

The Prudential Project

Introduction for Teachers

About This Project:

This project teaches students about physics and engineering by having them design their own roller coasters.

Standards Addressed:

Physical Sciences (Chemistry and Physics), Grades 6-8

Properties of Matter

1. Differentiate between weight and mass, recognizing that weight is the amount of gravitational pull on an object.

Motion of Objects

11. Explain and give examples of how the motion of an object can be described by its position, direction of motion, and speed.
12. Graph and interpret distance vs. time graphs for constant speed.

Forms of Energy

13. Differentiate between potential and kinetic energy. Identify situations where kinetic energy is transformed into potential energy and vice versa.

Materials:

Newton's First Law: balls (one per student)

Frictions: Toy cars, boards (or flat surface) to be used as ramps, something to elevate the ramps (a pile of books, etc.), and sandpaper

Newton's Second Law: Toy car (per group), weights for each toy car, stopwatches

Newton's Third Law: Ping-pong balls, spring jumpers, five pennies and tape (per group)

'Real' Roller Coaster: half a tube of foam pipe insulation, and a marble (per group)

The Project: Poster board, markers

Thanks to:

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What is Motion?

Scenario:

Your engineering team, Roller Coaster Engineering, Inc. has been given the responsibility of designing a roller coaster off the top of the Prudential Building to the ground. This roller coaster is different from others in that it will be powered by potential energy only.

Define the Problem:

In order to design your roller coaster, you need to gain familiarity with roller coasters, motion, speed, velocity, friction, acceleration, and gravity. You know that you need to design a roller coaster, but how can it be designed so that it will require no outside energy? Your engineering team must now begin to define the needs of this project and criteria for success.

Questions:

1. As an engineer, what problem are you going to solve?
2. What is a roller coaster?
3. What do you already know about roller coasters?
4. What features should your roller coaster have so that it requires no additional power?

5. How do you know that an object is in motion?

6. What is the difference between (**constant**) **speed** and **average speed**?
(Hint: Look at the formulas.)

7. What is **velocity**?

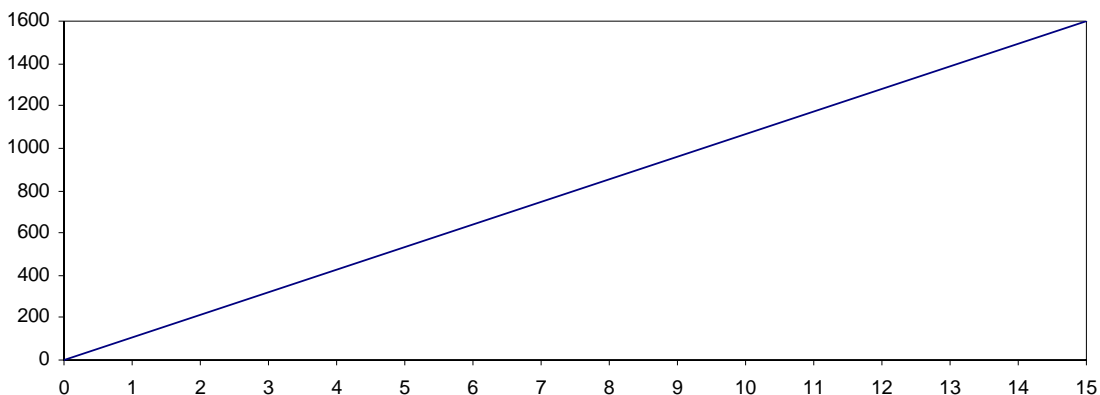
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Reading Motion Graphs

Scenario:

Your engineering team will be responsible to graph the motion of your roller coaster. To do this, you will become an expert of interpreting motion graphs. This activity is an introduction to teach you how to read motion graphs. You will be able to tell when an object is moving at a constant speed, when it is speeding up, and when it has come to a stop.

