

## UNIFORMLY ACCELERATED MOTION

### Investigation: Acceleration of a Freely Falling Picket Fence (Through a Photogate) [Activity P05]:

#### Experimental Objectives:

The purpose of this experiment is to study objects in motion. Specifically, we will determine the acceleration due to gravity by measuring the time of fall of a picket fence dropped through a photogate in free fall conditions (under constant gravitational acceleration) **Apparatus:**

Equipment Needed	Qty	Equipment Needed	Qty
Photogate/Pulley System (ME-6838)	1	Universal Table Clamp (ME-9376)	1
Picket Fence (ME-9377A)	1		

#### Theory

Neglecting air resistance, an object falls a distance proportional to the square of the time.  $d \propto t^2$

Galileo was the first to derive this mathematical relationship. He asserted that for a given location on Earth, all objects fall with the same uniform acceleration. This acceleration is commonly referred to as the **acceleration due to gravity**, and it is given the symbol  $g$ . This value is approximately  $g = 9.8 \text{ m/s}^2$ .

#### PROCEDURE:

##### **1: Computer Setup**

1. The 850 Universal Interface should already be connected to the computer. Turn it on.
2. Consult the Capston Experimental Setup document for instructions on computer setup. This is available at <http://sites.gsu.edu/claphast>.



##### **2: Equipment Setup**

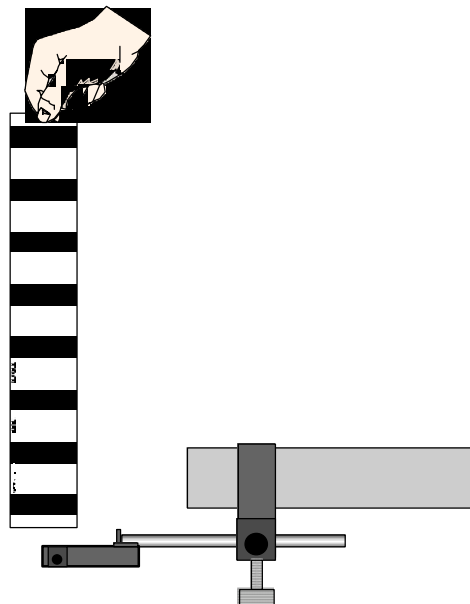
1. Mount the photo-gate as shown in the picture above.
2. A mouse pad should be directly below the opening of the photogate, so that when the picket fence drops to the table it will not break.

### 3: Data Acquisition

Drop a “Picket Fence” (a clear plastic strip with uniformly spaced opaque bands) through a Photogate. Each opaque band on the ‘Picket Fence’ blocks the Photogate beam and the time from one blockage to the next becomes increasingly shorter. Knowing the distance between the leading edge of each opaque band, the *Capstone* program calculates the average speed of the Picket Fence from one band to the next. The slope of the graph of average speed versus time gives the acceleration of the falling object.

#### 3.1 Trial Run of Data


1. Before recording data for later analysis, experiment with the Photogate and Picket Fence.
  - Place the soft mousepad on the floor directly below the Photogate, in order to cushion the falling Picket Fence when it lands on the floor.
2. When everything is ready, start recording data. Drop the Picket Fence vertically through the Photogate. Data recording begins when the Photogate beam is first blocked. **Stop** the recording once the Picket Fence has passed completely through the Photogate.
3. Rescale the data to fill the Graph window.




#### 3.2: Final Data Recording

1. Prepare to drop the Picket Fence through the Photogate beam again. Hold the Picket Fence at one end between your thumb and forefinger so the bottom edge of the Picket Fence is just above the Photogate beam.
2. Start recording data and then drop the Picket Fence through the Photogate beam. Remember, data collection begins when the Photogate beam is first blocked.
3. After the Picket Fence passes completely through the beam, stop recording.

### 4 Data Analysis

1. Set up your Table display so it shows the values of position, velocity, and acceleration.
2. If necessary, rescale the Graph to fit the data.
3. Examine the plot of Velocity versus Time in the Graph display. Determine the slope of the ‘best fit’ line for velocity versus time.
  - Hint: In *Capstone*, select ‘Linear’ from the ‘Fit’ menu ().

