Free Fall Lab

Materials:

- A ping-pong ball
- A tennis ball
- A golf ball
- A light and a heavy object (weights in a film canister or a 50 g and a 100 g mass)
- Spark-timer and spark-timer tape
- Ruler
- Masking tape
- Graph paper or graphical analysis computer program

Purpose:

How does gravity affect the motion of a dropped object? How does mass influence acceleration in free fall?

Pre-lab discussion:

1. Predict first: if you drop a ping-pong ball, a tennis ball and a golf ball, all from the same height, which one do you think will reach the ground first? Justify your prediction, discuss your ideas with your group, and whiteboard your group's consensus idea.

2. Drop **one** of the balls, and observe it as it falls.

   a) What factors do you think you could measure, given the appropriate instruments?

   b) Predict motion diagrams for all three objects and justify your diagrams.

   c) Draw force diagrams for all three objects and explain your diagrams.

3. Drop all three balls together. You might have to shut your eyes and listen to the sound of the balls hitting the floor so you are sure of your observations. Make sure the *same* person drops all balls at the *same* instant. Write your observations.

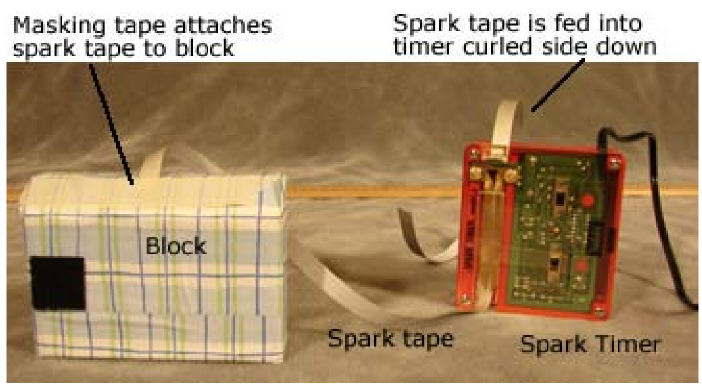
4. Revisit your predictions of motion diagrams and force diagrams. If you think any of them need to be changed, draw the changes below. Explain you reasoning.

5. Write your conclusions from the pre-lab discussion.

Directions:

Part I

6. Remind yourself about how the spark-timer is set up, and how it works. (For this lab, the setting should be 60 Hz).
Discuss what you will measure, and how you will analyze your measurements. Write your design for the experiment below.



Directions:

7. Conduct an experiment to investigate how the distance traveled by the object in one time interval changes with time. Your group must decide where position=0 and time=0 are on the spark tape, and make measurements from that point.

a) The Experimental Question:

b) IV:

c) DV:

d) Constants:

e) Hypothesis:

f) Materials List:

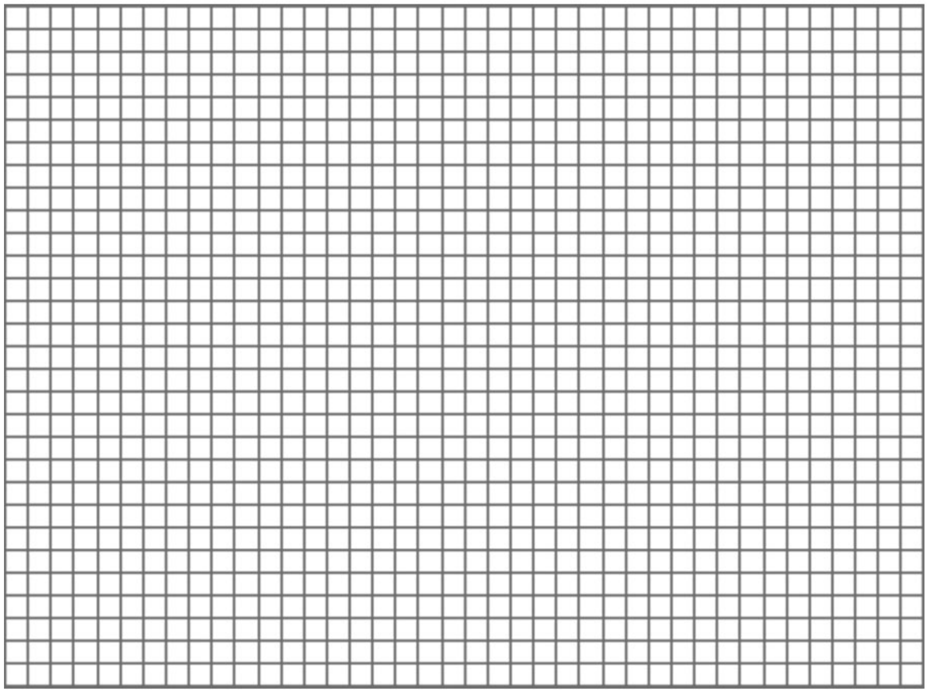
g) Procedure:

h) Data Table:

i) Graph:

Title of graph:

y =0

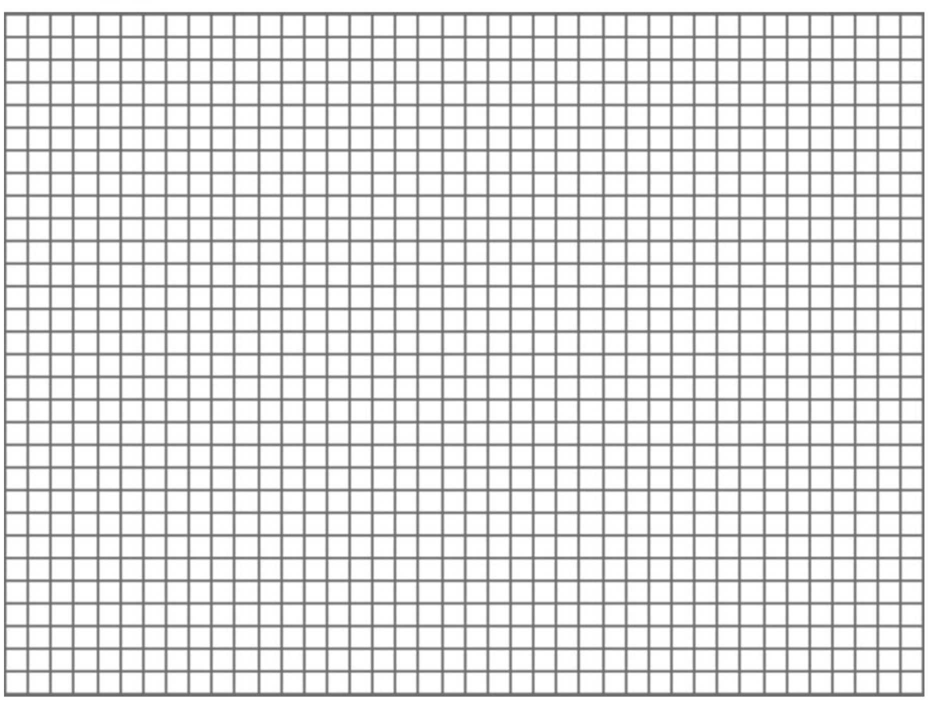


8. Analyzing the data:

a) Use the data you obtained to create velocity-time data (at the midpoint of each time interval), making extra columns in the data table for velocity calculations. Then make a velocity vs. time graph for the object, and determine the slope of the velocity vs. time graph:

Title of graph:

v_y =0



9. Calculate the slope of the v-t graph (call it "*g*"). What does the slope represent?

10. Use the velocity-time graph to develop a mathematical expression for the velocity as a function of time:

Post-lab Discussion:

11. A ball is dropped (i.e., it starts with zero velocity). Using the slope of your v-t graph:

a) What should its velocity be after 1 sec?

b) What should its velocity be after 2 sec?

c) If instead, the ball is <u>thrown</u> downward with a starting velocity of 20 m/s, what would its velocity be after 1 sec? After 2 sec?

d) For an object that is fluffy and light, so that it experiences a lot of air resistance, do you think its v-t graph will have a slope that is more than *g*, the same as *g*, or less than *g*? Explain.

12. Draw a motion diagram for the block. How does it compare to the spark tape?

13. Draw a force diagram for the block. What is the force just as the object begins falling? In the middle of its fall? Just before it hits the ground?

14. If Newton's law says that force = ma, what should the acceleration be? How does this relate to the acceleration you just measured?

Part II. Investigating the effect of mass on the rate at which an object falls

Pre-lab discussion:

15. Predict: Do you think a heavier mass will fall faster, slower, or at the same rate as a lighter mass? Explain your reasoning.

16. Draw two force diagrams: one of a heavy object held in one hand, and the other of a light object held in the other hand (before release).

17. Next, imagine that you drop the object. Draw two force diagrams: one for the forces acting on the heavy object while it is falling, and the other for the forces acting on the lighter object while it is falling.

18. If you were to conduct an experiment,

a) How can you make measurements to compare the motion of the two objects?

b) What factors would you compare?

c) What graphs would you draw?

d) Predict what those graphs might look like.

e) State your hypotheses clearly.

Directions:

19. Design and conduct an experiment to investigate and compare the motion of the two objects. You will need to construct a position-time graph.

a) The Experimental Question:

b) IV:

c) DV:

d) Constants:

e) Hypothesis:

f) Materials List:

g) Procedure:

h) Data Table:
Record position-time data and obtain velocity-time data in your table below.

i) Plot position-time (y-t) graphs and velocity-time graphs for the heavy object on the same graph as the light object (steps 7 and 8):

Post-Lab Discussion:

20. Calculate the slopes of the graph of velocity vs. time for the light object and the heavy object. Compare them and explain.

