Activities for Measuring Acceleration and Deceleration due to Gravity and Friction

Grade Level: Middle School

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Two activities are described below which involve determining the change in speed of a rolling ball. The first involves a deceleration of a ball primarily due to friction. The second involves an acceleration of a ball due to gravity. In both activities students use stop watches and yard sticks or meter sticks to determine the speed of the ball. Students will use medians of repeat measurements to improve the accuracy of their calculations. In both activities students will determine the acceleration or deceleration of the ball using simple calculations. Students can gain insight into the relative magnitude of acceleration due to friction and gravity for the case of a rolling ball. This can give them a basis for future explorations of other objects in motion.

Materials (for both activities):

Tracks (wall edging material from a building supply store) 10 feet long paper-faced taped inside corner bead $2.21, 1 short track 3/4 inch x 48 inch plain steel angle 1/8 inch thick Cost $6.57

Steel Balls (6) ¾ inch diameter (from American Physics and Supply in Geneva, Illinois), Cost $2.95

Stop watches (1 per person in class, or conduct experiment with 2 students per watch where students alternate between using the watch and recording the data) (from American Physics and Supply in Geneva, Illinois) Cost $2.95

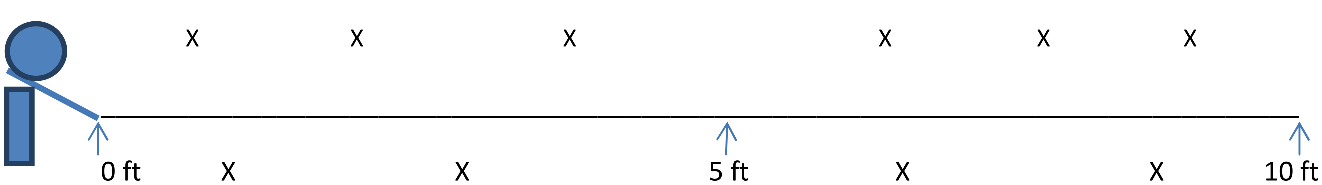
Text Books (or any books) (5)

Box 6 inch high

ACTIVITY 1: Determination of deceleration due to friction

Setup: Open three text books of roughly the same size at their middle and place the track in the "v" formed by the books. The track should be held well by the books because it also has a "v" shape. Use a box or several books to hold the ramp at an angle. Again open a book on top of the box to hold the track. The track should be clearly marked at the 5 foot position using a tape measure or yard stick.

Students should be divided into four groups so they can line up along the track and each have a line of sight to the moving ball. As an example 10 students are positioned as below:



First determine a ramp starting position that will cause the ball to barely reach the end of the track. Be sure it will have enough speed to fall off the end of the track but moving very slowly at the end. Then using this position on the ramp (mark it with a small piece of tape) you will be ready to have the students prepare to use their stop watches.

The teacher (or a student) will let the ball roll down the short ramp and continue across the 10 ft of track. The students between 0 ft and 5 ft will start their watches when the ball passes the 0 ft position (where the horizontal track begins) and stop their watches when the ball passes the 5 ft position. The students between 5 ft and 10 ft will start their watches when the ball passes the 5 ft position and stop their watches when the ball passes the 10 ft position (at the end of the horizontal track). After this the students will record their times on the same worksheet (for this setup).

Since the horizontal track is neither perfectly straight or level it will be necessary to repeat this experiment by moving the ramp to the other end of the horizontal track and repeating the experiment. Remember to again determine a ramp starting position that will cause the ball to barely reach the end of the track and again use tape to mark this position.

Calculations:

First students for each interval will work together to determine the median time from their data. Don't include any data that was a result of a stop watch failure (such as one that did not start or stop properly). If time permits run the experiment one or more additional times to collect more data, but make sure you release the ball from the same point on the ramp. If you have time for more runs, use all the data from all the runs to determine the median time for each interval. You will repeat these calculations using the data from the reverse direction run(s).

The speed of the ball will be calculated for each interval (0 to 5 feet and 5 to 10 feet) as follows:

Speed = 5ft/(median time)

Difference of speeds = (Speed for 5ft to 10ft interval) – (speed for 0 to 5 ft interval)

Deceleration = (Difference of speeds)/(Time for 5 to 10 ft interval)

These calculations should be done independently for the two directions the ball is moving. Finally, the deceleration due to friction is calculated as the simple average of the deceleration for the two directions as follows:

Deceleration from friction = (deceleration forward direction + deceleration reverse direction)/2

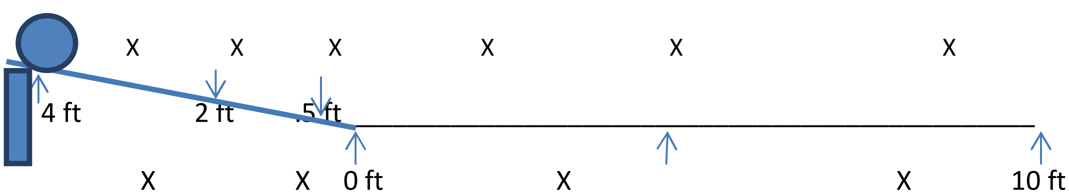
Teacher Notes: You can begin activity by asking students to think about a method to determine quantitatively if an object's speed changes and if so how it changes. This may provoke a range of answers, some of which may be valid. Teachers should build on any good idea and relate it to one that is valid which should be similar to the one outlined above. The method described above has been used successfully by students to measure how fast an object's speed changes. Eventually the students should arrive at the need to determine the object's speed at two different places on the track and then compare those speeds. Taking the difference between those speeds and dividing the difference by the time required for moving between those two positions will result in how fast the ball is slowing down (its deceleration).