4. Apply Statistics to each column in the Table display to determine the 'Mean' value of acceleration.
- Hint: In *Capstone*, select 'Mean' from the 'Statistics' menu (.
5. Record the value for the Mean of the acceleration, and the slope of the velocity vs. time in the Lab Report section.

**Record your results in the Data Sheet of your Lab Report.**

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**DATA SHEET: Freely Falling Picket Fence**

1. Print and attach a copy of the Position-time and Velocity-time graphs.
2. Print and attach a copy of the Position-Velocity-Acceleration Data Table obtained from *DataStudio*.
3. **Data Table:** Record the data obtained below.

Item	Value
Slope of velocity versus time	
Acceleration (mean)	

**Post-Lab Questions: Freely Falling Picket Fence**

1. How does the slope of your velocity versus time graph compare to the accepted value of the acceleration of a free falling object ( $g = 9.8 \text{ m/s}^2$ )? What is the percent error in the calculated acceleration due to gravity?
  
2. How does the mean of the acceleration from the table compare to the accepted value of the acceleration of a free falling object ( $g = 9.8 \text{ m/s}^2$ )?
  
3. Consider the following factors that may cause the experimental value to be different from the accepted value? How does each factor affect your result?
  - (a) The Picket Fence was not vertical during the fall through the Photogate.
  
  - (b) The initial speed of the falling Picket Fence as it enters the Photogate is not zero.
  
  - (c) The Photogate was not rigidly fixed or was held by hand.
  
  - (d) The Picket Fence was scratched, dirty or damaged

## UNIFORMLY ACCELERATED MOTION

### Investigation: Atwood's Machine (Photogate/Pulley System) [Activity P10]:

#### Experimental Objectives:

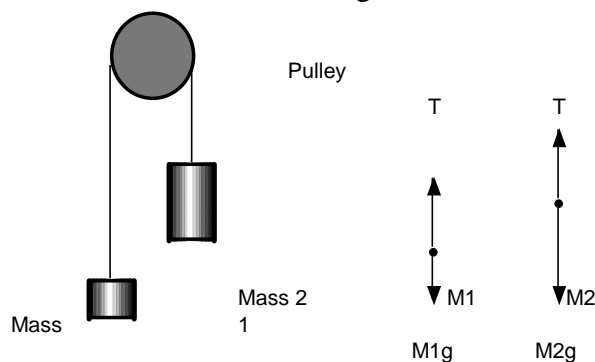
The purpose of this experiment is to study the relationship among force, mass, and acceleration using an Atwood's Machine apparatus.

#### Apparatus:

Equipment Needed	Qty	Equipment Needed	Qty
Photogate/Pulley System (ME-6838)	1	String (SE-8050)	1
Mass and Hanger Set (ME-8967)	1	Universal Table Clamp (ME-9376B)	1

#### Theory

The acceleration of an object depends on the net applied force and the object's mass. In an Atwood's Machine, the difference in weight between two hanging masses determines the net force acting on the system of both masses. This net force accelerates both of the hanging masses; the heavier mass is accelerated downward, and the lighter mass is accelerated upward.



Based on the above free body diagram,  $T$  is the tension in the string,  $M_2 > M_1$ , and  $g$  is the acceleration due to gravity. Taking the convention that up is positive and down is negative, the

$$T_1 - M_1g = F_{net} = M_1a$$

$$T_2 - M_2g = F_{net} = M_2(-a)$$

net force equations for  $M_1$  and  $M_2$  are:

Assuming that the pulley is massless and frictionless, and the string has no mass and doesn't stretch, let  $T_1 = T_2$ . Solving for  $a$ , the acceleration of the system of both masses, the theoretical acceleration is  $g$  times the difference in mass divided by the total mass:

$$a = g \left( \frac{M_2 - M_1}{M_1 + M_2} \right)$$

**PROCEDURE:**

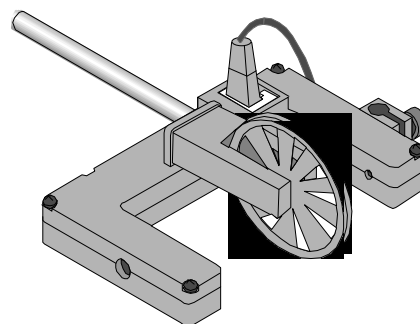
Use the Photogate/Pulley System to measure the motion of both masses as one moves up and the other moves down. Use *Capstone* to record the changing speed of the masses as they move. The slope of the graph of velocity vs. time is the acceleration of the system.