21. Does the height from which the objects were drop affect your results for the acceleration of the object?

22. Suppose that an object is dropped from a height of 2 m, while another object is dropped from 1 m. Draw a diagram.

a) Would their accelerations be different? Explain.

b) Would their velocities just before they hit the floor be different? Explain.

c) The objects are dropped at t =0 s. The downward speed of the first object at t =0.1 s is 0.98 m/s. When is the downward speed of the second object 0.98 m/s? Explain.

d) The downward speed of the first object 1.4 m above the ground is 3.42 m/s. At what position is the speed of the second object the same?

23. Explain the forces and accelerations of the light object and the heavy object based on Newton's Second Law.

24. Summarize your observations on the factors that affect acceleration due to gravity in the Student Summary Page: Free Fall

Throw the Ball Upwards Lab

Materials
- Basketball
- Motion Detector
- (Alternately- a wooden block or a ball and a video camera)

Purpose:

What is the acceleration due to gravity for an object that is thrown upward and then falls to the ground?

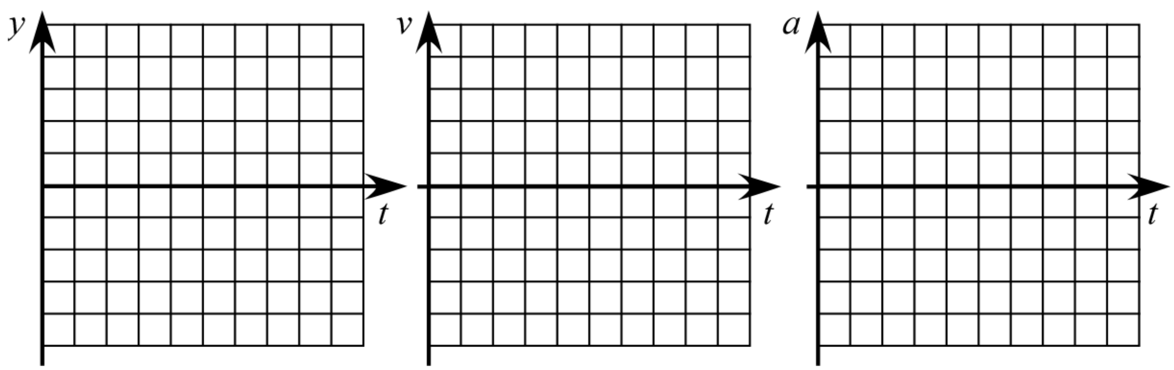
Pre Lab Discussion

1. Observe while your teacher throws a ball upward and then catches it. Based on your observations, <u>predict</u> the following:

   a) The velocity and acceleration of the ball at the very top of the trajectory.

   b) a motion diagram for the entire motion of the ball

   c) y-t (position time), v-t and a-t graphs:



   d) draw force diagrams of the ball midway up, at the very top, and midway down

   e) an equation to describe this motion

2. Develop a method of recording this motion using a motion detector (or using a video camera).

Directions

3. Design an method to study the vertical motion of a ball. First figure out what data you will measure and how you will obtain the data.

4. Next, design two experiments: A. For a ball that is dropped from head height and B. For a ball that is thrown vertically upward and falls.
Note: If you are using a motion detector, practice first. Throw the ball so it rises no more than 50-80 cm. Practice throwing it straight up, making sure your arms do not get in the way. You will also have to make sure the ball does not crash into the motion detector. You will have to

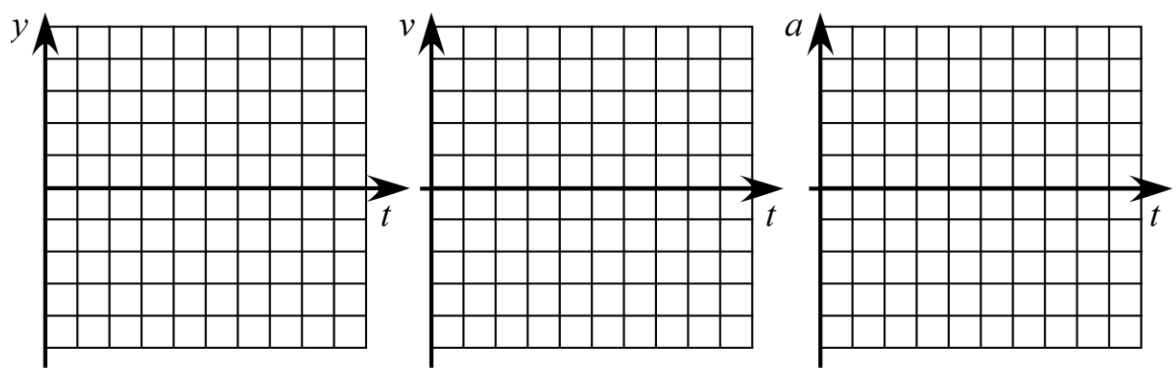
The information below is set up so you can do experiment A first and then experiment B.

Experiment:	A: Ball dropped from head height	B: Ball thrown vertically up and falls
a) Experimental Question:		
b) IV:		
c) DV		
d) Constants		
e) Hypothesis		
f) Materials list		
g) Procedure		

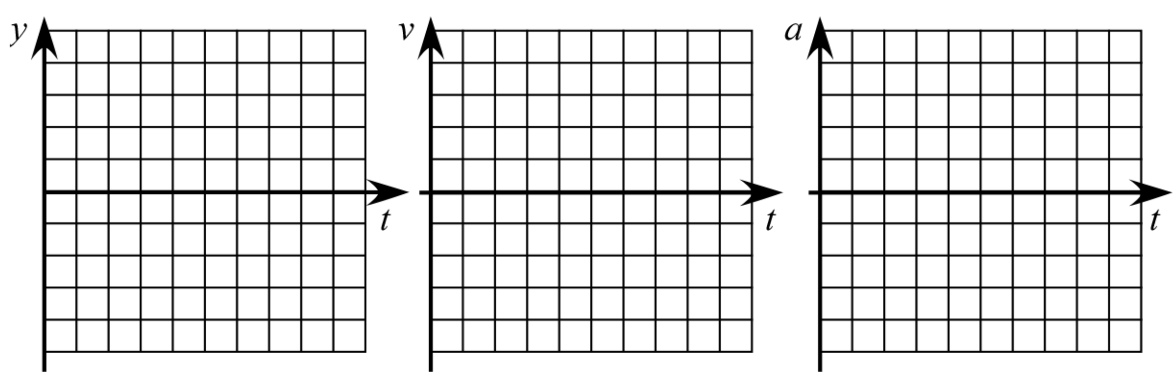
Experiment:	A: Ball dropped from head height	B: Ball thrown vertically up and falls
h) Data Table		

i) Graphs for experiments A and B (or you may print them from the computer):

A: Ball dropped from head height:



B: Ball thrown vertically up and falls:



Post-lab discussion:

5. Develop: motion diagrams for the motion in experiments A and B.

6. Compare the following quantities for the object:

Experiment:	A: falling down	B: moving up	B: at top of trajectory	B: falling down
a) Compare acceleration from the slope of v-t graph				
b) Force diagram				

7. For experiment B, discuss the similarities and differences of the motion of the ball while it is moving upward, downward and at the top of the motion.

8. Discuss the similarities and differences of the motion of the ball as it moves downward in experiment B compared to it moving downward in experiment A.

9. Discuss the similarities and differences among the four force diagrams you drew.

10. Discuss the shapes of various graphs:

a) Compare the position-time graphs for experiments A (ball dropped) and B (ball thrown up). Explain their similarities and differences.

b) What is the shape of the position-time graph for experiment B?

c) Compare the v-t graphs for experiment A and experiment B. Explain their similarities and differences.

d) What is the shape of the v-t graph in experiment B?

e) Compared to experiment A, what would be different if you threw the ball downward with a non-zero initial velocity (rather than just drop it)? Compare the v-t curve and acceleration. Explain your reasoning.

f) Compared to experiment B, what would be different if you threw the ball upward with the same velocity on the moon? Compare the v-t curve and acceleration. Explain your reasoning.

g) What is the velocity at the very top of the ball's trajectory in experiment B? Explain.

h) What is the acceleration at the very top of the ball's trajectory in experiment B? Explain.

i) What is the direction of the acceleration? Is the acceleration changing or constant? Explain.

j) What is the direction of the acceleration in experiment B as the ball rises? At the top of the trajectory? As it falls? Is the acceleration changing or is it constant? Explain.

k) In experiment B compare the velocity of the ball 10 cm below the top-most point on its way up, and on its way down. Explain their similarities and differences.

11. Return to *Student Summary Page: Free Fall*, and add observations from this activity.

Motion in Two Dimensions

Materials
- Two tennis balls
- OR two large washers or coins and a meter stick
- Ball drop and shoot apparatus (aka vertical acceleration demo) – optional
- Ruler and two marbles

Purpose:

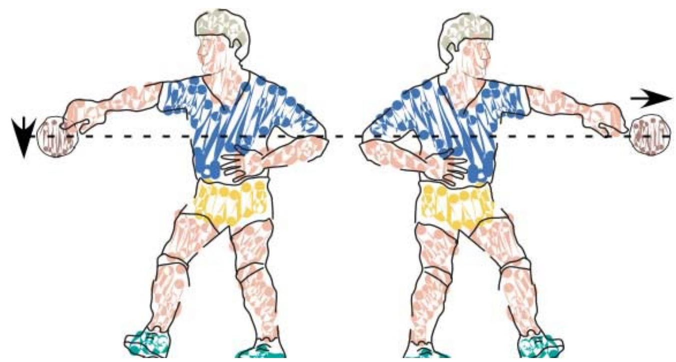
Will the effect of gravity be different on a ball that is dropped as compared with a ball that is thrown horizontally?

