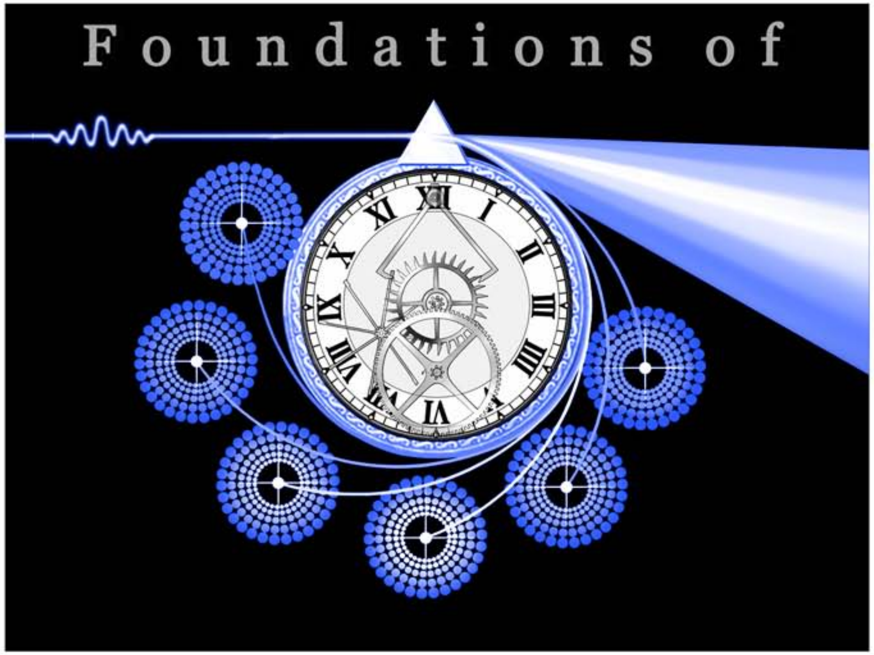

Physical Science

with Earth and Space Science

Tom Hsu, Ph.D.

FIRST EDITION
CPO Science
Peabody, Massachusetts 01960

cpo science

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5.1 Work

Learning Goals	Reading Synopsis	Materials and Setup
• Calculate the amount of work done by a simple machine. • Use units of joules to measure the amount of work done. • Analyze the effects of changing force or distance in a simple machine. **Key question:** What happens when you multiply forces in a machine? **Leading questions:** • What is work? • How is the amount of work measured? • How are force and distance related in machines?	The work done to an object is equal to the force applied times the distance the force is applied. When you push a box with a force of one newton a distance of one meter, you have accomplished one joule of work. One joule is equal to one newton-meter. The amount of work input for a machine must always be equal to or greater than the work output. The work output of a simple machine never exceeds the work input. In order to produce a large output force with a small input force, the input force is applied over a long distance. In a block and tackle system, you increase input distance by adding more supporting strands. Efficiency is the ratio of work output to work input. For real machines, work output is always less than work input because some work is always lost due to frictional forces. The rate at which work is done is called power. Power is work (in joules) divided by time (in seconds). The unit for power is the watt. One watt is equal to one joule/second. **Sequence:** Students complete the reading before the Investigation.	• Ropes and Pulleys set • Physics Stand • Force scale • Ruler or meter stick • Weights **Duration:** Two class periods

