Roller Coaster

Activity Guide

PITSCO EDUCATION

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Roller Coasters, Energy, and Hang On!

Anyone who visits an amusement park or sees a video about coasters knows that the roller coaster is a favorite thrill ride. Thousands of people line up every day to take a fast, curvy ride that scares even grown men to the point of screaming like a little girl.

But while roller coasters are common in the United States, they are uncommon in the amount of science, technology, mathematics, and engineering required to make them safe and fun.

Energy is the name of the game with roller coasters. Two forms of energy, potential and kinetic, determine the action of the coaster. Potential energy is the energy of position (its energy due to how high it is off the ground), while kinetic energy is the energy of motion (how fast it is going). If you add the amount of potential energy and the amount of kinetic energy, the total would be the same at any point along the ride.

Roller coasters are a moving picture of how potential and kinetic energy work. Typically, the roller coaster car is moved to the top of a tall hill by electric motors, gears, chains, and sprockets. When the car reaches the top of the hill, its potential energy is large, due to its position (its height).

As the car begins to roll down the track, more and more of the potential energy is converted to kinetic energy (the car moves faster) and it reaches its peak speed at the bottom of the hill. As it goes back up, it begins to slow back down – some of the kinetic energy is being converted back into potential energy. This exchange between potential and kinetic energy occurs constantly throughout the roller coaster ride.

How these energy exchanges occur is determined by the hills and curves of the track. Numerous mathematical formulas and computations have to be made for any track design to be effective and safe.

Construction materials must also be considered when designing. Most modern roller coasters are constructed of steel, but some are still built with wood. Some people enjoy the looser feel that a wood track creates.

In these activities, you will explore a few of the science, math, and technology concepts used in roller coaster design. Then you will use that knowledge to engineer a simple roller coaster that has a specific purpose.

So hang on – we are about to reach the top of the hill and plunge down into these activities!

Table of Contents

Using the Roller Coaster Track and Stands

Cautionary and Warning Statement

- This kit is designed and intended for educational purposes only.
- Use only under the direct supervision of an adult who has read and understood the instructions provided in this user guide.
- Read warnings on packaging and in manual carefully.

Materials Included

- Roller coaster track
- Metal ball
- Wooden ball
- Acetal ball
- Track stand (4)
- Metal rod (4)
- Track pad (4)
- Angle track pad (3)
- Washer (7)
- Clamp (8)
- Wing nut (7)

Putting Together the Pieces

1. Screw a metal rod into a track stand. Repeat this for all four stands. The tallest metal rod goes into the largest track stand.
2. There are three types of track pads: the large track pad that goes on the large track stand (1); three normal track pads that go on the normal track stands (2); and three angle track pads that combine with the other track pads (3) (Figure 1). Follow Step 2A or 2B depending on the type of track pad used.

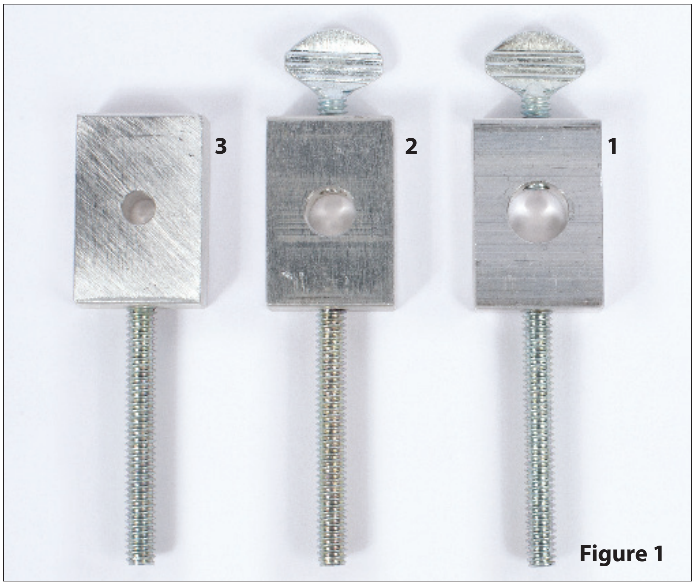


Figure 1

A. Take a normal track pad and place two clamps on its rod. Secure the clamps with a washer and a wing nut (Figure 2). This method is used for normal track pads and the large track pad.