Pre-lab discussion:

1. Here's the scenario: Two people hold a tennis ball each. Both hold the balls at the same height, and both let go of the ball at the same instant. Rob, on the left, lets it drop directly downward. Pearson gives the ball a horizontal push. Emphasize same mass, different horizontal velocities.

Optionally, the same idea can be demonstrated with the ball and shoot apparatus

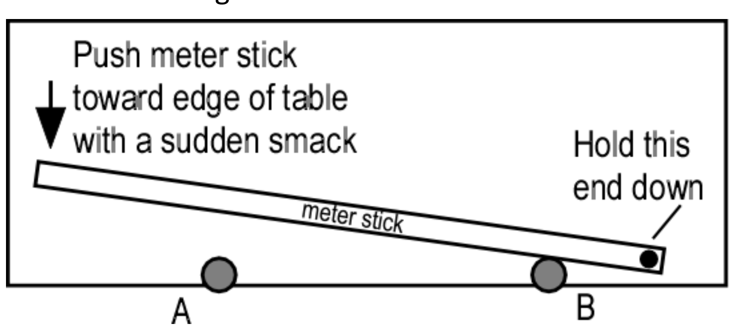
2. Predict which ball reaches the ground first, and explain your reasoning.



Directions:

3. Try it out. Be watchful of how the balls are dropped. The person throwing the ball downward should be sure to just *drop* the ball, not throw it down. The person giving the ball a horizontal push must be sure the push is *only horizontal*, and that the ball does not go upward and then fall. Both people should start at the *same* height and at the same time.
Describe what happened. You might have to shut your eyes and listen to be sure of your observations.

4. Try a similar activity with a meter stick and two large washers. Place the two washers about 50 cm apart, close to the edge of the table. Place the meter stick at an angle, almost touching one of washers (B), but 30-40 cm from the washer A. Give the end of the meter stick a sudden push so it sweeps across the table and pushes both washers off the edge of the table.
Describe what happened.



Post-lab discussion:

5. What is different between the vertically dropped ball vs. the one that received the horizontal push?

6. Draw diagrams of the trajectories of the two balls/washers.

7. Write a description of what you learned from this activity. Explain your reasoning for why the balls/washers behave as they do.

8. Compare these two trajectories to that of a baseball or a soccer ball.

Trace that Trajectory Lab

Materials:

- Movie of horizontally launched ball, self made or pre-made

If you are making your own movie:

- Marble launcher (e.g., CPO or Pasco)
- Screen and video camera (or digital camera in movie mode)

Purpose:

What is the shape of the trajectory for a ball launched horizontally?

Pre-lab discussion:

1. Open the PHET simulation Projectile Motion (http://phet.colorado.edu/en/simulation/projectile-motion). Download and open the simulation.

   a) Click and drag the canon such that it is at a certain height above the ground.

   b) Orient the canon such that it shoots horizontally. Set the angle to 0 degrees.

   c) Select an object to shoot.

   d) For the same object, use different initial velocities. Make a sketch of the trajectories. What are the shapes of these trajectories?

   e) For the same initial velocity, change the mass of the object. Describe the trajectories.

   f) Use the same object and the same initial velocity. Change the angle. Describe the trajectories.

   g) Change the value of "g." Describe how the trajectories change

2. What affects the shape of a trajectory?

3. Where have you seen motion like this in everyday life?

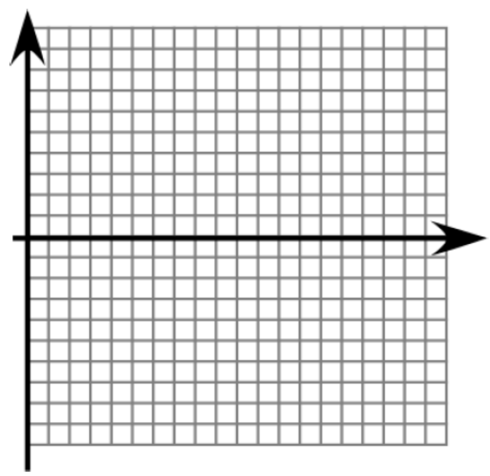
4. Why is it that the trajectory of the object shot from the canon ball Is not a straight line?

Directions:

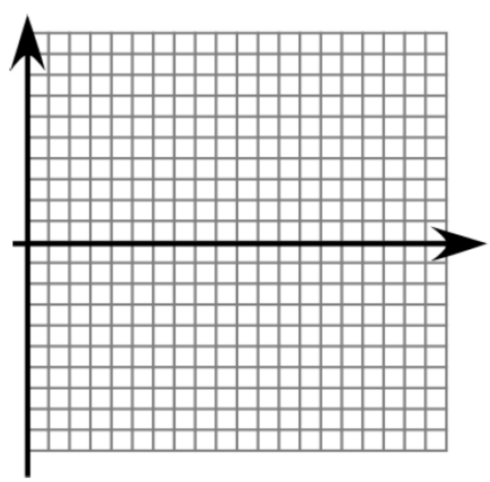
5. In this lab we will study the motion of a projectile with an initial horizontal velocity.
   a) Import the movie "Horizprojectile.avi" into Logger Pro. You will analyze the motion of the basketball in this movie.
   b) Advance the movie frame by frame, and mark the position of the ball. Don't forget to set the origin of the coordinate system and the standard length.

Part 1: Analyze the motion of the basketball along the horizontal.

6. Let's start with the motion along the x axis. Right click in the graph window and select Graph Options. In the window that shows up, select the second tab at the top, Axes Options. Unselect the Y (m) axis. This leaves only the x vs t graph in your graphs window. Sketch the x vs t graph.



   a) Look at the position vs time graph. What type of motion does the ball have along the x axis? Explain your answer.



   b) Predict the shape of the v vs t graph, and sketch it here.
   c) Use the linear fit (from the menu bar, Analyze: Linear Fit) to find the velocity along the x-axis).
      From your fitted line, describe the velocity (is it changing? Moving in the positive or negative direction?).

d) What is the initial velocity of the ball along the horizontal axis? What is the final velocity of the ball (just before it hits the ground) along the horizontal axis? How do you know?

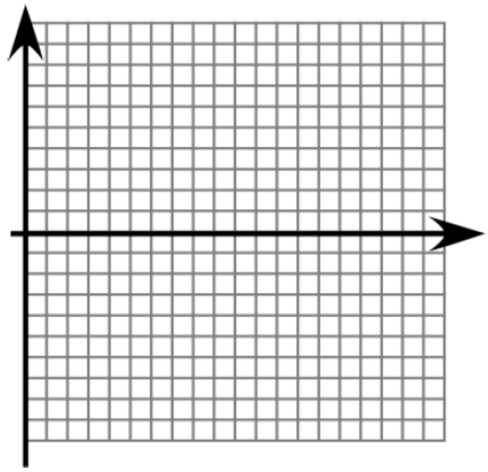
e) Switch your graph to X Velocity vs. time. Right click in the graph window and select Graph Options. In the window that shows up, select the second tab at the top, Axes Options. Un-select the X (m) axis and select X Velocity (m/s) axis. Use Analyze: Statistics to find the mean value of the horizontal velocity over time. Record the value below. How does this value compare to the value of the velocity read from the x vs t graph?

f) Draw a force diagram for the ball. What is the net force along the horizontal axis?

g) How is your answer supported by the results of your lab?

h) Which of Newton's Laws does this part support?

Part 2: Analyze the motion of the basketball along the vertical.



7. Let's analyze now the motion along the y axis. Right click in the graph window and select Graph Options. In the window that shows up, select the second tab at the top, Axes Options. Unselect the X (m) axis and select the Y (m) axis. This leaves only the y vs t graph in your graphs window. If your graph is out of the boundaries of the window, use the Auto Scale tool.

a) Sketch the y vs t graph.

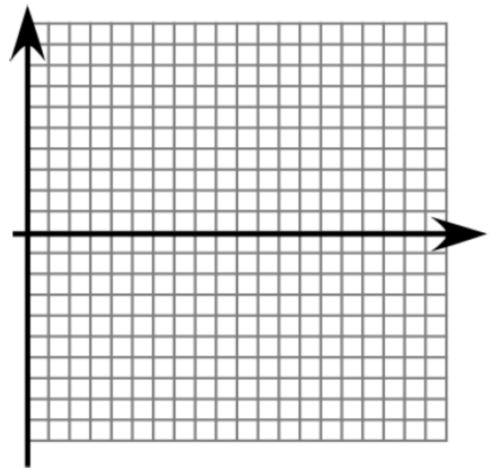
b) Look at the y position vs time graph. What type of motion does the ball have along the y axis? Explain your answer.

c) Use the curve fit (from the menu bar, Analyze: Curve Fit) to find how velocity changes along the y-axis. Which general equation should you use for your curve-fit? Write its expression.

d) From your fitted curve, what is the initial speed of the ball along the y-axis? Explain your answer.

e) From your fitted curve, what is the acceleration of the ball along the y axis? Explain your answer.

