Manual

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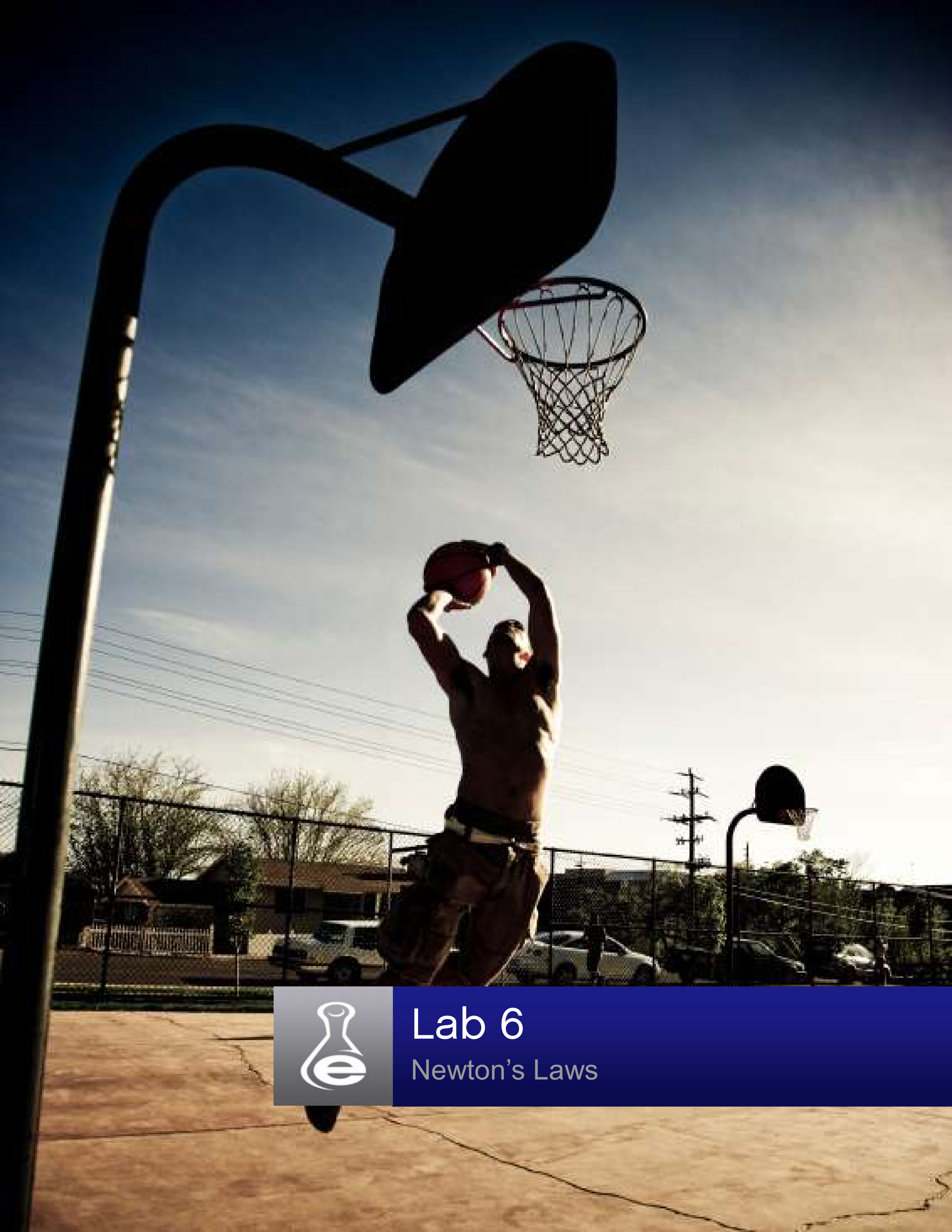

Lab 6

Newton's Laws

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Learning Objectives

- Formulate the law of inertia
- Relate force and acceleration
- Apply action and reaction pairs to forces
- Draw and explain free body diagrams
- Apply Newton's 2nd Law to the Atwood Machine

Introduction

The laws of physics that we know today were discovered and have been studied for centuries. In the fourth century B.C. Aristotle proposed the general belief that a force causes a constant velocity. In addition to Aristotle, Isaac Newton, famous for his Laws of Motion, based his work on the discoveries and experiments of Galileo and Johannes Kepler. In order to reduce the plague from spreading through the college where Newton was a fellow, it was temporarily closed. During this closure, Newton spent a few years in relative isolation where he started to formulate ideas on mathematics and physics. Newton was trying to figure out what objects in orbit and objects falling toward the Earth have in common. The answer actually required a new type of math: calculus! Newton formulated quantitative explanations for the motion of falling objects, orbiting objects, pulley systems, and much more. These ideas were able to explain all types of motion and can be broken down into three basic laws.