Motion Graph #1:

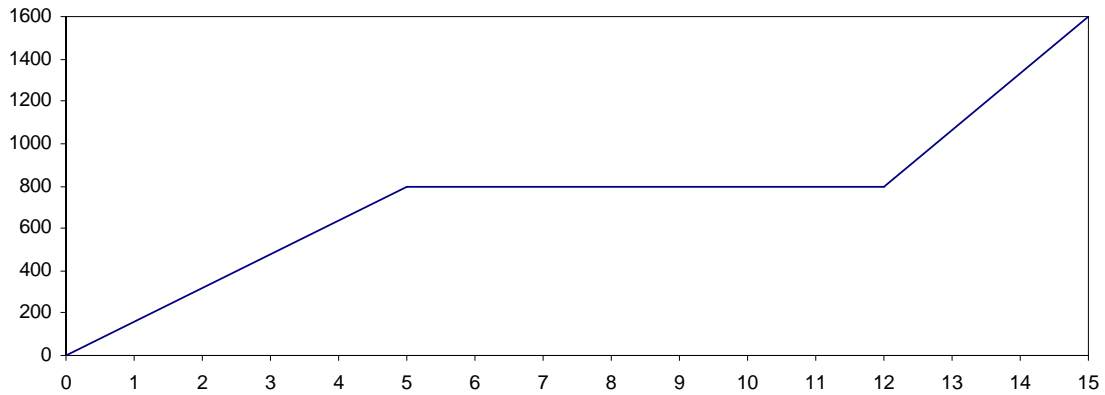


Questions:

1. Label the axes. Don't forget the units! (Hint: Think of the formula for speed.)
2. Is this object moving at a **constant** speed?
3. What is the formula for speed?
4. Find the speed of this object. (Again, don't forget the units!)

5. On the above graph, draw a line that shows the motion of an object moving faster than the object whose speed is already represented in the graph.

Motion Graph #2:



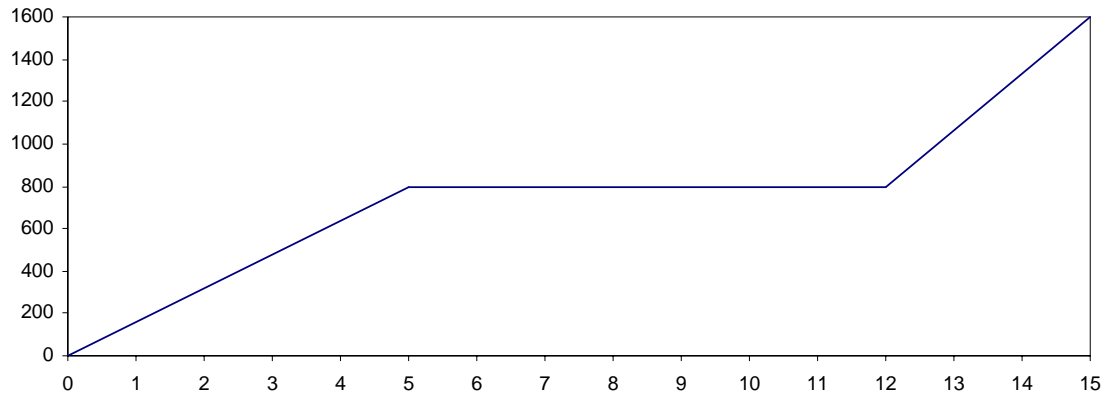
Questions:

1. List one time interval when the object is moving at a constant speed.
2. Calculate the speed during the **first** time interval.
3. Calculate the speed during the **third** time interval.
4. What can you tell about the relationship between slope and speed?
5. What is happening from 5 minutes to 12 minutes?
6. What is the **average speed** for the entire trip?

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Pop Quiz!

Motion Graph:



Questions:

1. What is the formula for speed?
2. During what time interval is the object stopped?
3. What is the average speed for the entire trip?

