

## 5.2 The Second Law: Force, Mass, and Acceleration

### What is the relationship between force, mass, and acceleration?

British scientist George Atwood (1746–1807) used two masses on a light string running over a pulley to investigate the effect of gravity. You will build a similar device, aptly called an Atwood's machine, to explore the relationship between force, mass, and acceleration.

In this investigation, you will:

- measure the acceleration for an Atwood's machine of fixed total mass.
- create a graph of force versus acceleration for the Atwood's machine.
- determine the slope and y-intercept of your graph, and relate them to Newton's second law.

#### Materials List

- Physics stand
- Double pulley
- Red safety string
- Mass hangers (2)
- Steel washers
- Plastic washers
- Measuring tape
- Photogate
- DataCollector
- Electronic scale or triple-beam balance

### 1 Analyzing the Atwood's machine

To accelerate a mass, you need a net force. Newton's second law shows the relationship between force, mass, and acceleration:

#### NEWTON'S SECOND LAW

$$\text{Force (N)} \quad F = ma$$

Mass (kg)

Acceleration ( $\text{m/s}^2$ )

The Atwood's machine is driven by a net force equal in magnitude to the weight difference between the two mass hangers. You will vary the two masses,  $m_1$  and  $m_2$ , but you will keep the total mass constant. As you move plastic washers from  $m_2$  to  $m_1$ , you will use a photogate to measure the acceleration of the system. If you know the acceleration and the total mass of the system, you will be able to calculate the net force that is responsible for accelerating the system. The equation for the system's motion is a variation of the basic second law formula:

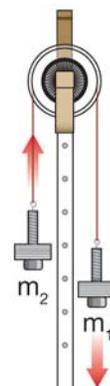
$$F_{\text{net}} = (m_1 + m_2)a$$

An ideal pulley would be frictionless and massless, and would just redirect the one-dimensional motion of the string and attached masses without interfering with the motion. However, the pulley you will use has mass and there will be some friction involved. For the purpose of this investigation, we will neglect the mass of the pulley, but we will be able to analyze the friction involved with our Atwood's machine. To represent the friction present in the system, you must subtract it from the net force, since the friction opposes the force of weight provided by  $m_1$  and  $m_2$ :

$$F_{\text{net}} - \text{friction} = (m_1 + m_2)a$$

It is easiest to move the friction force ( $f$ ) to the other side of the equation, so you get:

$$F_{\text{net}} = (m_1 + m_2)a + f$$



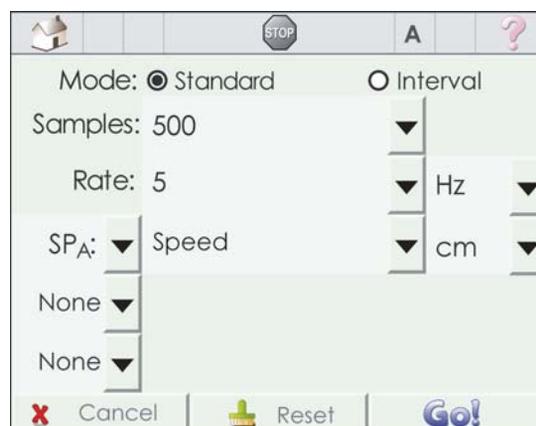
## 2 Setting up the Atwood's machine

- Set up the Atwood's machine as shown in the photograph at right. Attach the double pulley to the top of the physics stand. You will only use the striped pulley.
- Attach the mass hangers to the red safety string. Place 10 steel washers on the other mass hanger. This will be  $m_1$ . Place eight steel washers and six plastic washers on one mass hanger. This will be  $m_2$ . Place the string over the dynamic pulley.
- Pull  $m_2$  down to the stand base. Place a sponge or some other small cushion on the base to protect it from the falling  $m_1$ . Let go of  $m_2$  and observe the motion of the Atwood's machine.
  - Which mass moves downward and why?
  - What would happen if  $m_1$  and  $m_2$  were equal masses? Why?
  - Do the masses accelerate when they move? Explain.
  - How does the acceleration of  $m_1$  compare to the acceleration of  $m_2$ ?
  - The system's net force equals the weight difference of the mass hangers. Write a simple formula that will allow you to use the mass difference and  $g$ , the acceleration due to gravity, to calculate the weight difference of the mass hangers.



## 3 Collecting data

- Find the total mass of  $m_1$  and  $m_2$  and record in Table 1.
- Attach a photogate to the double pulley as shown at right. Plug the photogate into the DataCollector (input A). The striped pattern on the pulley will break the light beam of the photogate as the pulley rotates.
- Turn on the DataCollector. At the home window, select data collection mode.
- At the go window, tap on the setup option at the bottom of the screen.
- In the setup window, chooses standard mode.
- Set samples to 500, the data rate to 5 Hz.
- For input, select the  $SP_A$  setting, then select speed in cm/s. Set the other inputs to none, working from bottom to top.
- Pull  $m_2$  to the base. Tap go at the bottom of the setup window.
- When the experiment has started, release  $m_2$ . When the hanger falls onto the cushion, press the button on the top left of the DataCollector to stop the experiment.



10. Select the graph tab at the bottom of the screen, and study the graph of the speed data. The speed should be increasing at a constant rate. Determine the acceleration by calculating the slope of the speed versus time graph. Convert to units to  $\text{m/s}^2$ . Record the acceleration in Table 1. Calculate the net force (see your answer to 2e) and record it in Table 1.
11. Transfer one of the plastic washers from  $m_2$  to  $m_1$ .
12. Press the button on the DataCollector to resume data collection. Repeat steps 7–10 until you have transferred all of the plastic washers to  $m_1$ .

**Table 1: Acceleration and force data**

Acceleration ( $\text{m/s}^2$ )	Calculated net force (N)

#### 4 Analyzing the data

- a. Make a net force vs. acceleration graph (force on the  $y$ -axis and acceleration on the  $x$ -axis). Draw a best-fit line through the data points.
- b. What kind of relationship does the graph show? Is this consistent with Newton's second law? Explain.
- c. Determine the slope of your line. What is the significance of the slope in your experiment?
- d. Compare your slope and the known total mass of the system. What is the percent difference? What could account for any difference?
- e. Determine the  $y$ -intercept of your line. The equation for a line is  $y = mx + b$  ( $m$  is the slope and  $b$  is the  $y$ -intercept). Substitute your variables in for  $y$ ,  $m$ , and  $x$ . Compare this equation to the one presented in part 1.

$$F_{\text{net}} = (m_1 + m_2)a + f$$

- f. Based on your answer to the previous question (4e), what does the  $y$ -intercept represent? Does this value make sense? Explain.