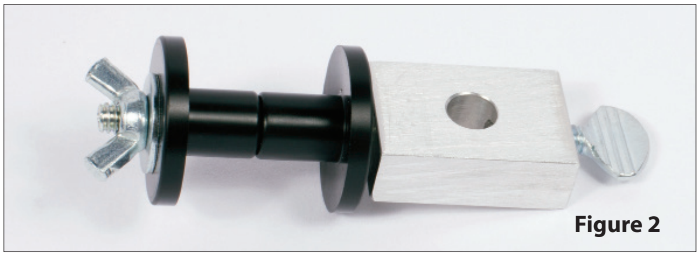


Figure 2

B. Take an angle track pad and place it on the rod of a normal track pad. Secure the angle track pad to the normal track pad with a washer and a wing nut. Place two clamps on the rod of the angle track pad. Secure the clamps with a washer and a wing nut (Figure 3).

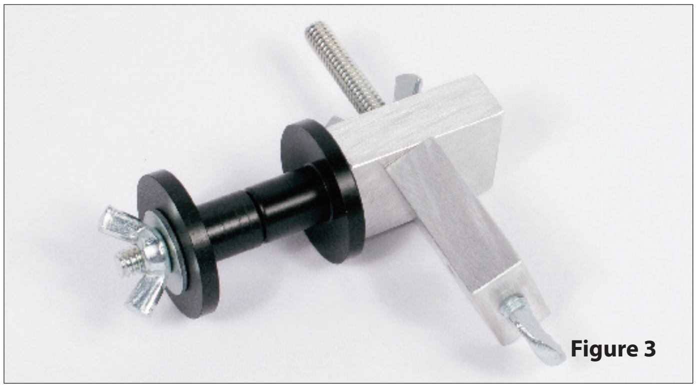


Figure 3

3. Place the hole of a track pad over the rod of a track stand and tighten the bolt of the track pad to secure the track pad to the track stand.

Setting Up a Track

Before starting, you might try to mentally plan or sketch on paper your roller coaster design.

1. Place the tallest track stand where you want the track to start. Place a track pad at the desired height.
2. Unroll your rubber track. Take the start end and place it between the clamps on the track pad. Secure the track to the track pad by tightening the wing nut.
3. Use the three smaller stands to create your track. There are three methods for holding elements of the rest of your track:

   A. Rest the track on top of the track pad clamps (Figure 4). This works for hills.

Figure 4

   B. Hold the track in place with the track pad clamps (Figure 5). This works for loops.

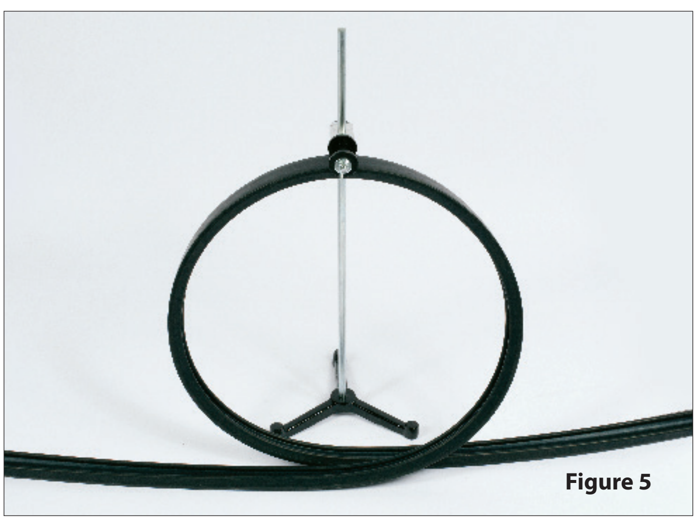


Figure 5

   C. Hold the track in place with the angle track pad clamps (Figure 6). This works for banked curves.

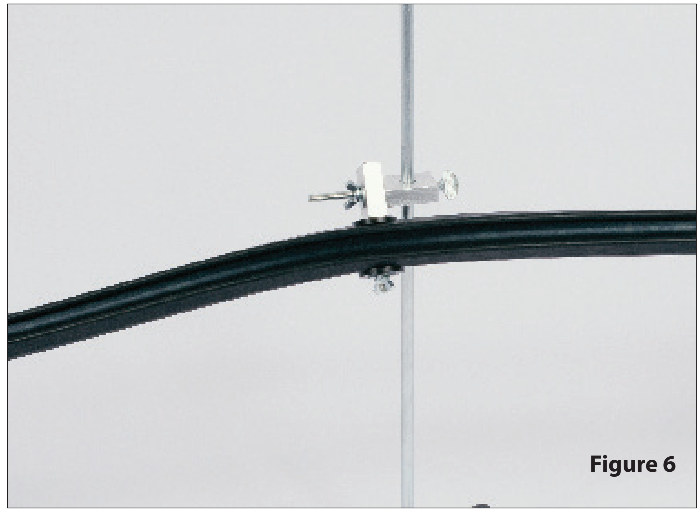


Figure 6

4. After you lay out the track, it is a good idea to place something (such as a cup turned over on its side) to catch the balls as they come off the track. Or, you can design your track so the balls come back to you.

Track Design Tips

- The start of the track must be higher than the first loop or hill. Otherwise, it will not have enough momentum to go through the loop or over the hill.
- Unlike a real roller coaster car, the balls in this set are not held to the track with a mechanical device. So, you will have to design the track to keep the balls on the track and to keep the balls moving. Balls stay in loops fairly well because of the centripetal force acting on them. However, hills usually must be small in order for the balls to not pop off the track.

Note about Worksheets

There are three different worksheets in this guide: "Potential for Kinetic Energy Worksheet," "Watch Out for the Curve Worksheet," and "Give It a Rise So It Can Run Worksheet."

These are tools to encourage students to think critically about their test results, so many of the worksheet answers will vary depending on test results and the individual student's thought processes. As a result, only one worksheet, "Give It a Rise So It Can Run Worksheet," has an answer key.

Science Activity – The Potential for Kinetic Energy

Exploring the conversion of potential to kinetic energy

"In any given closed system, the sum of the potential energy and kinetic energy is constant."

That statement is commonly referred to as the law of conservation of energy. At any point, the sum of the potential energy and kinetic energy is constant. This can be written in a mathematical formula:

KE1 + PE1 = KE2 + PE2

KE1 is the kinetic energy at the first point and PE1 is the potential energy at that same point. KE2 is the kinetic energy at the second point and PE2 is the potential energy at point two. Both these forms of energy are measured in units called joules (J). One joule is the amount of energy required to accelerate a 1kg mass to a velocity of one meter per second in a distance of one meter and in a time of one second. It has the units kg m^2/sec^2.

To calculate KE and PE, there are two helpful formulas:

Kinetic energy equals one half of the mass (m) times the square of the velocity (v): $KE = 1/2mv^2$

Potential energy equals the mass (m) times the acceleration due to gravity (g) times the height (h): PE = mgh

The value of g for our purposes will be 9.8 m/sec^2.

For example, if a roller coaster with a mass of 2 kg is at a height of 3 meters and is traveling 4 meters per second, its KE and PE are:

$KE = 1/2mv^2$
$KE = 1/2 * 2\ kg * (4\ m/sec)^2$
$KE = 1\ kg * (16\ m^2/sec^2)$
$KE = 16\ kg\ m^2/sec^2$ or 16J

PE = mgh
$PE = 2\ kg * 9.8\ m/sec^2 * 3\ m$
$PE = 19.6\ kg\ m/sec^2 * 3\ m$
PE = 58.8J