5.2 Energy Conservation

Learning Goals	Reading Synopsis	Materials and Setup
• Identify the relationship between speed and height on a roller coaster. • Describe the motion of the marble on the Rollercoaster in terms of energy and the law of conservation of energy. • Discuss the energy transformations that occur in a given situation. **Key question:** What is energy and how does it behave? **Leading questions:** • How are speed and height related on a roller coaster? • What is energy? • How are energy and motion related? • How is energy conserved on a roller coaster?	Energy has many forms (motion or heat) and it can travel in different ways (as light, sound, or electricity). The workings of the universe depend on flowing energy. Energy is the ability to do work. This means that any object with energy can create a force that is capable of acting over a distance. Like work, energy is measured in joules. This is because energy is really stored work. Two (of many) kinds of energy are potential and kinetic energy. Potential energy is related to the position of an object relative to the surface of the Earth. The formula for potential energy is the mass of an object times the acceleration of gravity times height of the object. Kinetic energy is energy of motion. The formula for kinetic energy is 1/2 times mass of the object times its speed squared. The law of conservation of energy states that energy cannot be created or destroyed as it flows from place to place or is transformed. **Sequence:** Students complete the reading before the Investigation.	• Roller coaster • Timer and one photogate • Physics Stand • A steel marble (for the Investigation) • A black marble (for the Extended Activity) • Pencils, rulers, and simple calculators **Duration:** One class period

5.2 Energy Conservation

Key Question: What is energy and how does it behave?

In a simple system like the roller coaster, the components of energy can be measured easily. The potential energy is determined by the height of the marble at any position on the track. The kinetic energy is determined by using the photogate timer to measure the speed of the marble at corresponding places on the track. This Investigation helps students to develop the conceptual understanding that the marble gains one kind of energy from height and trades it for speed and vice versa. The concept of conservation of energy, that total energy remains the same, is presented. Students develop an understanding of this concept as they try to explain why the speed and height on the roller coaster are inversely related.

Reading Synopsis

Students read section 5.2 Energy Conservation before the Investigation.

Energy has many forms (motion or heat), and it can travel in different ways (as light, sound, or electricity). The workings of the universe depend on energy flowing from one place to another and changing from one form to another.

Energy is the ability to do work. This means that any object with energy can create a force that is capable of acting over a distance. Like work, energy is measured in joules. This is because energy is really stored work. Two (of many) kinds of energy are potential and kinetic energy. Potential energy is related to the position of an object relative to the surface of the Earth. The formula for potential energy is the mass of an object times the acceleration of gravity times height of the object. Kinetic energy is energy of motion. The formula for kinetic energy is one-half times the mass of the object times its speed squared.

The law of conservation of energy states that energy cannot be created or destroyed as it flows from place to place or is transformed.

The Investigation

Leading Questions

- How are speed and height related on a roller coaster?
- What is energy?
- How are energy and motion related?
- How is energy conserved on a roller coaster?

Learning Goals

By the end of the investigation, students will be able to:

- Identify the relationship between speed and height on a roller coaster.
- Describe the motion of the marble on the roller coaster in terms of energy and the law of conservation of energy.
- Discuss the energy transformations that occur in a given situation.

Key Vocabulary

energy, kinetic energy, potential energy, law of conservation of energy

Setup and Materials

Students work in groups of three to five at tables.

Each group should have:

- Roller coaster
- Timer and one photogate
- Physics stand
- Steel marble (for the Investigation)
- Black marble (for the extension activity)
- Metric rulers
- At least one calculator
- Investigation 5.2 answer sheets
- Pencils

Details

Time One class period

Preparation Practice working with the roller coaster before conducting the Investigation with your class.

Assignments Section 5.2 Energy Conservation in the **Student Edition** before the Investigation

Skill Sheets 5-B Power

Reference Guide Equipment Setup: Roller Coaster

Equipment Setup: Timer II and Photogates

Teaching Tools: Graphing

Teaching the Investigation

1. Discussing energy
2. Introducing the Investigation
3. At which place (or places) will the marble be moving the fastest on the roller coaster
4. Measuring the speed of the marble on the roller coaster
5. Collecting and recording the data
6. Discussing the data
7. Introducing potential and kinetic energy
8. Investigating energy conservation using the roller coaster
9. Graphing height and speed vs. position
10. How is energy conserved in the marble and roller coaster system?

Discussing energy

What happens to energy when you ride a bike up and down a hill?

Food energy → muscle power to pedal up the hill → increase in height → speed energy down the hill

Define "energy" as the ability to do work.

Any object that has energy can do work (apply a force over a distance).