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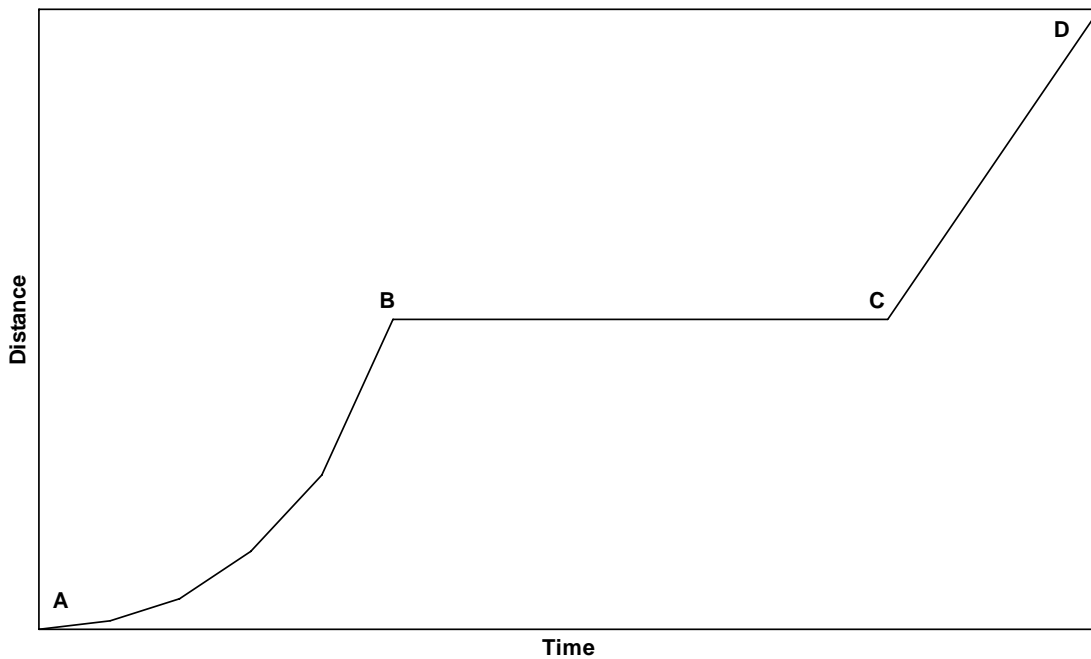
The Bike Ride

Scenario:

You are going on a bicycle trip. Write a story using physics vocabulary where your motion reflects the motion graph below. Be creative! Set the story up as follows:

- paragraph 1 – introduction
- paragraph 2 – interval A - B
- paragraph 3 – interval B - C
- paragraph 4 – interval C - D
- paragraph 5 – conclusion

Motion Graph:



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Newton's First Law

Scenario:

When designing your roller coaster to go off the top of the Prudential Building, it is crucial that you understand motion. A large part of this is learning and understanding Newton's Laws of Motion. This will ensure that your roller coaster stays on the right track!

1. What is a force?
2. What are some examples of forces?
3. Who is Sir Isaac Newton?

Activity A:

You will make observations like those made by Sir Isaac Newton and discover for yourselves the laws of motion. In this activity, we will be learning about Newton's First Law of Motion.

1. Place the ball on a smooth, flat surface. Use your right hand to push the ball gently to the left. **Draw** the motion of the ball.
2. When you push the ball, you are exerting a force on it. Was the direction of the force to the left or to the right?
3. Which direction did the ball move after you pushed it?

Activity B:

Roll the ball away from yourself slowly. While the ball is rolling, give the ball a gentle push with your right hand, identical to the push in Activity A.

1. **Draw** the motion of the ball.
2. Was the direction of the force to the left or to the right?
3. Which direction did the ball move after you pushed it?
4. Using your textbook, state Newton's First Law of Motion.
5. Explain how you demonstrated Newton's First Law in this activity.

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Friction

Scenario:

To understand Newton's First Law better, we will study the behavior of a toy car.