Force

While **force** can be described as a push or a pull, it is more clearly defined as an action that causes an object to change its motion. Force is what causes the direction of an object's velocity to change. Therefore, a net force acting on an object causes acceleration.

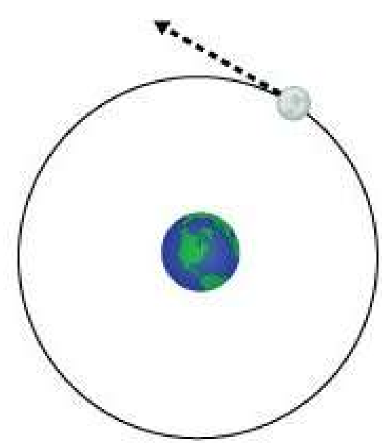

Figure 1: ***The motion of moon as predicted by Newton's First Law should follow the dotted path. Since the moon does not follow the predicted path, there must be a force acting on it.***

Newton's First Law of Motion

Newton's First Law of Motion states that an object will maintain its state of motion until acted upon by an external force. In other words, an object will remain at rest or move at a constant velocity until an outside force acts upon it (Figure 1). Newton's First Law is also called the Law of Inertia. **Inertia** is an object's tendency to resist changes in motion (speed or direction). Matter has this property whether it is at rest or in motion. When a net force on an object is applied, the object will accelerate in the direction of that force. The movement of planets around the sun is an example of inertia. Planets have a lot of mass, and therefore a great amount of inertia - it takes a huge force to accelerate a planet in a new direction. The pull of gravity from the sun keeps the planets in orbit; if the sun were to suddenly disappear, the planets would continue at a constant speed in a straight line, shooting off into space!

Mass vs. Weight

Newton observed a special relationship between mass and inertia. Mass is often confused with weight, but the difference is crucial in physics. While **mass** is the measure of how much matter is in an object (how much stuff is there), **weight** is a measure of the force experienced by an object due to gravity. Thus, weight is relative to your location. Your weight differs at the Earth's core, the summit of Mount Everest, and especially in outer space, when compared to the Earth's surface. Conversely, mass remains constant in all these locations. Mathematically, weight, *w*, is the mass, *m*, of an object multiplied by its acceleration due to gravity, *g*:

$$w = mg$$

Newton's Second Law of Motion

Newton also noted that the greater an object's mass, the more it resisted changes in motion. Therefore, he concluded that mass and inertia are directly proportional: when mass increases, inertia increases. This prediction produced **Newton's Second Law of Motion**, an expression for how an object will accelerate based on its mass and the net force applied to the object. This law can be summarized by the equation:

$$\Sigma F = ma$$

where ΣF is the sum of all forces acting on the object, *m* is its mass and *a* is its acceleration. The kilogram (kg) is the standard measurement for mass, and meter/second/second (m/s^2) is the standard measurement for acceleration. The standard measurement for force is the **Newton**, where 1 N = 1 $kg \cdot m/s^2$. Comparing this equation to the first one (w = mg) helps reinforce the difference between mass and force (such as weight).

Free body diagrams (as seen in Figure 2) are a useful tool for solving problems related to Newton's Second Law of Motion. They allow you to identify and draw all of the forces acting on an object. Objects can be represented by simple shapes like circles and squares. Forces are represented by solid arrows. It is helpful to visualize the net force acting on an object by labeling all objects and forces included in the free body

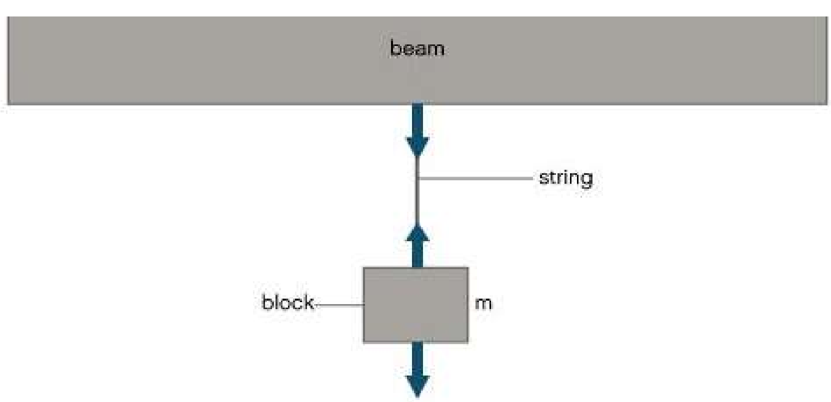

Figure 2: ***Free body diagram of a block hanging form a beam by a string.***

diagram.