Can someone describe what happens when you ride a bike up and down a hill?

The first part of the activity asks students to think about their own experiences riding a bike up and down hills. The discussion should be steered to develop the obvious realization that it is hard to go uphill but easy to go down.

Why is it difficult to go up the hill and easy to go down?

There will be a variety of responses, but you should focus the discussion on those related to the concept of energy.

Introduce the concept of energy by talking about how food provides the energy to drive the muscle power needed to pedal. It is easy to go down because the energy from the food is now stored up in height energy. This reservoir of height energy is readily converted to speed energy as the student travels down the hill. However, converting food energy to speed (or height) energy is not so easy because it takes muscle work. You do not need to introduce the terms kinetic or potential energy at this point. It is better to let your students have some real experience with the roller coaster first so that the concepts can be introduced based on their experiences.

How can we define energy?

Students should remember that energy is the ability to do work. Any object that has energy can do work (apply a force over a distance).

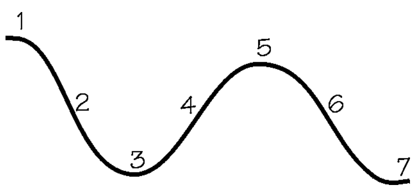
Introducing the Investigation

Review:
Conservation of work = the amount of work output in a machine can never exceed the amount of work input.

Today you are going to analyze the movement of a marble on a roller coaster. Through this, you will discover more about the concept of energy. To help us talk about what we see, we'll sometimes call the roller coaster and the marble a system.You will be investigating how the energy of this system is conserved. Do you remember what is meant by the term "conserved" from the last Investigation?

Students should remember the rule of work output and work input in a machine, which they discovered in the last Investigation. This rule, that you can never get more work out of a machine than the amount that you put into it, is an example of conservation.

At which place (or places) will the marble be moving the fastest on the roller coaster



Point to different places on the roller coaster and ask the question.

1 Set up the roller coaster as shown in part 1 of the Investigation.

I will draw a profile of the roller coaster on the board. Here are seven places. At which place (or places) do you think the marble moves fastest? Why?

Draw a profile of the roller coaster like the one shown at left. After discussing energy in this general way, the students should be able to speculate on the behavior of the marble on the roller coaster. They should write down where along the roller coaster they think the speed of the marble will be greatest. The numbered points (1-7) provide easy reference. Without correcting their assumptions, ask them to explain their answers. Each student should write something on the Investigation Guide describing why he or she thinks his or her choice is correct. Some common answers are:

1 "Place 2, because it is steepest there."

2 "Place 7, because it is the end."

3 "Place 3, because it is at the bottom."

The purpose of this exercise is not to get the correct answer but for students to make a prediction based on their own experience and analysis of the marble on the roller coaster. It is important not to label any of the reasons wrong yet. The students will discover which is the correct answer in the Investigation.

5.2 Energy Conservation

Question: What is energy and how does it behave?

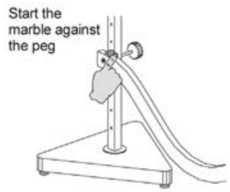
In this Investigation, you will:

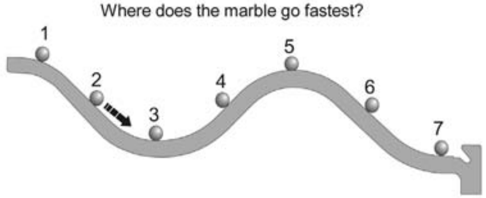
1. Discover the relationship between speed and height on a roller coaster.
2. Describe how energy is conserved on a roller coaster.

To pedal your bike up a hill, you have to work hard to keep the bike going. However, when you start down the other side of the hill, you coast! You hardly have to pedal at all. In this Investigation, you will find out what happens to the speed of a marble as it rolls up and down the hills and valleys of the CPO roller coaster.