1. State Newton's First Law of Motion.
2. Roll a toy car across the table. According to Newton's First Law, what will happen to the toy car?
3. What force slows the car?
4. If the toy car is rolling to the **right**, in what direction is friction acting?
5. There are two kinds of friction: **rolling** friction and **sliding** friction. Give an example of each that relates to a toy car.

Activity:

You will find the speed of your toy car moving on three different surfaces. From this, you will learn about the effects of friction, as well as the difference

between rolling friction and sliding friction. You will then be asked to apply this knowledge in your lab report.

The three surfaces will be:

- car rolling on its wheels
- car sliding on its rooftop
- car rolling on sandpaper

1. To find the speed of the car, you must use the formula for speed. This formula is:
2. How many trials will you complete for each surface?
3. What is your variable?
4. What are your controls?
5. State your hypothesis **before** you begin the experiment!
6. What is the **distance** your car will travel in this experiment?
7. Before beginning, set up your data table. You will have to include the **time** for each trial on each surface. The **average time** for the trials will then have to be calculated. When this is done, you can average the speeds together to find the **average speed** for each surface. Don't forget to include **units**!

Name of Surface	Times			Average Time	Average Speed
	Trial 1	Trial 2	Trial 3		

8. In your **conclusion**, you must discuss the following:
 - What was the effect of friction on the speed of the car?
 - What was the difference between rolling friction and sliding friction?
 - Discuss why different shoe soles have different designs (i.e. sneakers, dress shoes, etc.)
 - Discuss at least two sources of experimental error.

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Newton's Second Law

Scenario:

Now that you understand Newton's First Law, let's move onto the Second Law. Newton's Second Law deals with the relationship between force, mass and acceleration. When designing your roller coaster, you will have to understand how these three components affect each other to ensure that your coaster doesn't jump the tracks!

1. What is the formula stated in Newton's Second Law?
2. If mass is increased, what happens to the acceleration?
3. If force is increased, what happens to the acceleration?

Activity:

You will use your car and ramp to solidify your understanding of the relationship between force, mass and acceleration.

1. Place your toy car at the top of the ramp and let it slide down. What force acts upon the car to make it slide down the ramp?
2. Now increase the force acting on the car by increasing the starting height of the ramp. What happens to the car's acceleration?
3. Tape the mass to the top of the car. How does this affect the car's acceleration?

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Newton's Third Law

Scenario:

Most motion on earth's surface depends on Newton's Third Law of motion. This activity will introduce you to the law so you will be able to identify it when designing your roller coaster.

1. What is Newton's Third Law?
2. Each pair of forces is identified by an *action force* and a *reaction force*. What is the difference between an action and reaction force?

Activity A:

Drop a ping-pong ball. Watch as it hits the table and bounces back up.

1. What force pulls the ball downward?
2. When the ball hits the ground, it pushes downward. The ground reacts by pushing the ball upward toward your hand. Which of these two forces is the *action force*?
3. Which force is the *reaction force*?
4. What do you know about the *strength* and *direction* of these two forces?
5. Throw the ball toward the ground so that it hits with a greater action force. What is the effect on the reaction force?

Activity B:

Squeeze the spring jumper together very lightly and place it on the table. Watch as the jumper jumps off the table.

1. What produces the *action* force?
2. What produces the reaction force?
3. When you squeeze the jumper together, you are storing potential energy in the compressed spring. What happens to this stored energy when the suction cup releases?
4. The strength of the force pushing the jumper up is determined by the stored energy in the jumper's spring. Increase the jumper's mass by taping two pennies to its back. How does this affect the spring jumper?
5. Now tape five pennies to the jumper's back. How does this affect the strength of the jump?
6. Use Newton's second law to explain what you just observed regarding the relationship between mass and force.