8. Change your graph to y velocity vs. time. Right click in the graph window and select Graph Options. In the window that shows up, select the second tab at the top, Axes Options. Unselect the Y (m) axis and select Y Velocity (m/s) axis.



a) Sketch the v vs t graph.

b) What does the slope of the v vs t graph represent?

c) Use a linear fit to find the slope of the v vs t graph. What value have you obtained for it?

d) How does the value for your acceleration compare to the actual value of the gravitational acceleration?

e) From the fitted line to the v vs t graph, what is the initial speed of the ball along the y axis.

f) Draw a force diagram for the ball. What is the net force along the vertical axis?

g) How is your answer supported by the results of your lab?

Postlab Discussion

9. What type of motion does the basketball have along the x axis?

10. What type of motion does the basketball have along the y axis?

11. Is motion along the x axis affected by the motion along the y axis?

12. Compare and contrast the velocity of the ball along the x axis and along the y axis.

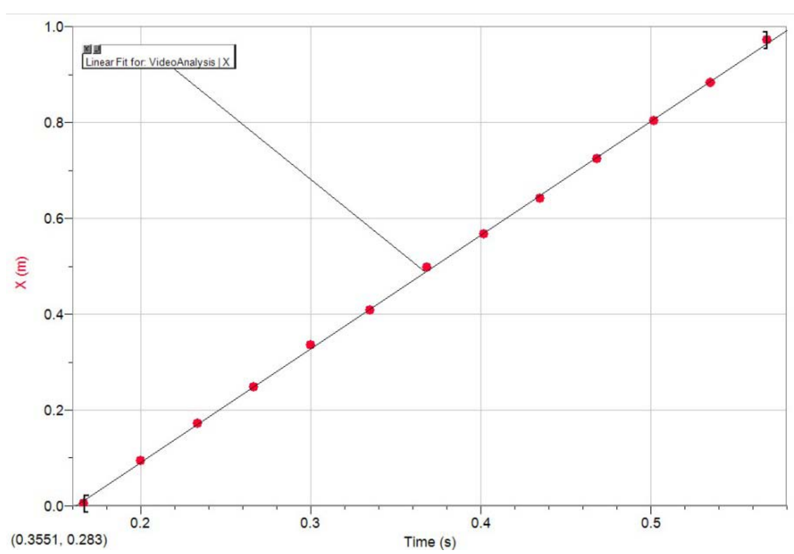
13. What is the mathematical equation you would use to find the position of the ball along the x axis?

14. What is the mathematical equation you would use to find the position of the ball along the y axis?

15. What is the mathematical equation you would use to find the velocity of the ball along the x axis?

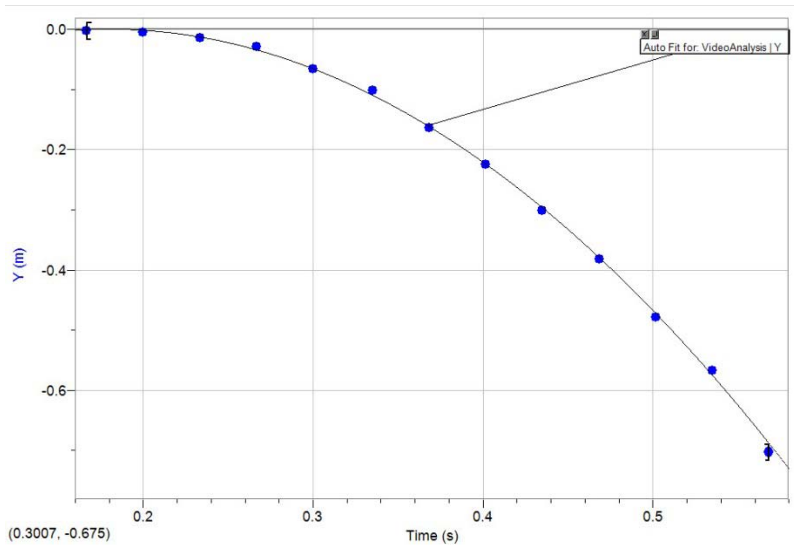
16. What is the mathematical equation you would use to find the velocity of the ball along the y axis?

17. Using the graph below, draw a motion diagram for the motion of the ball along the x axis.



18. Using the graph below,

a) draw a motion diagram for the motion of the ball along the y axis.

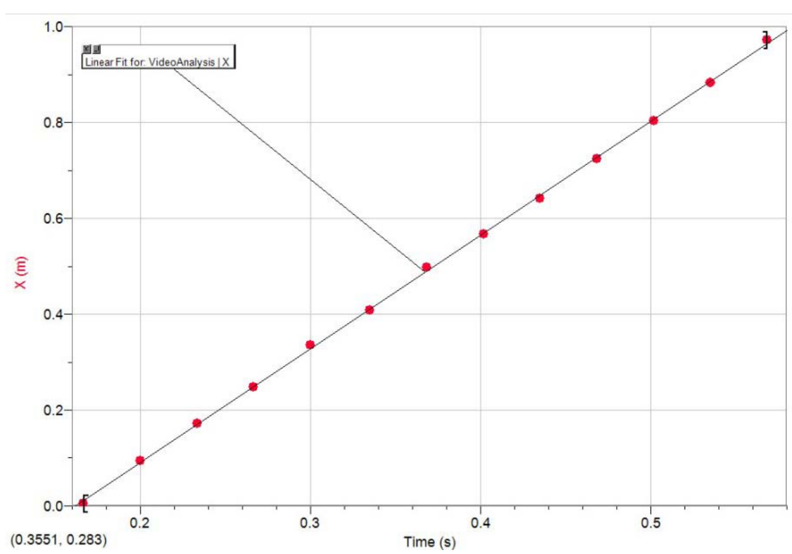


b) How are the acceleration of the ball and the direction of the net force related?

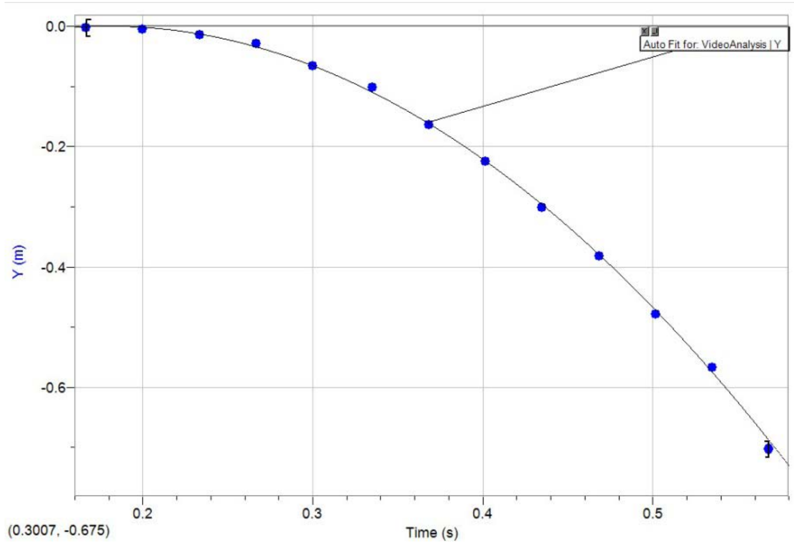
c) How is the acceleration of the ball related to the direction of motion of the ball?

19. On the graph below

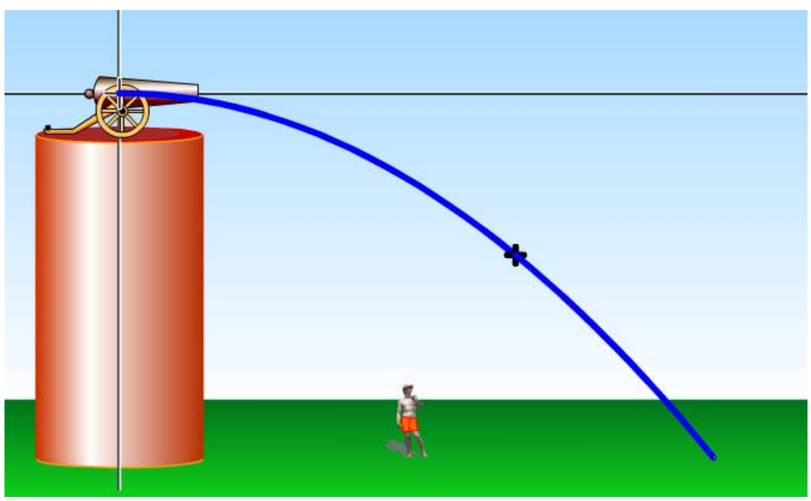
a) At every point marked along the trajectory, draw arrows to represent the horizontal velocity of the ball.



b) At every point marked along the trajectory, on the graphs below, draw arrows to represent the vertical velocity of the ball.



c) Look at the snapshot of the firing cannon from the PHET simulation. What do you think that the vertical and horizontal axes represent in this figure?