Newton's Third Law of Motion

Newton's Third Law of Motion states that for every action (force) there is an equal and opposed reaction. Imagine standing on an ice skating rink and holding a ball (Figure 3). Initially you are not moving. You throw a ball and as you do, you start to move backwards on the ice. When you exerted a force on the ball it exerted a force on you equal in magnitude and opposite in direction. Even when you walk, you push against the ground, and it pushes right back!

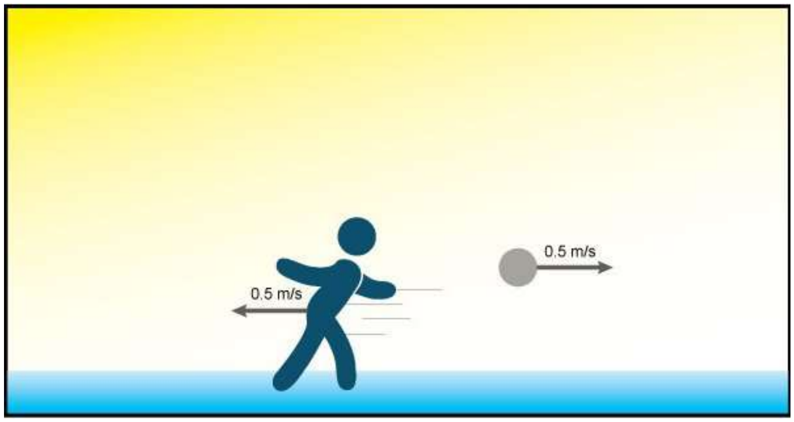

***Figure 3:* Newton's Third Law of Motion explains why you move backwards when you throw a ball on ice.**

Newton's three laws of motion govern the relationship of forces and acceleration. There are many applications of Newton's Laws in your everyday life. To get that last bit of ketchup from the bottle, you shake the bottle upside-down, and quickly stop it (with the lid). Consider riding in a car. Have you ever experienced inertia while rapidly accelerating? Thousands of lives are saved every year by seatbelts, which are safety restraints that protect against the inertia that propels a person forward when a car comes to a quick stop.

Pre-Lab Questions

Use the free body diagram of the pulley (Figure 4) to answer the Pre-Lab Questions.

1. Draw a free body diagram for M_1.

2. Draw a free body diagram for M_2.

3. Apply Newton's 2nd Law to write the equations for M_1 and M_2. You should get two equations with Tension in

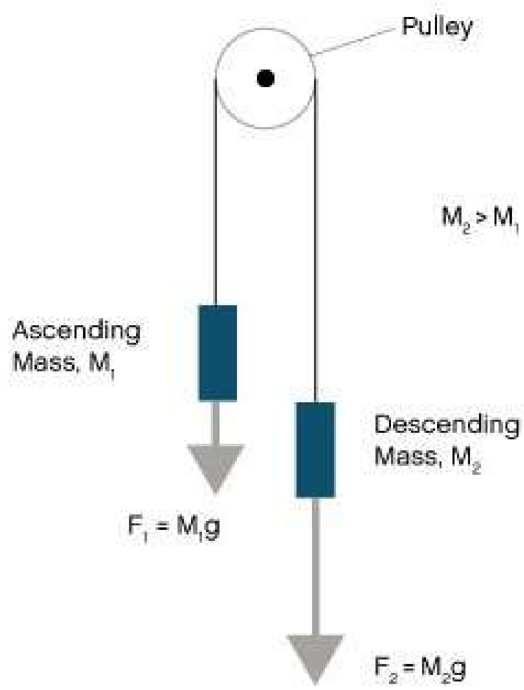

***Figure 4:* Free Body Diagram: 2 objects with mass hanging on a pulley by string.**

the string, weight for each mass and accelerations for each mass (a_1 and a_2).

4. This results in two equations with three unknowns! A third equation is required to solve the system. What is the third equation? (Hint: What is the relationship between a_1 and a_2?)

Materials

(1) 3" by 5" Notecard	*Water
(1) 8 oz. Styrofoam® Cup	
1 Washer	*You Must Provide
*Deep Container (Bowl or Pitcher)	

Experiment 1: Newton's First Law of Motion

In this experiment, you perform a series of motions and analyze the results to explain Newton's First Law of Motion.