1 Setting up the roller coaster

Attach the roller coaster to the fifth hole from the bottom of the stand. Use the starting peg to start the marble in the same place each time you roll it down. It sometimes takes a few tries to roll it straight so that it stays on the track. Watch the marble roll along the track. At which place (or places) do you think the marble moves fastest? Why?

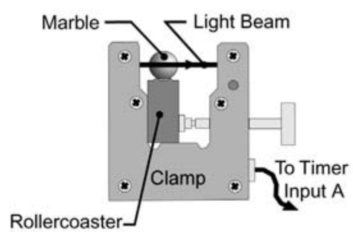




2 Measuring the speed of the marble

To understand what is happening to the marble, you need to measure the speed and the height at different places on the roller coaster.

1. To measure the speed of the marble, attach a photogate so that the marble breaks the light beam as it rolls through.
2. Plug the photogate into input A of the timer and use interval mode.
3. Be sure that the bottom of the photogate is flat against the bottom of the roller coaster. If the photogate is not attached properly, the light beam will not cross the center of the marble and the speed you calculate will not be accurate.



How does a roller coaster work?

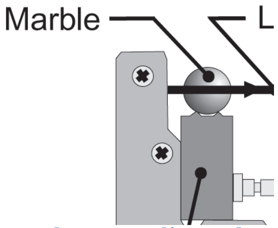
Amusement parks are great places to study physics. Your students will learn from using the roller coaster that once the marble is released, it never goes higher than the starting hill. Real roller coasters work in the same way. At the start of the ride, the roller coaster cars are pulled to the top of the first hill by motors that are part of the track. At the top of the first hill (the highest hill in the ride), the roller coaster has a lot of potential energy. The thrill of the rest of the roller coaster ride is due to the exciting conversion of all that potential energy to kinetic energy. However, due to frictional forces between the track and the cars, the cars are not able to get as high or higher than the first hill of the ride. Although the ride will be exciting, it is an exercise in expending potential energy. Eventually, the cars slow down.

For an extended activity, have your students design a roller coaster (and cars) they think will work. They can use flexible wire or other more elaborate materials to figure out their design. Have them justify their design by explaining why they think their roller coaster cars will coast to the end of the ride without the help of a motor. Encourage them to research the physics and history of roller coasters to get ideas for their design.

Example Answers

1. The marble moves fastest at points 3 and 7. We know that speed increases down a ramp and the greatest at the lowest points on the roller coaster.

Measuring the speed of the marble on the roller coaster



2

Do you remember how to determine the speed of an object?

Students should remember that speed is equal to the distance traveled divided by the time taken.

How would I measure the speed of this marble (hold up one of the marbles) on the roller coaster using one photogate and the photogate timer?

Roll the marble on the roller coaster.

What information do I need to calculate its speed?

You would need the time from the timer. You would also need the distance traveled by the marble. Using one photogate, the distance traveled is the width of the marble.

The width of the marble is 0.019 meters. So this would be the distance traveled by the marble in order to calculate its speed at different points on the roller coaster.

Collecting and recording the data

Remind students to use a consistent release technique so that they obtain accurate data.

The photogate should be pushed up tight under the roller coaster.

Now, you are going to test your hypothesis to find out where the marble is going fastest. Look at the picture of the roller coaster on the first page of the Investigation. You are going to calculate the speed of the marble at each of the seven points. Put your photogate at position 1 first. Record your data into the table in part 2 of the Investigation. Do a few trial runs first so you can get used to releasing the marble the same way each time. Try to get very accurate and precise results.

As students do the experiment, give them tips on releasing the marble the same way each time. Students will find that they can get the exact same time each time if they use a consistent release technique. The photogate needs to be pushed up tight under the roller coaster so that the marble crosses the infrared beam on the photogate at the right place.

Discussing the data

Have students compare their data and review their original hypothesis about the speed of the marble on the roller coaster.

Explain why the marble moves fastest at the lowest points on the roller coaster. The marble accelerates all the way down the hills.

You may need to review the concept of acceleration.

Where was the speed of the marble highest?