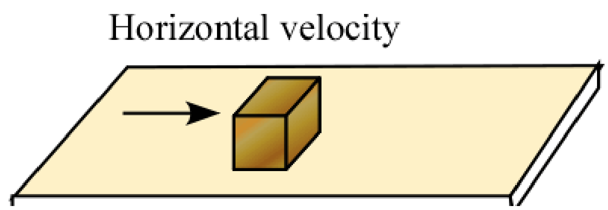
Forces and Projectile Motion

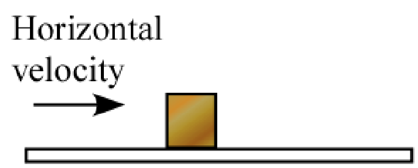
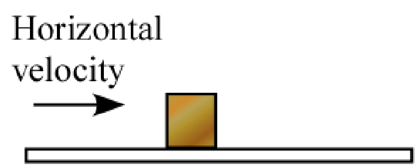
Purpose:

What are the forces at work in projectile motion?

Thought experiments:

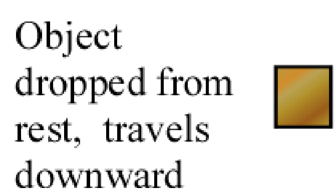
1. An object is set in motion across a flat surface with a horizontal velocity, as shown in the picture. Examine the forces it feels, and draw the force diagrams.



a) Assuming that the surface is perfectly smooth and frictionless, draw the force diagram in the picture below, and explain your reasoning. Is there a non-zero net force? What is the effect of the net force on the motion?	
b) Assuming that the surface is slightly rough (no longer frictionless), draw the force diagram in the picture below, and explain your reasoning. Is there a non-zero net force? What is the effect of the net force on the motion?	

2. The object is dropped from rest, and is traveling downward (no air resistance). The picture below depicts it at a certain instant in time about half-way to the bottom. Draw the force diagram in the picture, and explain your reasoning.

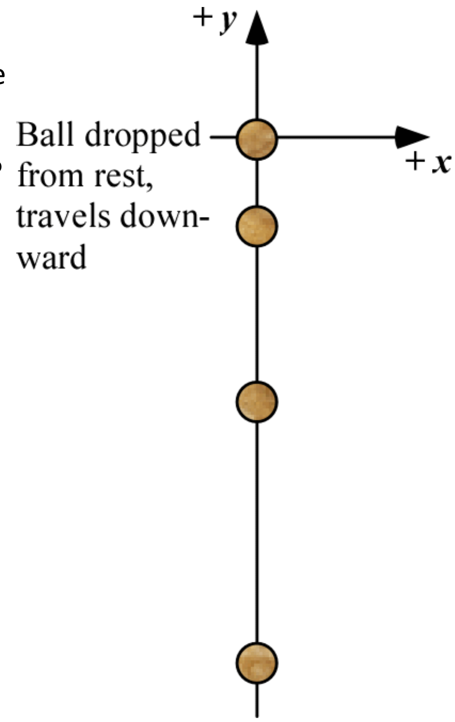
Is there a non-zero net force? What is the effect of the net force on the motion?



3. A ball is dropped from rest, and is traveling downward (no air resistance). The picture below shows the ball at four positions on its way down.

a) Draw the force diagrams for all four positions in the picture below, and explain your reasoning.

b) Does the ball experience horizontal forces? Vertical forces?



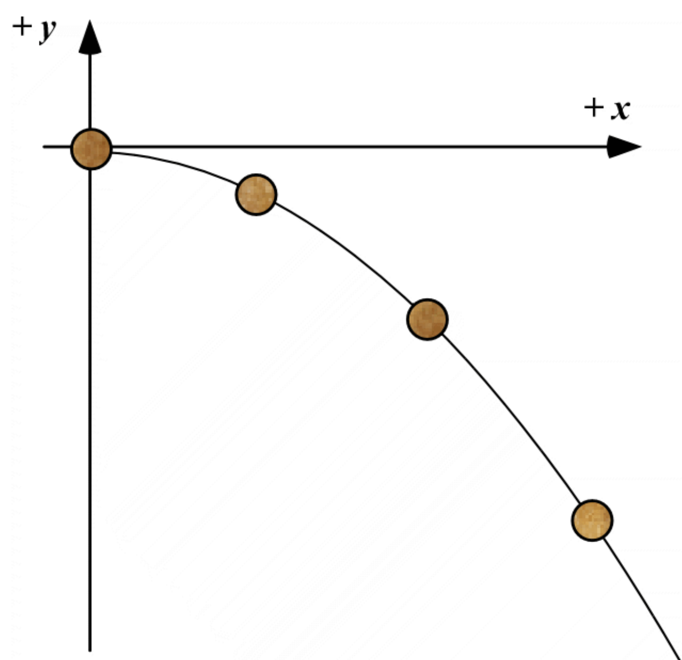
c) What is the effect of the net force on the motion?

d) Compare the forces on the ball at the four positions.

4. A ball is thrown out of a second floor balcony (no air resistance). The picture below shows the ball at four positions on its way down.

a) Draw the force diagrams for all four positions in the picture, and explain your reasoning.

b) Does the ball experience horizontal forces? Vertical forces?



c) What is the effect of the net force on the horizontal and vertical motion? Compare the forces on the ball at the four positions.

5. Two balls fall from the roof of a building (no air resistance). Ball 1 is dropped and falls vertically downward. Ball 2 is thrown with a horizontal velocity. Draw force diagrams in order to compare the forces (horizontal and vertical) on a ball at the following positions:

Position of ball	Ball 1: dropped vertically down. Force diagram:	Ball 2: thrown with horizontal velocity. Force diagram:
Just when dropped		
One quarter of the way down		
Half way down		
Just before it hits the ground		

6. In each case, how is the forces related to the acceleration of the balls

7. What conclusions can you draw from this series of thought experiments?

Hit the Can - Practicum

Materials:

- A can (or other object such as a roll of tape)
- Two rulers (with a ridge running along the center), or a hot wheels track and a ruler
- A small marble
- Tape
- Photogate(s) and timer

Purpose:

What factors must we calculate to hit a can placed on the ground with a marble that runs off a table with a horizontal velocity?

Pre-lab discussion:

1. Examine the set up the experiment. Your teachers may demonstrate how it works. Make a ramp with the ruler (or other track), and let the marble run down the table for a few inches to consistently obtain the same horizontal velocity.

2. The lab should *not* be conducted by trial and error, but by figuring out the factors one must control, measuring necessary parameters, and then, finally, placing the can at the appropriate spot and hitting it – in one try.

Directions:

3. Without the can, set up the equipment and experiment with the different factors you can change. Write down the factors you can measure. Think about which factor(s) control exactly where on the ground the marble will land.

4. The teacher is going to place the can at a distance of __ m (your teacher will choose the distance that is reasonable for the parameters of the setup).

5. Figure out what measurements are necessary, and what factors you must control so that the marble will hit the can.

6. Make measurements of the constants of the experiment that matter, and make your calculations, and set up their experiment. When they are ready, the teacher will place the can in the designated spot, and allow the students <u>one</u> try.

7. Discuss what worked, what did not work, and what changes you have to make in order for the experiment to work.

8. Present your calculations and data.

9. Additional questions you must answer in your report/presentation:

   a) How would the result change if the table were shorter? Taller?

   b) What would you have to change if the can were placed 10 cm closer? 10 cm farther?

   c) What other variations can you make of this activity?

Launching Darts Lab

Materials:
- Dart gun or stomp rocket
- Large protractor
- Tape Measure – 8 to 10 m preferred
- Graph paper
- 1 sheet of carbon paper
- 1 sheet or plain paper to place under carbon paper
- Note: it is best to conduct this lab in a room with a 3-4 m ceiling and about 10-20 m of clear space

Purpose:

What other parameters affect the trajectory of a projectile?

Part I

Pre-lab discussion:

1. So far you have dealt mainly with projectiles launched with a horizontal velocity.
Examine the dart gun. Do you have to "shoot" darts with a horizontal velocity? Predict what you think will happen if you tip the gun upward a bit?

2. Try shooting one or two darts (not more). Brainstorm the variables you can measure, and the variables you can vary. Discuss how you will conduct the measurements. Share your ideas through a whiteboard discussion.
While it is a bit tricky to measure the landing point of the projectile, it can be done with some amount of planning and repeated trials. You may use a sheet of carbon paper with a plain sheet of paper under it to help identify the point of impact.
Design your experiment and describe how you will collect data:

Directions:

3. For this first part, all groups should use the same launch speed, and measure the horizontal distance traveled by the dart as a function of the launch angle. First predict the graph you expect to obtain, and explain your reasoning (hold the dart gun as close to the floor as possible when you launch the dart:
(the horizontal distance between the launch point and the point where the dart hits the ground is called the range)

4. Practice launching the dart, placing the dart gun against the launcher so that the angle of launch can be repeated for multiple trials. Take data every 15°, starting at 0.

a) The Experimental Question:

b) IV:

c) DV:

d) Constants:

e) Hypothesis:

f) Materials List:

g) Procedure:

h) Data Table:
Note: while you make measurements of the range, keep qualitative notes of other factors that are different, such as time of travel, height of trajectory, etc.

i) Range vs. Angle graph::

Title of graph:

5. Analysis of data:

a) How does your plotted data compare with your predicted graph?

b) What conclusions can you draw from your data?