Total energy = KE + PE
Total energy = 16J + 58.8J
Total energy = 74.8J

The Activity

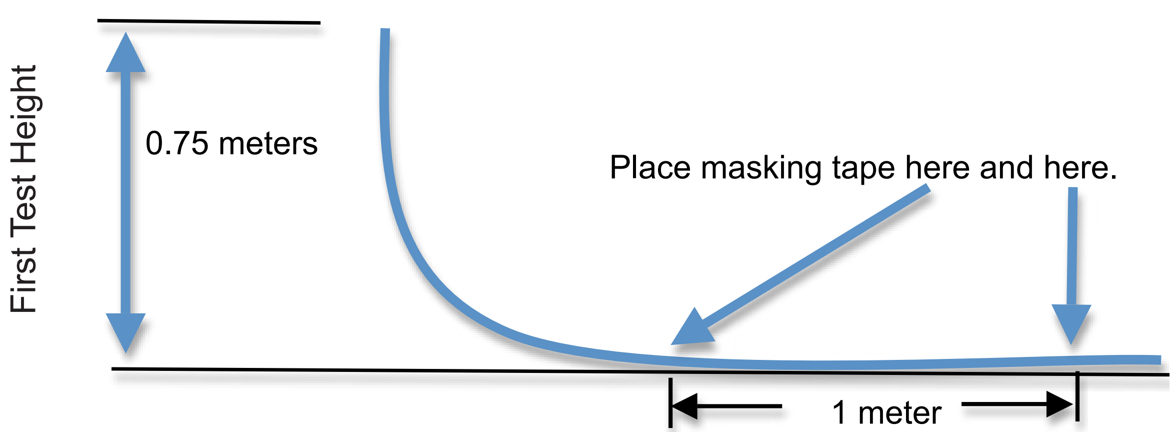
In this activity, find the velocity of a ball (simulating a roller coaster car) dropped from three different heights using a stopwatch.

Materials

- Steel ball (roller coaster car)
- Rubber track
- Track stands
- Masking tape
- Meter stick
- Stopwatch
- Digital scale (digital or triple beam)
- "Potential for Kinetic Energy Worksheet"

Procedure

1. Answer the first question on the worksheet.
2. Measure the mass of the steel ball. Record the mass in the data table on the worksheet.
3. For the first test, set up the rubber track to have a drop of at least 0.75 meters to a straight section of track extending out on the floor as shown below. If necessary, set a stand on a table or other piece of furniture to obtain enough initial drop height.
4. Place a small piece of masking tape on the side of the track where the track meets the floor. This is where the timing starts. Place another small piece of tape on the track one meter away from the first



piece of tape. This is where the timing stops.

5. Working as a team, one student determines the drop height and starts the ball from that point on the track. Another student starts the stopwatch when the ball reaches the first piece of tape and stops it when the ball gets to the second piece of tape. You may want to try this several times for each drop height until you get a consistent time.
6. Adjust the drop height for each remaining test and enter the time for each drop height in the data table on the worksheet.
7. When all the times have been recorded, calculate the velocity for each drop height using the formula:
   Velocity (v) = Distance (d) divided by Time (t)
   v=d/t
8. Record the values in the data table.
9. Complete the data table and answer the worksheet questions.

Extension (optional)

Now calculate the theoretical velocity that the ball should have reached. To do this, we assume that all the potential energy the ball has when it is dropped (PE1) is converted to kinetic energy as it reaches the bottom of the hill (KE2).

PE1 = KE2
$mgh = 1/2mv^2$

Plug in all the values for the drop height and solve the equation for *v*. Compare the theoretical value of the velocity to your measured value. If they are different, what could be some reasons for the difference?

Potential for Kinetic Energy Worksheet

1. Which height do you think would provide the most velocity for the ball?
   a) the highest drop point
   b) the lowest drop point
   c) the drop point between the highest and lowest

Mass of the ball: ______

Drop Height (m)	Distance (m)	Time (sec)	Velocity (distance/time)
0.75	1		
0.5	1		
0.25	1		

Remember, to find the velocity, divide the distance by the time.

2. Which drop height provided the greatest velocity?
   a) the highest drop point
   b) the lowest drop point
   c) the drop point between the highest and lowest

3. Were you right when you answered the question before you did the activity?

4. Which one of these activities do you think would hurt more?
   a) falling out of a tree 15 feet above the ground
   b) falling out of a tree 10 feet above the ground
   c) falling out of a tree 5 feet above the ground

5. Which of the following statements would best describe the concept you explored today?
   a) Falling out of trees is less fun than riding a roller coaster.
   b) The greater the height, the greater the energy available to be converted to velocity.
   c) Kinetic and potential energy are exactly the same thing.
   d) Potential energy is a moving experience.

Technology Activity – Watch Out for the Curve

Determining the Limits of Safety

Highways often have warnings about safe speeds for upcoming curves in the road. And if you notice, curves will often be banked to help drivers stay on the road.