Procedure

Part 1

1. Fill the container with about four inches of water.
2. Find an open space outside to walk around in with the container of water in your hands.
3. Perform the following activities and record your observations of each motion in Table 1:
    a. Start with the water at rest (e.g., on top of a table). Grab the container and quickly accelerate it.
    b. Walk with constant speed in a straight line for 15 feet.
    c. After walking a straight line at constant speed, make an abrupt right-hand turn. Repeat with a left-hand turn.
    d. After walking a straight line at constant speed, stop abruptly.

Table 1: Motion of Water Observations	
Motion	**Observations**
a	
b	
c	
d	

Table 2: Observations After Flicking Notecard Off of Cup	
Trial	**Observations**
1	
2	
3	
4	
5	

Part 2

1. Place a 3 x 5 notecard on top of a Styrofoam® cup.
2. Place a washer on the middle of the 3 x 5 notecard.
3. Hole the Styrofoam® cup with your non-dominant hand and flick the notecard with your dominant hands (the hand you write with) so it moves off of the Styrofoam® cup. Record your observations in Table 2.
4. Repeat Steps 1- 3 four times for a total of five trials.

Post-Lab Questions

1. Explain how your observations of the water and washer demonstrate Newton's law of inertia.

2. Draw a free body diagram of your containers of water from the situation in Part 1 Step 4d. Draw arrows for the force of gravity, the normal force (your hand pushing up on the container), and the stopping force (your hand accelerating the container as you stop.) What is the direction of the water's acceleration?

3. Can you think of any instances when you are driving or riding a car that are similar to this experiment? Describe two instances where you feel forces in a car in terms of inertia.

Materials

5 N Spring Scale	0.5 kg Mass
10 N Spring Scale	Pulley
(2) 30 cm Pieces of String	

Experiment 2: Newton's Third Law and Force Pairs

In this experiment, you will investigate Newton's Third Law of Motion by observing forces exerted on objects.

Procedure

Part 1

1. Make sure the spring scales are calibrated using the standard masses.
2. Hook the handle of the 5 N spring scale to the hook of the 10 N spring scale.
3. Holding the 10 N spring scale stationary, pull the hook of the 5 N spring scale until the force reads 5 N on it. Record the force on the 10 N spring scale in Table 3.
4. Repeat Steps 2 and 3 with the 10 N spring scale hanging from the 5 N spring scale. Record the force on

Table 3: Force on Stationary Springs
Force on Stationary 10 N Spring Scale (N)
Force on Stationary 5N Spring Scale (N)

the 5 N spring scale in Table 3.

Part 2

Figure 5: ***Pulley Set Up***

1. Suspend the 0.5 kg mass in the air using the 10 N spring scale. Record the force on the 10 N spring scale in Table 4.
2. Tie one end of one of the pieces of string to the 0.5 kg mass and the other end to the hook of the 10 N spring scale.
3. Suspend the mass in the air by lifting the 10 N spring scale. Record the force on the 10 N spring scale in Table 4.
4. Untie the end of the string attached to the 0.5 kg mass and tie it to the hook of the 5 N spring scale.
5. Hook the 0.5 kg mass to the handle of the 5 N spring scale. Suspend the mass, scales, and string by holding the handle of the 10 N spring scale. Record the values of the spring scales in Table 4.

Figure 6: ***Step 7 reference (string length and mass may vary).***

Table 4: Spring Scale Force Data		
Suspension Set Up	**Force (N) on 10 N Spring Scale**	**Force (N) on 5 N Spring Scale**
0.5 kg Mass on 10 N Spring Scale		
0.5 kg Mass with String on 10 N Spring Scale		
0.5 kg mass, string and 5 N Spring Scale on 10 N spring scale		
0.5 kg mass, string and 5 N Spring Scale on 10 N spring scale on Pulley		

6. Secure the pulley on a table top by tying string to one of the hooks. Then, use masking tape to secure the string to a table top so that the hook on the top of the pulley lays flat on the side of the table top (Figure 5).
7. Using the mass setup from Step 5, place the string over the pulley by unhooking one of the spring scales, feeding the string through the pulley and reattaching the string to the hook of the spring scale (Figure 6).
8. Hold the 10 N spring scale in place so that the scales and mass are stationary. Record the values for both spring scales in Table 4.