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Momentum

Scenario:

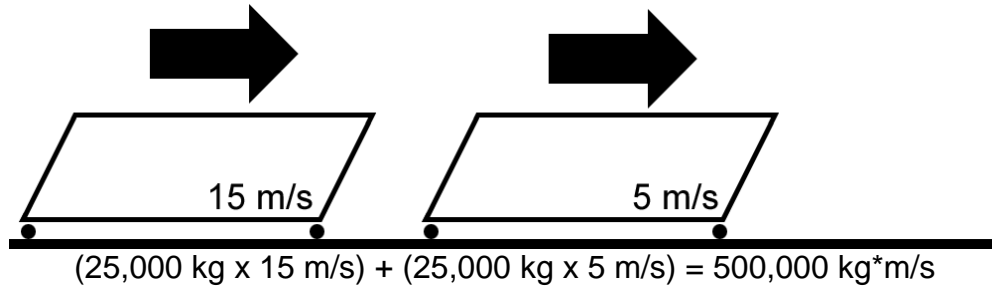
When Newton presented his three laws of motion, he used two different words to describe moving objects. He used the word velocity, but he also wrote about something that he called the “quantity of motion.” Today, we call this *momentum*.

1. What is the *formula* for momentum?
2. What are the *units* for momentum?
3. If an object has a lot of momentum, is it harder or easier to stop?
4. Which has more momentum: a 4 kg sledgehammer swung at 2 m/sec or a 5 kg sledgehammer swung at 1.5 m/sec?
5. What is the Law of Conservation of Energy?

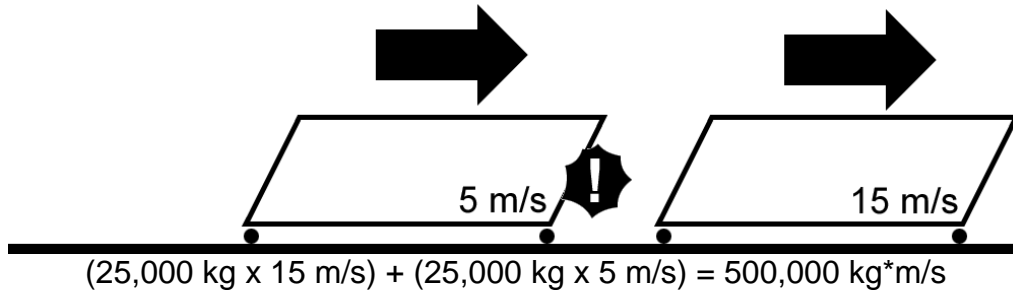
Activity:

This is a “pretend” activity.