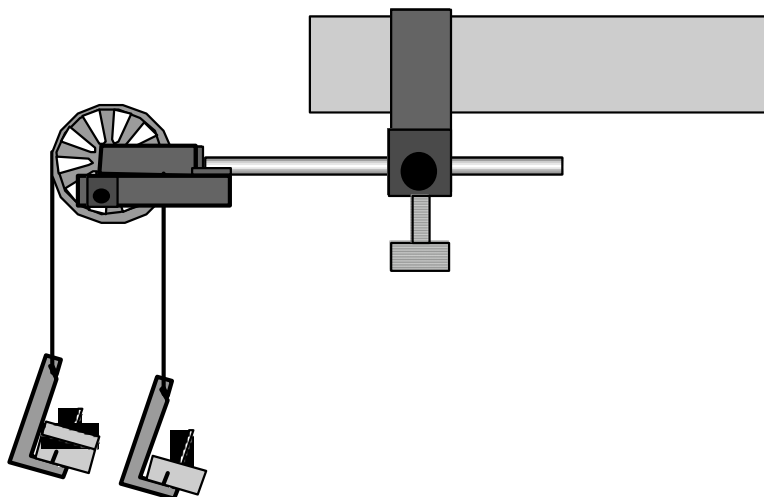
**1: Computer Setup**

1. Follow the instructions in the Atwood's Machine section of the Capstone Experimental Setup document, available at <http://sites.gsu.edu/claphast>.

**2: Equipment Setup**

1. Mount the clamp to the edge of a table.
2. Use the Pulley Mounting Rod to attach the Pulley to the tab on the Photogate.
3. Place Photogate/Pulley in the clamp so that the rod is horizontal.
4. Use a piece of string about 10 cm longer than the distance from the top of the pulley to the floor. Place the string in the groove of the pulley.
5. Fasten mass hangers to each end of the string.
  - To attach the string to the hanger, form a loop at the end of the string and tie it back on itself to 'knot it' or wrap the string about 5 times around the notch in the mass hanger.
6. Place five to six masses from your mass set, totaling (approximately) 100 grams of mass on each mass hanger and record the total mass as  $M_1$  in the Data Table in the Lab Report section. Be sure to include the mass hanger in the total mass during calculations. On the other mass hanger, record this total mass of the masses and mass hanger as  $M_2$  in the Data Table in the Lab Report section.
7. Move the  $M_2$  mass hanger of upward until the  $M_1$  mass hanger almost touches the floor. Hold the  $M_2$  mass hanger to keep it from falling. Turn the pulley so that the Photogate beam is unblocked (the red light-emitting diode (LED) on the Photogate does not light).





8. In order to compensate for the opposing **force of friction** due to the pulley bearing, place small masses (less than 2 g at a time) on the descending side (M2) until the descending mass moves at constant velocity when it is given a very slight push.
    - Release the mass M2 (with the compensating small mass) and let it fall. Start recording data. Stop recording just before the M2 mass hanger reaches the floor. Repeat the process until you obtain a satisfactory constant velocity graph, which should confirm your visual observation. Record the masses in the Data Table.
    - Retain this mass difference for the remainder of the experiments in order to compensate for the frictional force in the pulley.
- Do not let the upward moving mass hit the pulley during any data run.



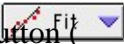
### 3- Acquisition – Constant Total Mass

1. Transfer a 2-g to M2. Release the (descending mass hanger) M2 and let it fall.
2. Start recording data. Stop recording just before the M2 mass hanger reaches the floor.
  - “Run #1” will appear in the Data list.
3. For Run #2, move a mass from the M1 mass hanger to the M2 mass hanger. This process changes the net force without changing the total system mass. Record the new total mass for each hanger with masses in the Data Table in the Lab Report section. Allow the mass to fall. Begin data recording. Stop recording data just before the hanger reaches the floor.
4. Repeat the above step to create three more mass combinations. For each run, the net force changes but the total mass of the system remains constant.