Post-Lab Questions

1. How did the magnitude of the forces on both spring scales compare after you moved the 10 N spring scale?

2. How did the magnitude of the forces on both spring scales compare after you move the 5 N spring scale?

3. Use Newton's 3rd Law to explain your observations in Questions 1 and 2.

4. Compare the force on the 10 N spring scale when it was directly attached to the 0.5 kg mass and when there was a string between them.

5. Compare the force on the two spring scales in Steps 5 and 6. What can you conclude about the tension in a string?

Materials

Masking Tape	Stopwatch
2 Paperclips	String
Pulley	Tape measure
5 N Spring scale	15 Washers

Experiment 3: Newton's Second Law and the Atwood Machine

This experiment will demonstrate the mechanical laws of motion using a simple assembly named the Atwood machine that is similar to that used by Rev. George Atwood in 1784 to verify Newton's Second Law.

Procedure

Part 1

1. Support the pulley so that objects hanging from it can descend to the floor. Do this by tying a short piece of string to one of the pulley hooks. Use a piece of masking tape to secure the string to a table top or door frame so that the pulley hangs plumb (Figure 5).

   Note: A higher pulley support will produce longer time intervals which are easier to measure.

2. Thread a piece of string through the pulley so that you can attach washers to both ends of the string. The string should be long enough for one set of washers to touch the ground with the other set near the pulley. (You may attach the washers using a paperclip or by tying them on).
3. Use the spring scale to weigh the set of fifteen washers. Divide the total mass by fifteen to find the average mass of a washer. Record the total mass of the washers and average mass of one washer in Table 5.
4. Attach seven washers to each end of the string.

5. Observe how the washers on one side behave when you pull on the washers on the other side.
6. Add the remaining washer to one end of the string so one side of the string has seven washers (M_1), and the other has eight washers attached to it (M_2). Answer Post Lab Question 1 based on your observations.
7. Place M_1 on the floor. Use the tape measure to measure the height that M_2 is suspended while M_1 is on the floor. Measure the distance M_2 will fall if you release the light set when it is in contact with the floor. Record the distance in Table 5.
8. Time how long it takes for M_2 to reach the floor. Repeat Steps 7-8 four more times (five times total), recording the values in Table 5. Calculate the average time.
9. Calculate the acceleration (assuming it is constant) from the average time and the distance the washers moved.

Part 2

1. Transfer one washer, so that there are six on one end of the string (M_1) and 9 on the other (M_2).
2. Determine the mass on each end of the string.
3. Place the M_1 on the floor. Measure the height that M_2 is suspended at while M_1 is on the floor. Measure the distance M_2 will fall if you release the light set when it is in contact with the floor.
4. Time how long it takes for the heavy set of washers to reach the floor. Repeat Steps 3-4 five times, re-

Table 5: Motion Data			
Mass of 15 Washers (kg)		**Average Mass of Washer (kg)**	
Procedure 1			
Height (m):			
Trial	**Time (s)**		
1			
2			
3			
4			
5			
Average			
Average Acceleration (m/s^2)			
Procedure 2			
Height (m):			
Trial	**Time (s)**		
1			
2			
3			
4			
5			
Average			
Average Acceleration (m/s^2)			

cording the values in a table and then calculate the average time.

5. Calculate the acceleration (assuming it is constant) from the average time and the distance the washers moved.

Post-Lab Questions

1. When you give one set of washers a downward push, does it move as easily as the other set? Does it

stop before it reaches the floor? How do you explain this behavior?

2. Draw a free body diagram for M_1 and M_2 in each procedure (Procedure 1 and Procedure 2). Draw force arrows for the force due to gravity acting on both masses (F_{g1} and F_{g2}) and the force of tension (F_T). Also draw arrows indicating the direction of acceleration, *a*.

3. Use Newton's Second Law to write an equation for each of the free body diagrams you drew in Question 2. (Note: Be sure to use the correct signs to agree with your drawings). Solve these four equations for the force of tension (F_T). You answer should be in variable form.

4. Set the two resulting expressions for the force of tension equal to one another (as long as the string does not stretch, the magnitude of the acceleration in each equation is the same). Replace F_{g1} and F_{g2} with M_1 and M_2, respectively. Solve the resulting equation for *a*. Then, go back to Question 3 and solve for the F_T.

5. Calculate the acceleration for the two sets of data you recorded and compare these values to those obtained by measuring distance and time using percent error. What factors may cause discrepancies between the two values?

6. Calculate the tension in the string for the falling washers. From these two values, and the one where the masses were equal, what trend do you observe in the tension in the string as the acceleration increases?