The same is true for roller coasters. The velocity of a roller coaster coming into a curve must not exceed the safe limit for that curve or the car might come off the track. Also, if the roller coaster curve is banked, the velocity that the coaster enters the curve with can be faster.

The Activity

Find the greatest height that a ball can be dropped on a roller coaster track and stay on the track through a curve.

Materials

- Steel ball (roller coaster car)
- Rubber track
- Track stands
- Masking tape
- Meter stick
- "Watch Out for the Curve Worksheet"

Procedure

1. Set up a track with an initial drop of at least one meter. Where the track initially contacts the floor, curve the track to the left or the right so it makes a 180-degree (semi-circle) turn. The radius of this turn should be about 15 centimeters.
2. Using tape loops and small strips of tape, carefully tape the track to the floor so that there is no banking to the turn.
3. Drop the steel ball from various heights and determine the maximum height that the ball can be dropped from and still stay on the track through the curve. Record this height on the worksheet.
4. Un-tape the track from the floor and place objects under the curve to change the banking of the curve.
5. Determine the greatest height from which the ball can be dropped for this amount of banking.
6. Complete the "Watch Out for the Curve Worksheet."

Extension (optional)

Determine the tightest curve that can be done at a specified height.

Watch Out for the Curve Worksheet

1. What is the maximum height you could drop a ball and have it make it through the flat curve?
   ________cm

2. What is the maximum height you could drop a ball and have it make it through the curve with banking?
   ________cm

3. Why do you think banking helps keep the ball on the track as it goes through the curve?

4. If you were asked to make a sign for the maximum safe drop height for this curve, what would that sign read?

5. Do you think engineers recommend placing the fastest possible speed that a car could go through a curve on a warning sign for that curve? How many miles per hour less than the maximum do you think the sign might indicate would be a safe speed?

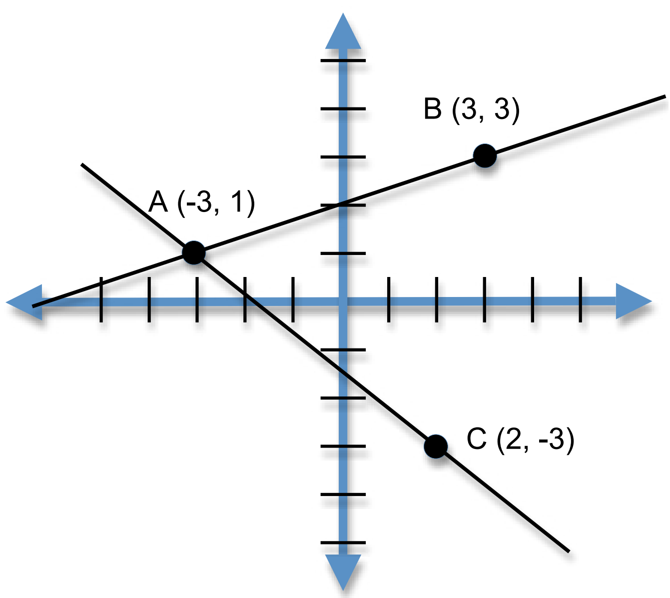
Mathematics Activity – Give It a Rise So It Can Run

Connecting Slope to Velocity

In mathematics, lines are graphed on a Cartesian coordinate system, with each point of the line having a specific x-y coordinate. The slope of the line is defined as the difference in the y coordinates divided by the difference in the x coordinates. The difference in the y coordinates is often called the rise, while the difference in the x coordinates is called the run. So, we can say that the slope of a line is the amount of rise over the amount of run.

Carpenters often use this term when describing the slope of a roof. As they construct the rafters, they determine the amount of rise that the roof will have over the distance from the center of the house to the side of the house – the run. This will determine how steep the roof will be.

Here is an example of a graph of a line, and how the slope of that line is calculated:



For the line going through points A and B:
slope = rise/run = $(Y_B - Y_A)/(X_B - X_A)$
slope = (3-1)/(3-(-3)) = 2/6 = 1/3

So, the line rises one unit for every three units of run. Sometimes slope is termed as a ratio, so the slope of this line as a ratio would be 1:3 – again, rise to run.

Between any two points along the Line AB, the slope will be the same: one-third.