Extended Activity: This activity can be repeated with other balls such as a marble, ping pong ball, golf ball etc. which can have differences in deceleration. However if this activity is done after the activity below, much higher frictions can be measured for rolling balls, such as rolling on a carpet instead of a track. In this case use the ramp set-up from the following activity and use the calculated speeds for the ball on the horizontal track. Then with the same ramp slope direct the ramp to allow the ball to roll on a carpet instead of the horizontal track. Then you only need to start the watch when the ball leaves the ramp and stop it when it rolls to a stop on the carpet. The deceleration is then calculated as the final ramp speed (from the activity below) divided by the time on the carpet (when the speed becomes zero). These decelerations should be much higher than those calculated earlier for the track.

ACTIVITY 2: Determination of acceleration due to gravity

Setup: Open three text books of roughly the same size at their middle and place the track in the "v" formed by the books. The track should be held well by the books because it also has a "v" shape. Use a box or several books to hold the ramp at an angle. Again open a book on top of the box to hold the track. The ramp track should be clearly marked at the 0.5 foot, 2 foot, and 4 foot position using a tape measure or yard stick.

Students should be divided into two groups so they can line up along the track and each have a line of sight to the moving ball. As an example 10 students are positioned as below:



One group will be along the 4 foot ramp and the other along the horizontal track. The teacher or student will set the ball on the track at the lowest position about 6 inches from the lower end. He will then warn the students he is about to let the ball roll by saying something such as "one ,two, three, start". Once he lets go on "start" the students along the ramp will start their stop watches. They will then stop them when the ball hits the bottom of the ramp. The second group of students along the horizontal track will then start their watches when the ball first enters the horizontal track and then stop them when it rolls past the end of the track. After this the students will record their times on the same worksheet (for this setup). Repeat this for the other two positions the ball is released on the ramp (2 feet and at the end of the ramp at 4 feet).

Calculations:

First students for each interval will work together to determine the median times from their data. Don't include any data that was a result of a stop watch failure (such as one that did not start or stop properly). If time permits run the experiment one or more additional times to collect more data, but make sure you release the ball from the same points on the ramp you used before (such as at 6 inches, 2 feet and 4 feet). If you have time for more runs, use all the data from all the runs to determine the median time for each appropriate interval.

The time on the ramp for each position will be paired with its respective horizontal speed calculation as follows:

Note: All times below should be the median of the multiple measurements for each position.

Median Ramp time for 6 inch position, horizontal speed for 6 inch position = 10/(median horizontal time)

Median Ramp time for 2 foot position, horizontal speed for 2 foot position = 10/(median horizontal time)

Median Ramp time for 4 foot position, horizontal speed for 4 foot position = 10/(median horizontal time)

Then the calculations for acceleration are as follows:

Acceleration = (horizontal speed for 6 inch position)/(median ramp time for 6 inch position)

Acceleration = (horizontal speed for 2 foot position)/(median ramp time for 2 foot position)

Acceleration = (horizontal speed for 4 foot position)/(median ramp time for 4 foot position)

These three accelerations should be approximately the same. They can then be averaged together to give a better measure of the acceleration of the ball down the ramp.

Teacher notes: You can begin this activity by asking students to think about a method to determine quantitatively how a falling object's speed changes. This may provoke a range of answers, few of which may actually be valid. Teachers should build on any good idea and relate it to one that is valid which is to measure how fast an object's speed changes. If students already completed first activity they may remember that the friction caused deceleration was calculated as a change in speed per unit time (second). In this activity a steel ball will roll down a ramp using a method somewhat like one Galileo used to investigate acceleration. This is because rolling a ball down a ramp with a gentle slope produces a much smaller acceleration than an object falling straight down. Teachers can demonstrate how difficult it is to measure the speed of an object that is falling straight down by dropping a ball from a height of two feet and asking students to measure the time with a stop watch. Then let the ball roll down a gentle sloping 4 foot ramp (its high end raised 6 inches from its other end). The vertical drop will take about a half second while the ramp roll will take about 2 seconds which is much easier to measure with a stop watch for most students. Small distances dropping vertically would be nearly impossible to measure this way. For example a one half foot vertical drop will take less than 0.2 seconds, less time than most students need to start and stop a stop watch. However, using a gentle ramp will result in speeds that are then slow enough to be more accurately measured by a stop watch (or a simple timing device in Galileo's time).

To calculate how fast the rolling ball gets faster requires that we know two different speeds and the time required to reach those speeds. Using the ramp the two different speeds are the beginning speed immediately before the ball starts rolling (which is zero) and the final speed at the bottom of the ramp (which is calculated as the length of the horizontal track divided by the time required to roll that length). The time the ball is rolling down the ramp is the time required to reach that final speed. Dividing the speed by this time gives the acceleration. Since the slowing of the ball due to friction on the horizontal track is quite small compared to the speed of the ball, this calculated speed will be close to the speed of the ball when it leaves the ramp.

At the end of this activity students will directly see from their measurements that acceleration is constant (within experimental error) regardless of how long the ball is rolling down the ramp. This means that the speed changes the same amount each second as long as the ball is on the ramp. All measurements above should be made using the same gentle slope of the ramp. However, at the conclusion of this activity students may be impressed if the ramp is increased to a steeper angle and the ball is then rolled down from the four foot position. After the ball reaches the horizontal track its speed will be quite high. It will not get close to the ultimate acceleration due to a vertical free fall which is 32 feet/sec/sec. This means after 1 second a vertically falling dense object will have a speed of 32 feet/sec at one second and 64 feet/sec at 2 seconds, etc. In the first activity above, the deceleration is found to be very small compared to this (probably less than 0.1 ft/sec). Thus earth's gravity near its surface produces an acceleration more than 300 times larger than the deceleration due to friction on the steel rolling ball.