Post-lab discussion:

6. Discuss the following questions in your group, and then with the whole class:

   a) Is there an angle for which the horizontal distance traveled (called the range) is the largest?

   b) Look at the range traveled by the dart for a launch angle of 30°. What other angle produced the same range? While the ranges are the same, how are other factors different – for example, time of travel, height of trajectory? Your descriptions can be qualitative.

   c) For any launch angle below 45°, can you launch at a different angle and still have the dart travel the same range (for the same launch velocity)? Describe the relationship between these angles.

   d) Dart 1 is launched from floor level. Dart 2 is launched a few cm above the floor with the same initial velocity and launch angle. Do you think Dart 2 would travel a shorter, longer or the same distance?

   e) You are challenged to launch a dart to travel a distance of 4 meters (with the same initial velocity as the dart in part (d). What launch angle(s) must you use?

   f) In what ways is this lab different from the one where the dart was launched with only a horizontal velocity?

7. Summarize the important things you learned from this activity.

Part II. (Optional - if you have a marble launcher or a dart gun with more than one launch velocity

Pre-lab discussion:

8. Now that you have investigated the main principles of projectiles, expand the activity further and design an experiment where you investigate how the speed of the dart affects the range. Brainstorm the parameters you will keep fixed.

Directions:

9. Have each group of students choose a different launch angle, which they hold constant, while the speed of the launch is changed. Make predictions of the trajectories you expect for your angle.

10. Conduct the experiment:

a) The Experimental Question:

b) IV:

c) DV:

d) Constants:

e) Hypothesis:

f) Materials List:

g) Procedure:

h) Data Table:

i) Graph::

Title of graph:

Post-lab discussion:

11. Discuss the following questions in your group, and then with the whole class:

a) If we placed a can at a distance of 5 m from the launcher, what parameters can you vary to hit the can? Is there only one set of such parameters?

b) When the quarterback wants to throw the ball the largest distance, what should he do?

c) From looking at the dart's path, what do you think is the shape of the trajectory? (The trajectory is the y vs. x curve!).

Circular Motion of a Flying Pig

Materials:

- A squishy ball or other soft toy tied to a string
- A Flying Pig toy, attached to the ceiling or a tall light fixture, if possible
- Coin
- Tennis ball
- Bucket
- Masking Tape
- Marble

Purpose:

What does circular motion look like?

Station 1. Ball or Toy on a string

1. Hold the end of the string on the ball-on-string toy and swing it around in a horizontal circle. (Make sure you have a clear space around you).

   a) What factors might be used to fully describe the motion?

b) Draw a motion diagram (top view).	c) Draw a force diagram (side view).

   d) Predict what would happen if the string were to break suddenly. What would the motion of the object look like?

e) Draw a motion diagram just after the string breaks (top view).	f) Draw a force diagram just after the string breaks (side view).

Station 2. Flying Pig

2. Set the pig in motion in a circular path.

   a) Observe the motion of the pig and discuss the forces that act on it.

   b) What is the job the motor does?
   (To figure out the job of the motor, stop the pig and just have it flutter its wings. Then turn off the motor and pull the pig to one side and have it execute a pendulum-style motion, and then circular motion. So what's the motor really doing?)

   c) Draw a picture of the pig at one instant in time (a snapshot picture) and draw the force diagram for the pig (side view).

Station 3. The ball in the bucket

3. In this activity you will place a ball in a bucket, and swing it in a vertical circle.

   a) Predict what will happen:

   b) Try it. Describe your observations and explain them.

   c) What forces act on the ball?

Station 4. Tape and Marble

4. Place a roll of masking tape on the table or on an overhead projector, with a small marble inside it. Rotate the roll of tape quickly making the ball travel in a circle, hugging the inside of the roll.

a) What is the direction of the velocity at each point in the path of the ball?

b) Predict what will happen if you suddenly lift the roll of tape while the ball is traveling in a circle. Explain your reasoning.

c) Try it, and explain what happens.

5. Summarize what you learned about circular motion from these activities.

6. Think back to the Broom Ball Lab, and describe in which part of the ball's path you observed circular motion.

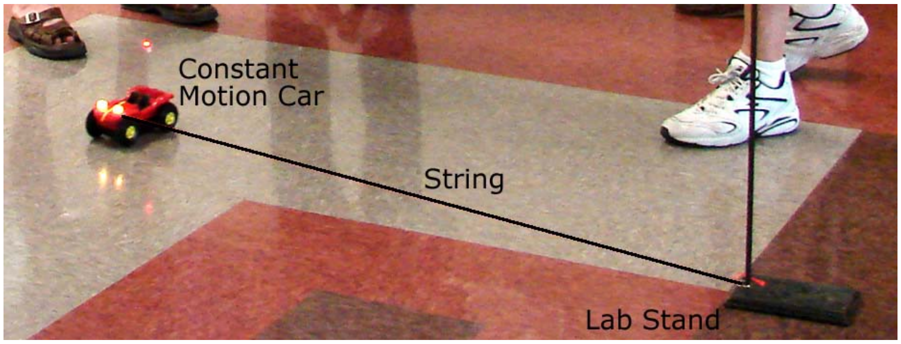
Describing Circular Motion Lab

Materials:

- Constant speed car
- Lengths of sturdy string with a loop on one end and a key ring tied to the other end (e.g., 6 different lengths of string ranging from 20 cm to 1 m).
- Lab stand with a circular pole (~ 1 cm dia). A short length of pole is preferred (15-20 cm), with a tennis ball attached to top (cut a hole in the ball) to avoid injury.
- Stopwatch
- Masking Tape
- Meter stick
- A space with a smooth floor, but not so smooth as to make the car slip

Purpose:

What factors describe circular motion?



Pre-lab discussion:

1. Set up the equipment. Using a medium-length string, place the loop of the string over the headlight of the car, and slip the keyring over the pole of the lab stand. Place the car close to the stand, with the string slack. [Note: the car may tumble over if the loop is attached further back in the car]

   a) What do you think will happen if you turn the car on? Discuss your answers among your group and come to a consensus.

   b) Next, turn the car on, and watch its motion. Brainstorm what is measurable, and whiteboard your ideas.

Directions:

2. Design an experiment to relate the period of the car (time taken to travel one full circle) to the radius of the circle. (Note: the radius of the circle is the distance from the center of the pole to the outside edge of the car)

   a) The Experimental Question:

   b) IV:

   c) DV:

   d) Constants:

e) Hypothesis:

f) Materials List:

g) Procedure:

h) Data Table:

i) Graph:

Title of graph:

3. Analysis of data:

a) What kind of relationship does this graph indicate? Is it a direct or an inverse proportion?

b) If the radius (r) is 1.2 m, what would the period (T) be?

4. Next, draw a circle on a piece of paper. Suppose that a constant speed car travels along the circular path.

a) What is the relationship between the circumference of the circle (C) and the radius, r?

b) Suppose that it takes a time T to travel in the circular path of radius r. How far does the car travel in time T?

c) If v is the velocity of the car, how are the velocity, circumference and period (v, C and T) related?

d) Since you know the relation between C and r, now develop a mathematical relationship between v, r and T.

e) Measure the velocity of the car by letting it travel in a straight line. How is this velocity related to the slope of your graph?

f) Alternatively, from your data, calculate the velocity of the car from the slope of the graph. How does this compare with your measured velocity for the car when it is traveling in a straight line?

5. From your answers above, establish the relationship between the circumference, velocity and period.

6. Summarize what you learned about the period, the velocity and the radius of an object traveling in a circular path.

Forces in Circular Motion Lab

Materials:

- Constant speed car
- Lengths of sturdy string with a loop on one end and a key ring tied to the other end (6 different lengths of string ranging from 20 cm to 1 m).
- Lab stand with a circular pole (~ 1 cm dia). A short pole is preferred (15-20 cm) so students do not accidentally hurt themselves while bending over the pole)
- Stopwatch
- Masking Tape
- Meter Stick
- Spring scale (2N)
- A space with a smooth floor, but not so smooth as to make the car slip
- Bypass for one car battery

Purpose:

What forces are involved in circular motion, and how are they related to other factors that describe circular motion?

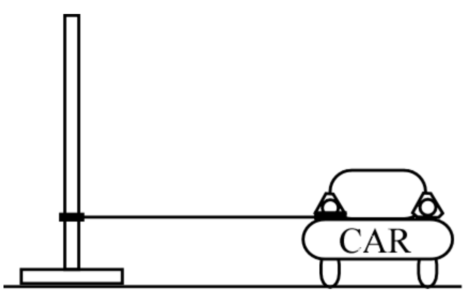
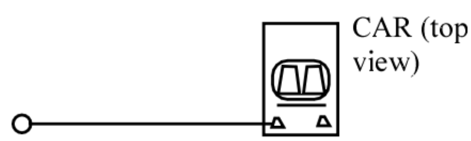
Pre-lab discussion

1. Tether the car to the stand, as before, and set it in motion.

   a) We know that the constant speed car goes in a straight line when it is not tethered to the stand. What makes it go in a circle?

   b) Is there a force involved here, and what does it do?