Lines can also have negative slope, such as the line between points A and C.

slope = rise/run = $(Y_C - Y_A)/(X_C - X_A)$
slope = (-3 – 1)/(2 – (-3)) = -4/5

Lines with positive slope rise from left to right, lines with negative slope drop from left to right.

The Activity

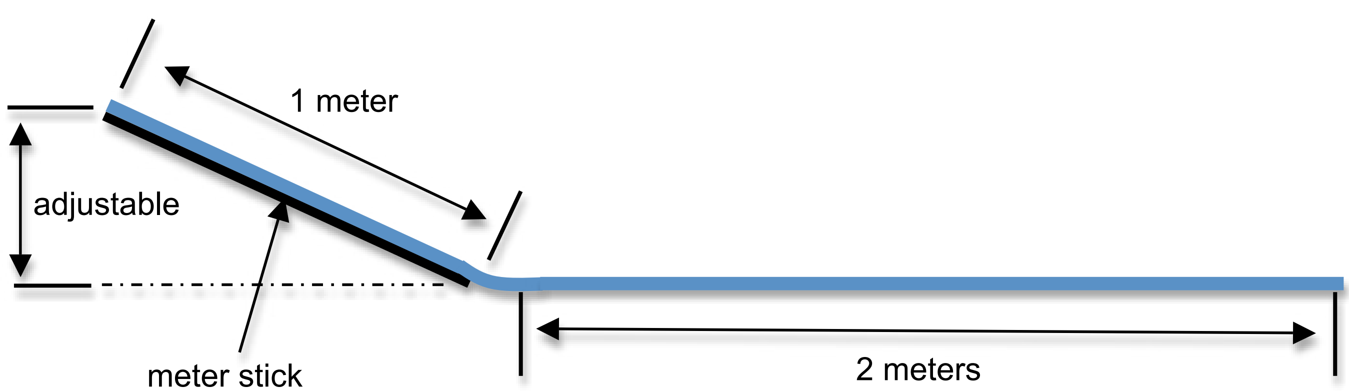
In this activity, determine the effect of the slope of a roller coaster track on the velocity of the ball.

Materials

- Steel ball (roller coaster car)
- Rubber track
- Track stands
- Masking tape
- Meter sticks
- "Give It a Rise So It Can Run Worksheet"

Procedure

1. As a team, construct a track that has one end of the track sitting on a meter stick that is supported by a track stand at one end. The other end of the meter stick and track will be at ground level and should stretch out in a straight line at least two meters as



shown below.
2. Place a small piece of tape on the floor where the track makes first contact with the floor. Place a second piece of tape on the floor two meters from the first piece of tape. These will be the start and finish points for timing the ball.
3. Raise or lower the track and meter stick support so the end of the track is 10 centimeters from the floor. Determine the slope of the track (the rise/run) and record the slope in the data table on the worksheet.
4. Place a ball at the top of the track and let it roll down the track. When the ball passes the first piece of tape, start the stopwatch. When the ball passes the second piece of tape, stop the stopwatch.
5. In the data table, record the amount of time it took the ball to go the two-meter distance.
6. Now raise the track and meter stick support so that the end of the track is 30 centimeters up from the floor. Again, determine the slope and record it in the data table.
7. Start the ball at the top of this setup and use the stopwatch to time the ball between the two pieces of tape. Record the time in the data table.
8. Now raise the track and meter stick support so the end of the track is 40 centimeters up from the floor. Again, determine the slope and record it in the data table.
9. Start the ball at the top of this setup and use the stopwatch to time the ball between the two pieces of tape. Record the time in the data table.
10. Complete the worksheet.

Engineering Challenge – It's In the Can

Design a track with whatever materials your teacher makes available (tables, chairs, stools, track stands, and so forth) and the roller coaster track. You can include as many curves, loops, and hills as possible, but the ball must stay on the track at all times. At the end of the track, the ball must land in a container.

Give It a Rise So It Can Run Worksheet

Refer to the graph on the right to answer the questions below.

