9 Newton's Second Law
Atwood's Machine

Purpose

To investigate how force, mass, and acceleration are related.

Required Equipment and Supplies

Apple II Series computer
2 photogates (light probes) with interface box
LabTools software
Atwood's Machine precision pulley from PASCO (Cat. # SA-9241)
rod clamp
2 weight hangers
assortment of slotted weights
thread *or*
Smart Pulley System from PASCO

Note: This experiment can be attempted with a stopwatch, but experimental results with photogates will be superior.

Discussion

Have you ever noticed that when an elevator cage at a construction site goes up, a large counterweight (often a mass of concrete) comes down? The elevator and the counterweight are connected by a strong cable. Thus, the elevator doesn't move without the counterweight moving the same distance. Both form a *system*.

In this experiment two masses are connected over a pulley. This arrangement is common in physics labs and is called an *Atwood's Machine*. If the hanging masses are the same, no acceleration results. However, if the masses are unequal, the masses *accelerate*.

In Part A you will investigate how unequal masses in an Atwood's Machine affects acceleration while keeping the *mass of the system constant*. You'll do this by removing mass from one side of the pulley and placing it on the other side.

In Part B, you will investigate how the acceleration of an Atwood's Machine is affected by increasing the mass of the system. However, in order to do so we cannot add mass to just *one* of the falling weights. Just as an elevator and the counter-weight together form a system, so do *both* falling weights. One falling weight doesn't move without the other falling weight moving exactly the same distance. Adding mass only to one falling weight, would change the net force on the system. To keep the net force *constant*, the same mass must be added to *both* falling-weights. In doing so, you change only one variable—mass—to see how it affects the acceleration of the entire system.

Although the same general procedure is used in both Parts A and B, the acceleration can be obtained two ways (in this analysis, the rotational inertia of the pulley will be ignored). First, the acceleration can be calculated by measuring the time for one of the masses to accelerate through a fixed distance using the equation (from kinematics):

$$a = \frac{2d}{t^2}$$

The second way is to analyze the forces and the mass of the system (called dynamics) to find the acceleration—i.e, via Newton's Second Law:

$$a = \frac{F_{net}}{m}$$

The force on the system is simply the difference in the weights,

$$F_{net} = ma$$

$$m_2 g - m_1 g = ma$$

$$(m_2 - m_1)g = ma$$

which equals the mass of the system multiplied by the acceleration;

$$m_2 g - m_1 g = (m_1 + m_2)a$$

So that the acceleration of the system, a, is:

$$a = \frac{(m_2 - m_1)g}{m_1 + m_2}$$

The purpose of this experiment is to compare the values of the acceleration of the Atwood's Machine as calculated by each method.

Part A: Constant Mass—Changing Force

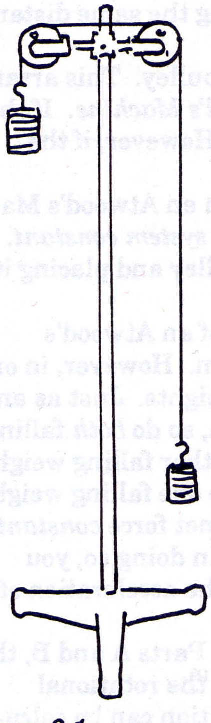

Figure 9.1

Procedure

Step 1. Set up a pulley system similar to that shown in Figure 9.1. Clamp the pulley to the table at least 50 cm from the floor. Use a piece of thread about 10 cm longer than the distance from the top of the pulley to the floor. Attach the thread to each mass hanger. Place a total of about 100 grams of mass on one hanger, m_1, with one 50-g, one 20-g, and six 5-g masses. Place *slightly* more (such as 5 grams) on the other hanger, m_2. This arrangement will enable you to transfer mass from m_1 to m_2 and thereby change the *net force* without changing the *total mass* of the system. A small amount of masking tape may help stabilize the masses. Record m_1 and m_2 (don't forget the mass of the mass hangers!) in Data Table 9.1.

Step 2. If you are using the "Chronometer" program on *LabTools* or an equivalent timing program, orient the first photogate so the lighter mass just eclipses it when released from the floor. This will start the timer. Position the second photogate on a ring stand a fixed distance above the first photogate, such as 50 cm. The timer stops when the second photogate is eclipsed. Placement of a 500-g mass or some other solid object below the hanger greatly facilitates releasing the hanging weight without tripping the

Data Table 9.1

TRIAL	m_1	m_2	$t_{avg.}$	MEASURED ACC.	NET FORCE	TOTAL MASS	F_{net}/m	% DIFF.

photogate-timer; doing so requires finesse! The photogates are sensitive and require careful alignment. Sometimes the masses also have a tendency to swing as they move. Practice by having your partner activate the computer just as you release the lighter hanging mass.

Step 3. Verify that the distance the system accelerates is precisely the fixed distance between the two photogates. The value of the actual distance is not as important as keeping it *the same for all subsequent timing trials.* Make certain the masses are free to accelerate the entire distance and do not hit the floor or pulley before moving the entire distance. Record the distance the masses will be accelerating.

d = ________

Step 4. Release the lighter mass and record the time the system accelerates. Repeat several times to get consistent results. Record your average time in Data Table 9.1. Assume the system accelerates from rest and calculate the acceleration of the system according to kinematic theory using the average time, t_{avg}. If you are using a Smart Pulley system, follow the accompanying instructions to obtain a value a for the accelerating system.

Step 5. Now remove a small amount of mass (such as 5 grams or less)* from m_1 and add it to m_2. How does this affect the total mass of the system? The net force? Calculate the net force, F_{net}, and the acceleration from dynamics theory, $a = F_{net}/m$ (remember to use the correct units for mass and force). Show sample calculations below and record your results in Data Table 9.1.

Step 6. Repeat Steps 4 and 5 at least 5 times recording your results each time in Data Table 9.1.

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*The appropriate mass to transfer depends on the total mass of the system. If the total mass of the system is small, the mass transferred should be as little as 1 or 2 grams at a time.

Data Table 9.2

TRIAL	m_1	m_2	$t_{avg.}$	MEASURED ACC.	NET FORCE	TOTAL MASS	F_{net}/m	% DIFF.

Part B: Constant Force—Changing Mass

Step 7. This time, you are going to change the total mass of the system but keep the net force constant by *adding the same mass to both hanging masses.* Set up the masses as in one of your runs in Part A and add identical masses, such as 20-g masses, to m_1 and m_2. Repeat Steps 4 and 5 several times. Record your results in Data Table 9.2.

Analysis

1. How does the acceleration of the system according to kinematic theory ($\frac{1}{2}at^2$) compare to dynamics theory (F_{net}/m)?

2. Calculate the percentage difference for the acceleration in each case. How do you account for any differences?