**3-B: Data Acquisition – Constant Net Force**

1. Arrange the masses as they were for Run #3. Now, change the total mass of the system but keep the net force the same. To do this, add exactly the same amount of additional mass to both mass hangers.
  - Be sure that the difference in mass is the same as it was in Procedure step #8 of Part 2. Why?
2. Add approximately 10 grams to each mass hanger. Record the new total mass for each hanger with masses in the Data Table in the Lab Report section. Release the  $M_2$  mass hanger and let it fall. Start data recording. Stop recording just before the  $M_2$  mass hanger reaches the floor.
3. Repeat the above step to create three more data runs. For each data run, the net force remains the same, but the total mass of the system changes.

**4: Data Analysis**

1. Determine the experimental acceleration for each of the data runs.
  - Click in the Graph display to make it active. Find the slope of the velocity vs. time plot, the average acceleration of the masses, following the directions below.
  - In *Capstone*, select Run #1 from the Data Menu () in the Graph display. If multiple data runs are showing, first select No Data from the Data Menu and then select Run #1. Click the “Scale to fit” button () to rescale the Graph axes to fit the data. Next, click the ‘Fit’ menu button () . Select ‘Linear’.
  - Record the slope of the linear fit in the Data Table in the Lab Report section. Repeat the above procedure for each of the remaining 9 data runs.
2. Calculate and record the force of friction ( $f_k$ ) due to the pulley.  
*[The unbalanced force due to the difference between the total weights at the two ends of the string, when moving at constant velocity, is equal to the opposing frictional force.]*

Therefore, when moving at constant velocity,

$$f_k = (\text{descending mass} - \text{ascending mass})g$$

3. For each of the data runs, using the measured mass values, calculate and record the net force in the Data Table in the Lab Report section, using the equation below.

$$F_{net} = (M_2 - M_1)g - f_k$$

4. Calculate and record the total mass in the Data Table.



5. Using the total mass and net force, calculate the theoretical acceleration using:

$$a = \frac{F_{net}}{M_1 + M_2}$$

6. For each data run, calculate and record the percent difference between the experimental acceleration and the theoretical acceleration.
7. For the Constant Total Mass data, plot a graph of  $F_{net}$  vs.  $a_{exp}$ . Note: Include a negative sign for acceleration values when  $M_1 > M_2$ . Attach your plot to the Lab Report.
8. Draw the best-fit line on your plot. What does the slope of the best-fit line represent? Compare the value of this slope with the total mass. Discuss briefly.

**Record your results in the Data Sheet of your Lab Report.**

**Data Sheet - Atwood's Machine [Activity P10]****Data Table [3-A]: Constant Total Mass**

For Constant \_\_\_\_\_ kg      Descending Mass,  $M_2$  \_\_\_\_\_ kg      Ascending Mass,  $M_1$  \_\_\_\_\_ kg      **Velocity:**

**Force of Friction:** \_\_\_\_\_ N

Run	M1 (kg)	M2 (kg)	Fnet (N)	M1+ M2 (kg)	atheory (m/s <sup>2</sup> )	aexp (m/s <sup>2</sup> )	Percent difference
Run #1							
Run #2							
Run #3							
Run #4							
Run #5							

**Data Table [3-B]: Constant Net Force**

Run	M1 (kg)	M2 (kg)	Fnet (N)	M1+ M2 (kg)	atheory (m/s <sup>2</sup> )	aexp (m/s <sup>2</sup> )	Percent difference
Run #6							
Run #7							
Run #8							
Run #9							
Run #10							

**Post-Lab Questions: Atwood's Machine**

1. Describe a real world application of Atwood's Machine.
2. Compare the experimental acceleration with the theoretical acceleration, based on the percentage difference. What are some reasons that would account for this percent difference?
3. If the initial velocity of the system were not zero, how would this affect your results?
4. How would the experimental results be affected if the pulley were not friction free and the rotational inertia of the pulley were not neglected?

Name \_\_\_\_\_

Class \_\_\_\_\_

Date \_\_\_\_\_

5. How does the plot of the Net Force vs. Acceleration relate to Newton's Second Law?