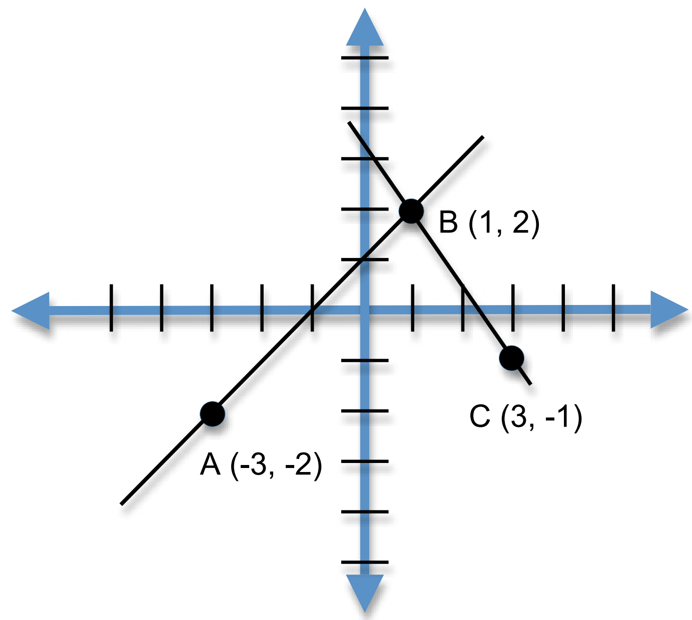
1. Which of the two lines, AB and BC, have negative slope?

2. Calculate the slope of line AB.

3. Calculate the slope of line BC.

4. Plot the point D on the graph with the x-y coordinates (-2, 3).

5. Which of the following lines would have a positive slope?
   a) Line AD
   b) Line BD
   c) Line CD



Data Table

Track Height (cm)	Slope of the Track	Time (sec)	Velocity (2 m/time)
10			
30			
40			

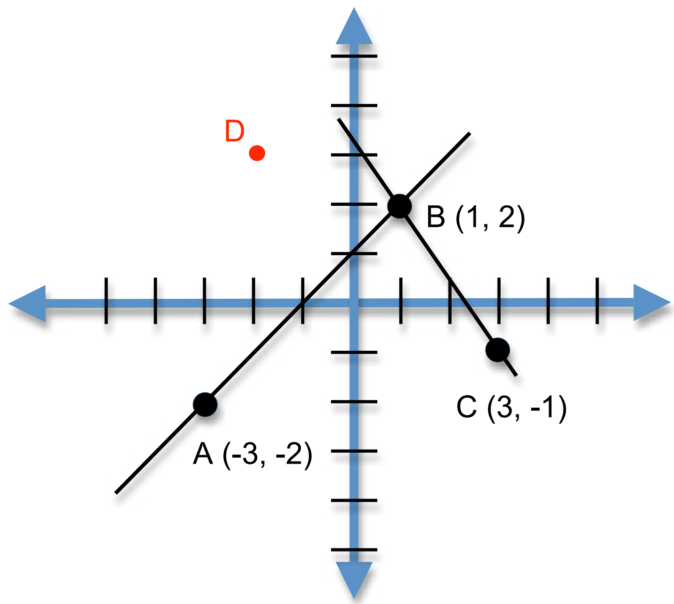
6. As the height of the track increased, what happened to the slope of the track?

7. As the slope of the track became steeper, what happened to the velocity of the ball?

8. Which would give you a greater velocity?
   a) a slope with the rise larger than the run
   b) a slope with the run larger than the rise
   c) a slope where the rise and run are equal

Give It a Rise So It Can Run Worksheet
Answer Key

Refer to the graph to answer the questions below.



1. Which of the two lines, AB and BC, have negative slope?

   Answer: Line BC

2. Calculate the slope of line AB.

   Answer: Slope = 4/4 = 1

3. Calculate the slope of line BC.

   Answer: Slope = -3/2

4. Plot the point D on the graph with the x-y coordinates (-2, 3).

5. Which of the following lines would have a positive slope?
   a) Line AD
   b) Line BD
   c) Line CD

   Answer: (A)

Data Table

Track Height (cm)	Slope of the Track	Time (sec)	Velocity (2 m/time)
10			
30			
40			

6. As the height of the track increased, what happened to the slope of the track?

   Answer: Slope increased

7. As the slope of the track became steeper, what happened to the velocity of the ball?

   Answer: Velocity increased

8. Which would give you a greater velocity?
   a) a slope with the rise larger than the run
   b) a slope with the run larger than the rise
   c) a slope where the rise and run are equal

   Answer: (A)