2. Draw force diagrams for the car in a circular path below - both side views and top views.

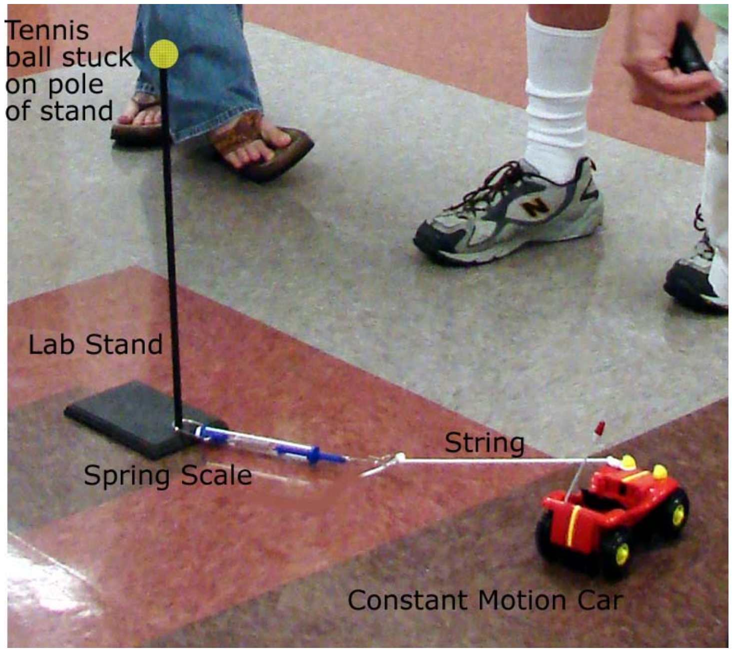
a) Force diagram - Side view	b) Force diagram - Top view
	

   c) What do the various forces do? Are there any forces that are unbalanced?

   d) Is the string taut or slack? If it is taut, is there a force along the string? What force can it be?

   e) Since an unbalanced force implies an acceleration, and acceleration implies a change in velocity, what *does* that unbalanced force do?

3. To measure the force that points toward the center of the circle, place a spring scale on the pole of the stand, then hook the string that connects to the car to the hook of the spring scale. Set the car in motion.

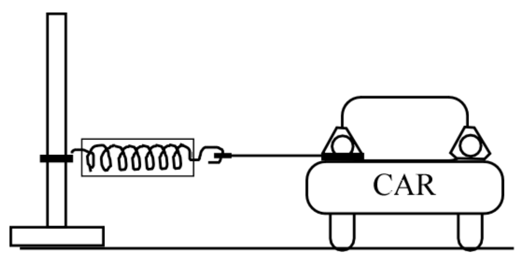


a) Make observations of the setup. What can be measured, and what information would those measurements provide?

b) Whiteboard your observations and brainstorm and design an experiment that you can conduct.

Directions:

4. Design and conduct the experiment to obtain the relationship between the radius of the car's circular path and the force exerted on the spring (which is equal to the tension on the string).



a) The Experimental Question:

b) IV:

c) DV:

d) Constants:

e) Hypothesis:

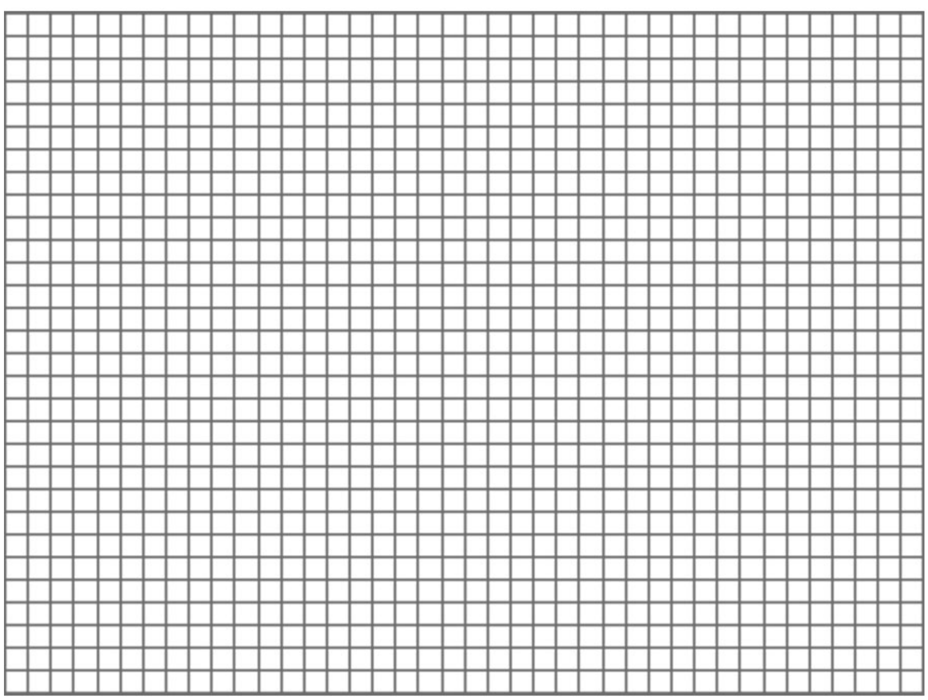
f) Materials List:

g) Procedure:

h) Data Table:

i) Graph:

Title of graph:



5. Analysis of data:

   a) What exactly does the force on the spring scale represent?

   b) What is the relationship between the force and the radius? Is it a direct or an inverse proportion?
   (Write the proportionality between the force and the radius in a mathematical form.)

   c) What other factors (other than the radius) do you think would affect the force, and how do you think they might affect it?

   d) Try out one or two of the factors and describe how they affect the force. (Note: if you want to change the velocity of the car, insert the spacer in place of one of the batteries. You will have to measure the velocity of the car again).

   e) Use the ideas generated by the class to describe proportionalities between the force that pulls the object toward the center of the circle to (a) the radius, (b) the mass of the object and (c) the speed of the object in mathematical form. You should be able to describe whether these factors are directly or inversely proportional to the force.

Note: The force toward the center of the circle has a name: it is called ________________________

6. Discussion questions:

a) A car on a racetrack experiences a centripetal force of 6000N. Draw a force diagram that identifies all the forces on the car. If the mass contained in a car is doubled, would it feel more or less force? How much more or less? How does this relate to a compact car vs. a mini-van that travels on a curved road?

b) A car on a curved road is traveling at a speed of 40 km/hr. If the driver speeds up to 80 km/hr on the same curve, is the centripetal force more, less or the same? Explain.

c) When you drive a car, or are a passenger, you feel a sideways force when the car turns a corner or goes around a curve. If the speed of the car is the same when it takes a left turn or a right turn, which turn would make the force larger? Explain.

7. Summarize what you learned about the forces present when an object travels in a circular path.

Exploring Momentum Lab

Materials:

- Station 1: Happy and sad balls
- Station 2: Astroblaster
- Station 3: Marble collision: ruler with groove, 3 small marbles, 1 large, a Dixie cup
- Station 4: Newton's cradle
- Station 5: Magnetic marble accelerator
- Station 6: Kinetic yo-yo
- Station 7: Shooter: suction cup dart

Purpose:

What happens when collisions occur?

Pre-lab discussion:

1. What do you think "a collision" means?

PREDICT what happens with each activity before you try it!

Directions:

2. Station 1. Happy and Sad Balls	
a) Examine the two balls. Predict what might happen if you dropped each one on the floor or table.	b) Try out the activity. What might be occurring at this station that can be called a "collision?"
c) Draw a diagram of the collision, and describe it in words.	
d) Was there anything unexpected that happened?	e) Think of one parameter that you could alter to change the collision.

3. Station 2: Astroblaster	
a) Examine the astroblaster. Predict what might happen if you dropped it on the floor.	b) Try out the activity. What might be occurring at that station that can be called a "collision?"
c) Draw a diagram of the collision, and describe it in words. How many collisions occur?	
d) Was there anything unexpected that happened?	e) Think of one parameter that you could alter to change the collision.

4. Station 3: Marble Collision:	
a) What would happen if you set the ruler on an incline, with a cut-away Dixie cup at the end. Roll one marble down the ruler, examine how far the cup is pushed. Predict for large and small marbles.	b) Try out the activity. What might be occurring at that station that can be called a "collision?"
c) Draw a diagram of the collision, and describe it in words.	
d) Was here anything unexpected that happened?	e) Think of one parameter that you could alter to change the collision.

5. Station 4: Newton's cradle	
a) Predict what would happen if you pulled one ball to the side and let go.	b) Try out the activity. What might be occurring at that station that can be called a "collision?"
c) Draw a diagram of the collision, and describe it in words.	
d) Was here anything unexpected that happened?	e) Think of one parameter that you could alter to change the collision.

6. Station 5: Magnetic marble accelerator (demo)	
a) Predict what would happen if you set a marble in the center and (1) rolled a regular marble down toward it and (2) rolled a magnetic marble toward it.	b) Try out the activity. What might be occurring at that station that can be called a "collision?"
c) Draw a diagram of the collision, and describe it in words.	
d) Was here anything unexpected that happened?	e) Think of one parameter that you could alter to change the collision.

7. Station 6: Kinetic yo-yo	
a) Predict what would happen if you swung one ball around.	b) Try out the activity. What might be occurring at that station that can be called a "collision?"
c) Draw a diagram of the collision, and describe it in words.	
d) Was here anything unexpected that happened?	e) Think of one parameter that you could alter to change the collision.

8. Station 7: Shooter with suction cup on dart	
a) Predict what would happen if you shot the dart.	b) Try out the activity. What might be occurring at that station that can be called a "collision?"
c) Draw a diagram of the collision, and describe it in words.	
d) Was here anything unexpected that happened?	e) Think of one parameter that you could alter to change the collision.

9. From the stations above, do you think that there is more than one kind of collision? If so, how could you classify the collisions?

10. Choose three stations above, and describe "before collision" and "after collision" for the station.

Exploring a Collision Lab

Materials:
- Track and cars/ carts
- Masses to add to car/carts
- Modeling clay

Purpose:

What are the parameters affected by a collision?