Have the students compare their predictions and measurements. The highest speed measured should be at position 7 or 3. These are the lowest points. In some cases, however, position 3 is fastest because friction (the rubbing of the ball against the track) slows the ball down by the time it gets to the end of the track. In the sample data you should notice that height position 7 is lower than position 3 and therefore faster despite the longer distance traveled (which results in higher frictional energy loss).

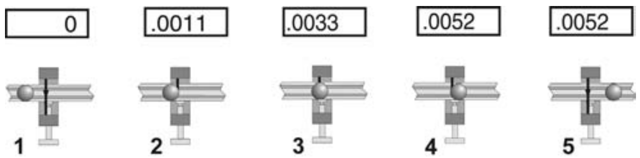
Can you explain why the speed is highest at the lowest points on the roller coaster?

Encourage students to discuss their ideas. Help students realize the reason the marble travels fastest at the lower portions of the track is because gravity has been acting on the marble, causing it to accelerate all the way down the hill. At the very bottom of the hill, the marble moves horizontally and is therefore no longer accelerating. The marble may accelerate most at positions 2 and 6, but it will have the greatest speed at positions 3 and 7 since any acceleration at all, even while tiny, still increases the speed.

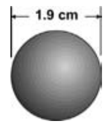
So, what is the relationship between the height of the marble and its speed on the roller coaster?

The marble is moving slowest at the high places on the roller coaster and fastest at the low places.

In the next part of the Investigation, we are going to discuss the relationship between speed, height, and energy of the marble and roller coaster system.



1. The ball has not broken the beam yet. The timer is not counting.
2. The timer starts counting when the front edge of the marble breaks the beam.
3. The timer keeps counting while the beam is blocked by the marble.
4. The timer stops counting when the back edge of the marble goes out of the beam.
5. The display shows the time that the marble blocked the beam.



Speed is the distance traveled divided by time taken to travel that distance. During the time that the timer is counting, the marble moves one diameter. Therefore, the distance traveled is the diameter of the marble, and the time taken is the time from photogate A. **The speed of the marble is its diameter divided by the time from photogate A.**

Use the photogate to test your hypothesis about where the marble would go fastest. Measure and record the speed of the marble at each of the seven places. Positions 2, 4, and 6 should be as close to the same height as you can get. If they are the same height, you can easily compare uphill and downhill motion.

Position number	Time, photogate A (sec)	Distance traveled (cm)	Speed of marble (cm/sec)
1	0.1079	1.9	17.6
2	0.0129	1.9	147.3
3	0.0108	1.9	175.9
4	0.0132	1.9	143.9
5	0.0303	1.9	62.7
6	0.0137	1.9	138.7
7	0.0104	1.9	182.7

a. Did your measurements agree with your hypothesis or did they point to a different hypothesis? If the answer did not agree with your hypothesis, what sort of hypothesis do the observations support about where the marble is fastest?

b. What did you notice about the motion of the marble from the measurements? For example, do you think that going uphill or downhill makes a difference in the speed? Does height affect speed? Which has a larger impact, height or direction (uphill or downhill)?

Extension activity

If a marble of lesser mass was used in the Investigation, would the data have been different?

Have your students investigate this question by comparing the speed of the black marble and the steel marble at position 3 on the roller coaster. The black marble has a mass of 4 grams. The steel marble has a mass of 28 grams.

The students will discover that the speeds of the marbles are the same! This phenomenon is explained by Newton's second law of motion ($a = F/m$). Additionally, the phenomenon is explained in the calculation of the energy involved in an event like a marble rolling down a hill. The initial energy of an object (potential energy plus kinetic energy) equals the final energy (potential energy). In this calculation, mass cancels out.

Potential energy (PE) = mgh Kinetic energy (KE) = $1/2mv^2$

m = mass of object; g = the acceleration of gravity; h_1 = initial height of object; h_2 = final height of object; v = speed

$PE_{initial} + KE_{initial} = PE_{final}$

$mgh_1 + 1/2mv^2 = mgh_2$

$m((gh_1) + 1/2v^2)) / m = (mgh_2) / m$

$(gh_1) + (1/2v^2) = gh_2$

Example Answers

2a. Our hypothesis was correct.