Pre-lab discussion:

1. You will be examining qualitative features of a very specific collision in this activity. A car will be launched on the track using the spring/rubber band. It will collide and stick to a second car.

2. Set up the track so that it has a slight slope, just enough to overcome friction. (Do not spend more than 5 or 10 minutes on setting up the track). For the CPO track, setting the top end of the track about 0.5 inch (1.25 cm) higher than the bottom end accomplishes this task adequately.

3. Attach a small piece of clay on the front bumper of the launched car. The second car sits stationary, with a larger piece of clay stuck on its rear bumper (so the two pieces of clay stick when the cars collide).
Do this once only! Launch the car from the top end of the track, giving it a small velocity by means of a rubber band or spring. Observe what happens to both cars.

4. Draw a diagram and indicate the system "before collision" and "after collision." The system consists of the objects affected by the collision.

5. Brainstorm the parameters you can change. Whiteboard your list, and have the class produce a consensus list.

Directions:

6. Create a table below listing the different collisions you plan to observe. Investigate at least two different starting velocities, and at least 4 combinations of masses.

Details of cars (qualitative velocity, mass of car)	Prediction of what will happen in collision	Observation of what happened in collision

Details of cars (qualitative velocity, mass of car)	Prediction of what will happen in collision	Observation of what happened in collision

7. Summarize what you learned from this activity.

8. Do you think there might be a general law that governs collisions?

If so, conjecture about what law that might be.

Elastic Collisions – Simulation Lab

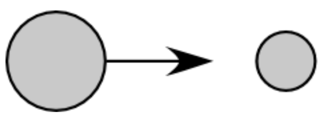
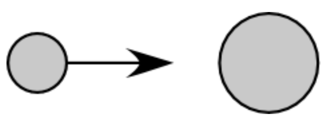
Materials:
- 2 small marbles
- 1 large marble

Purpose:

The purpose of the collision simulations is to see how momentum is conserved in collisions. In these simulations you will manipulate the mass, velocity and direction of motion of the objects colliding. For every set of parameters in a simulation you run you are asked to first calculate (predict) the result and then check it by running the simulation

Pre-lab discussion

1. What do you think happens when...

The collision involves...	Prediction:
A. A stationary marble is hit by a moving marble of the same mass 	
B. A stationary marble is hit by a moving marble of a larger mass 	
C. A stationary marble is hit by a moving marble of a smaller mass 	
D. Two balls of the same mass and same speed move toward each other and collide 	

Directions:

2. Go to the Collision Simulation at PHET (under Motion on the left), http://phet.colorado.edu/sims/collision-lab/collision-lab_en.html

Initially, set the options to: ON: 1 Dimension, elasticity 100% , More data button
OFF: all other options

3. Fill out the first two columns first. Then adjust the masses and speeds for A-D as given below, run each simulation and fill the third and fourth columns.

Initial masses and velocities of red and green balls	Calculate		Run simulation, record		Is momentum conserved for:
	Initial momentum	Final momentum	Initial system	Final system	
A. Ball 1 m1=0.5 v1=1.0					Red ball? Green Ball? System?
Ball 2 m2=0.5 v2 =0					
B. Ball 1 m1=1.0 v1=1.0					Red ball? Green Ball? System?
Ball 2 m2=0.5 v2 =0					
C. Ball 1 m1=0.5 v1=1.0					Red ball? Green Ball? System?
2 Ball 2 m2=1.0 v2 =0					
D. Ball 1 m1=0.5 v1=1.0					Red ball? Green Ball? System?
Ball 2 m2=0.5 v2 = -1.0					
E. Your choice:					Red ball? Green Ball? System?
F. Your choice:					Red ball? Green Ball? System?
G. Your choice:					Red ball? Green Ball? System?

Post-lab discussion:

4. Discuss if there general rules for the velocity of a single ball in a collision.

5. Is the momentum of either one of the balls conserved in a collision?

6. Is the momentum of the system conserved in the collision?

Elastic Collisions Lab (Optional)

Materials:
- Newton's cradle

Purpose:

How are elastic collisions different from inelastic collisions?

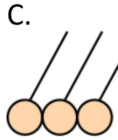
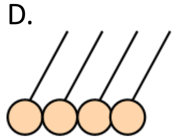
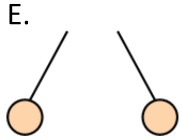
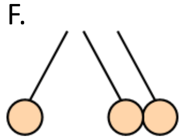
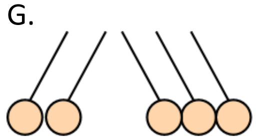
Pre-lab discussion:

1. Predict first: if you pull one ball to the side and let go, what do you think will happen? What do you think will happen if you pull *two* balls to the side and let go?

2. Discuss your predictions, write them on your whiteboards and explain your reasoning.

Directions:

3. Predict first, then try the following collisions. Only the balls pulled to the side are shown below.

Diagram	Prediction	What happened	Explanation
A. 			
B. 			
C. 			
D. 			
E. 			
F. 			
G. 			

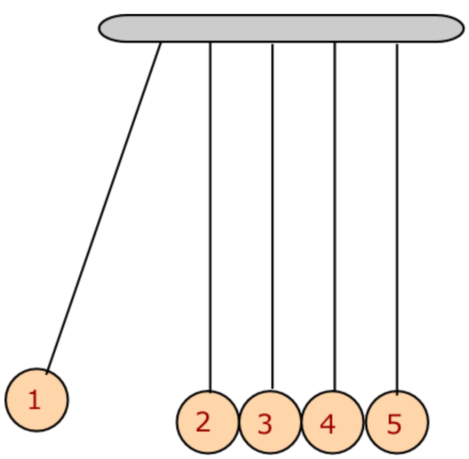
4. In the collisions,

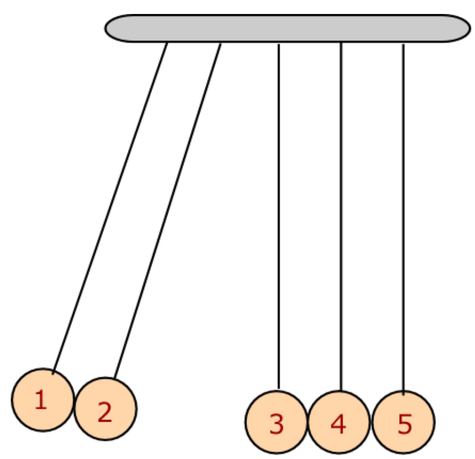
a) Why do you think that *one* ball does not go out with *higher* speed when *two* balls hit the ones that are still?

b) Why do you think that *two or three* balls do not go out at a s*lower* speed when *one* ball hits the ones that are still?

c) Can you explain this behavior only on the basis of conservation of momentum, or do you think something else needs to be conserved too?

5. Use the diagrams below to draw the paths of motion. Mark the points at which momentum is transferred.





Post-lab discussion:

6. How are elastic collisions different from inelastic collisions?

7. Is momentum conserved in elastic collisions?

8. Do you think something else needs to be conserved in elastic collisions? What might that be?

Comparing Inelastic and Elastic Collisions Lab

Purpose:

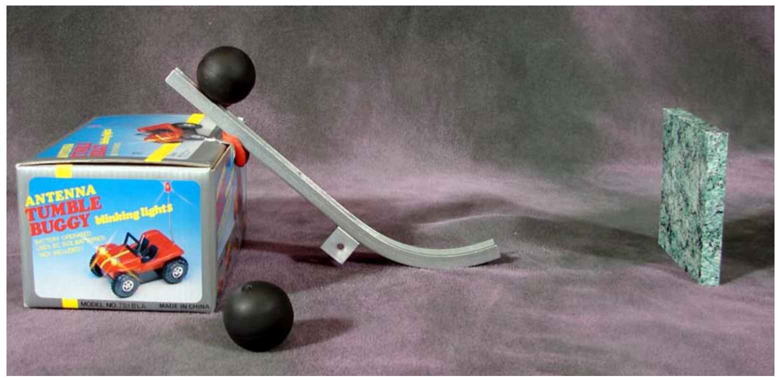
How are inelastic and elastic collisions different?

Materials:

- A pair of happy and unhappy balls (small, 1” size)
- A ramp or ruler with groove placed on a box
- A wood block (4”x4”x1/2”)

Pre-lab discussion:

1. Start by dropping the happy ball and the sad ball on the table. How are their behaviors different?



2. You will be rolling the ball down the ramp. Predict first:

   a) What do you think might happen to the block when the happy ball collides with the block? Explain.

   b) When the sad ball collides with the block? Explain.

   c) If you thought they would do the same thing, explain why; and if you thought they would be different, explain why.

Directions:

3. Here’s how the materials are to be set up. The block stands up on its narrow edge, about 2 inches (5 cm) from the bottom end of the ramp. The ramp is held so the ball can start at a specific height, roll down the ramp, and then collide with the block. The ramp can be held by hand, or fastened in place with a lump of modeling clay.

a) Roll each ball down the ramp. Describe your observations.

b) What do you think might be the reason that the block behaves as it does?

Post-lab discussion:

4. Remembering that momentum is a vector, draw a diagram that shows each ball's initial and final momentum.

5. Whose momentum changed more: the happy ball's or the unhappy ball's?

6. Now draw the momentum of the system just before and after the collision (the system is the ball and the block).

7. What can you say about the momentum of the block?

8. What do you think is the reason why the block reacted differently to the happy ball and to the sad ball?