2b. If the marble is at the same height, it's going about the same speed. It doesn't matter if it's going downhill or uphill.

Introducing potential and kinetic energy

Terms to define:

potential energy – energy that comes from the position of an object relative to the Earth.

kinetic energy – the energy of motion.

How do potential and kinetic energy relate to the movement of the marble on the roller coaster?

Before we do the next part of the Investigation, let's discuss two types of energy: potential and kinetic. Potential energy comes from the position of an object relative to the Earth. If I lift this marble off the table, potential energy is being stored. Since the Earth's gravity pulls the marble down, I must apply a force to lift it up. Applying a force over a distance requires doing work, which gets stored as the potential energy of the marble. Potential energy of this kind comes from the presence of gravity. Where is potential energy being stored on the roller coaster?

Students should see that potential energy is being stored as the marble travels up the hills. It is also being stored when the marble is lifted into the start position on the roller coaster.

Kinetic energy is the energy of motion. We need to know how much kinetic energy a moving object has. Consider a marble moving at a certain speed. To make the marble move faster, you need to apply a force to it. Applying a force means you do some work, which is stored as potential energy. The greater the speed of the marble, the more kinetic energy it has because you have to do work to increase the speed. Where is the kinetic energy of the marble greatest?

Students should respond that it is greatest at the lowest points on the roller coaster.

Investigating energy conservation using the roller coaster

The height of the marble is a measure of the potential energy.

The speed of the marble is a measure of the kinetic energy.

3

How would you measure potential energy on the roller coaster?

By the height of the roller coaster because potential energy comes from position.

How about kinetic energy?

The speed of the marble is related to kinetic energy because it is the energy of motion.

In part 3 of the Investigation, you will measure the height and speed of the marble at 12 different places along the roller coaster. Read the procedures carefully and record your data in the table.

Students should choose 12 positions to place the photogate along the roller coaster. The roller coaster is marked in centimeters so that students can easily determine each position. Make sure students measure the height correctly, release the marble consistently, and record their data in the table.

Graphing height and speed vs. position

4

Now, take your measurements, and make a graph of height and speed vs. position. The graph on your Investigation already shows the height of the roller coaster plotted against the position along the track. Plot speed vs. position along the same graph. After you are finished, answer questions 4a-d in your notebook.

Give students some time to graph their data and answer the questions.

How is energy conserved in the marble and roller coaster system?

As height increases, speed decreases, and as height decreases, speed increases.

Conservation of energy – Energy cannot be created or destroyed, but can only be converted from one form to another.

What is the relationship between speed and height on your graph?

Students should see clearly that as height increases, speed decreases, and as height decreases, speed increases. One trades off for the other.

What can you tell about the relationship between kinetic and potential energy from your graph?

The graph illustrates a powerful law, conservation of energy, that is true everywhere. Scientists have never found even one example where energy is not conserved. Help students conclude that both the speed and height of the marble are measures of different types of energy and that the total energy in the marble and roller coaster system (the speed energy plus the height energy) is conserved.

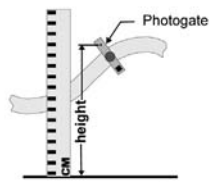
Think back to your experiments with the ropes and pulleys. Can you give me examples of kinetic and potential energy from your experiences?

Students should respond that when they pull the block to the top of the ropes and pulleys set up, the block has stored up the energy used to lift it. This is an example of potential energy. When they let go of the string and release the block, it falls back down. This movement is an example of kinetic energy.

3 Energy conservation

When the marble speeds up, it is gaining kinetic energy from falling down a hill. The kinetic energy is converted from the potential energy the marble had at the top of the hill. As the marble goes along it trades potential and kinetic energy back and forth.

To measure the kinetic energy, we use the photogate to find the speed of the marble. To get the potential energy, we need to measure the height. The light beam passes through the center of the marble, so you should measure the height from the table to the center of the hole for the light beam.



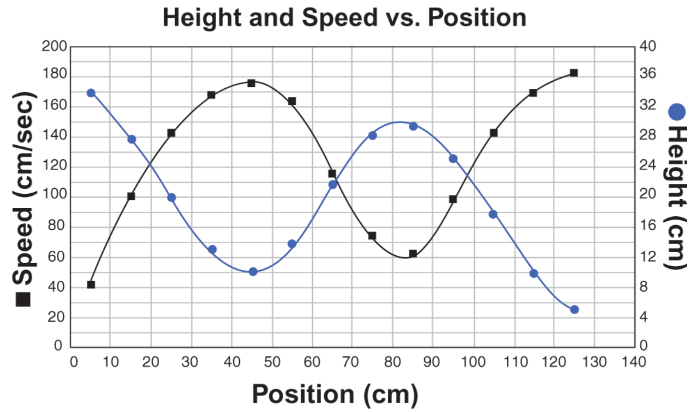
For the positions close to the start, you will have to measure from the base of the stand. Add the height of the base to the height you measure to get the total height.

1. Place the photogate at different places along the roller coaster. Measure the speed and height of the marble at each place.
2. Write your data down in the table below

Position (cm)	Height (cm)	Time from photogate A (sec)	Distance traveled (cm)	Speed of marble (cm/sec)
5	34.7	0.0452	1.9	42.0
15	29.3	0.0188	1.9	101.1
25	22.6	0.0133	1.9	142.9
35	16.6	0.0113	1.9	168.1
45	14.0	0.0108	1.9	175.9
55	17.2	0.0116	1.9	163.8
65	24.1	0.0164	1.9	115.9
75	29.7	0.0254	1.9	74.8
85	30.8	0.0302	1.9	62.9
95	27.0	0.0192	1.9	99.0
105	20.6	0.0133	1.9	142.9
115	13.7	0.0112	1.9	169.6

Answers from page four (not shown)

4 Graphing Height and Speed



Example Answers

4a. As height decreases, speed increases. As height increases, speed decreases.

4b. At the end of the roller coaster where the roller coaster is lowest in height.

4c. Height is the only contributing variable.

4d. Before the marble starts, it has a lot of potential energy and no kinetic energy. The marble's potential energy becomes kinetic energy as it rolls downhill. At the bottom of the hill, the marble has almost all kinetic energy and not much potential energy. The marble's kinetic energy becomes potential energy again when it rolls up the second hill. At the top of the second hill, the marble once again has mostly potential energy and not much kinetic energy. The marble rolls back downhill, and once again its potential energy becomes kinetic energy. The marble is going very fast at the bottom of the second hill. This is the point where the marble has the greatest amount of kinetic energy and the least amount of potential energy.

The cover colorfully combines illustrations of the forces of nature studied in the various fields of the physical sciences. Here, the "evolving tapestry of conceptual thinking" begins with water. Water droplets dance with the planets including our own watery planet and Saturn with its icy rings. Water reappears in the combustion reaction of methane, as the substance on which plants depend, as pounding waves, and, on the back cover, as the darkening clouds of a coming storm. From this cycle of water, a modern bicycle rolls into a graphical interpretation of white light split into its rainbow of wavelengths and a fiber optic. You may lose yourself in many of these images which represent hundreds of years of scientific and technological innovation. Nevertheless, that our innovations are inextricably woven into and from the natural world is illustrated by the images of Earth and the spiral connection between the DNA helix and a bicyclist ever-moving forward. On the back cover, images from physics, chemistry, and earth and space science move around a chambered nautilus seen through the windows of the Golden Rectangle. We at CPO Science with Bruce Holloway, the spirited illustrator of the cover, hope these images will inspire your interest and excitement about the discovery of science.

The CPO Science Development Team

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