Before

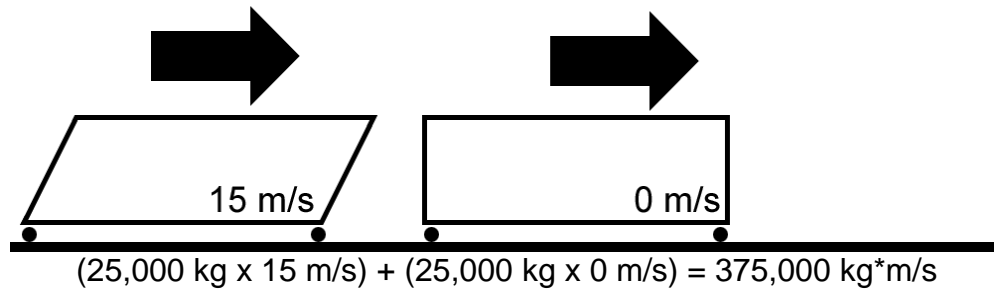


After

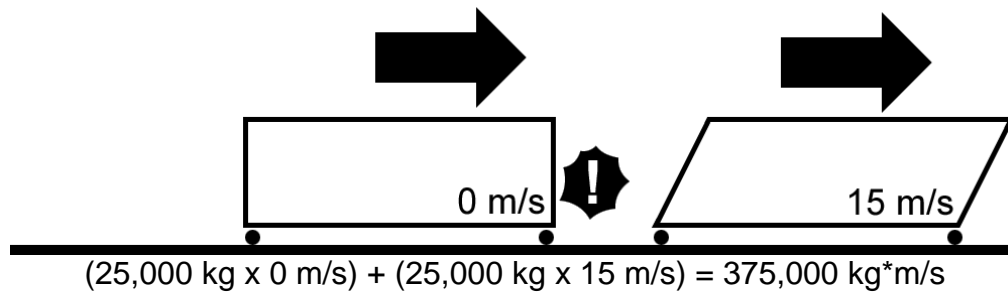


1. Look at the above scenario. Describe the motion of the two cars *before* the collision.
2. What happens to the velocity of the two cars after the collision?
3. It is clear that the total mass stays the same before and after the collision. What do you notice about the *total* velocity?
4. Which of Newton's laws does this provide an example?

Before

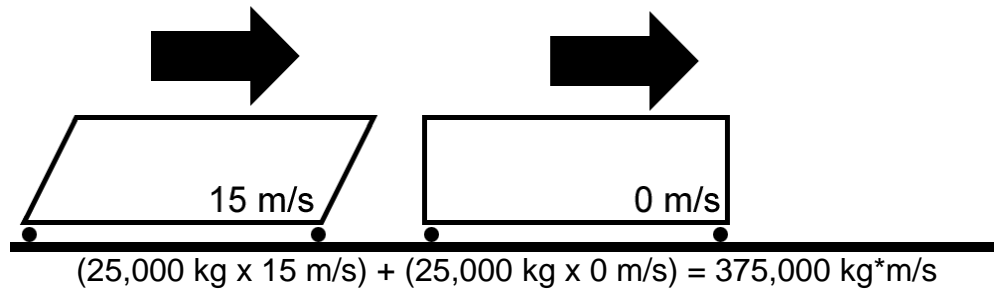


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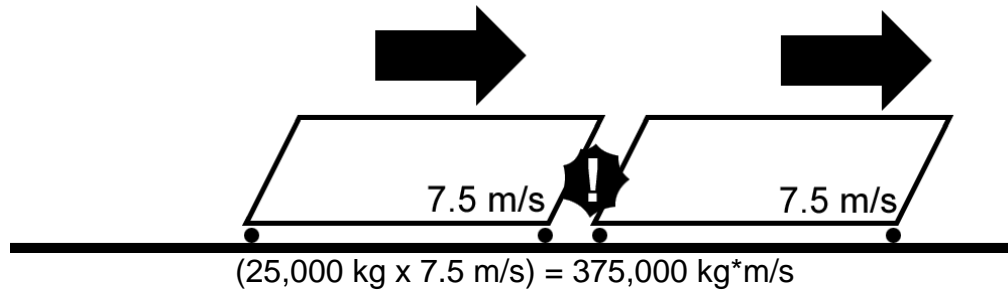


5. Look at the above scenario. Describe the motion of the two cars *before* the collision.
6. What happens to the velocity of the two cars after the collision?

Before



After



7. Look at the last scenario. This time when the two cars collide, they stick together (like having a magnet between them). Describe what happens to the velocity of the cars after the collision.

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A “Real” Roller Coaster

Scenario:

You will create your own roller coasters today. Remember that your actual roller coaster design begins on the top of the Prudential building in Boston and ends on the ground. It can include drops, loop-di-loops, or upside-down adventure, as long as it follows the laws of physics. You can see if your roller coaster obeys such laws by seeing if a marble actually rolls down your coaster

Project:

You will learn about the conversion of energy from gravitational potential energy to kinetic energy, heat, and sound by using foam pipe insulation as a roller coaster track and rolling a marble down it. The foam can be easily reconfigured into different roller coasters. Be sure that you can identify the points of highest gravitational energy and kinetic energy for each roller coaster you make.

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The Project

Scenario:

You have now learned about motion, speed, velocity, acceleration, friction, gravity, momentum, energy, and Newton's three laws. Whew! Now that you are a master of motion, show me. Get an 'A' on your poster project.

Project:

You will create a poster displaying your wild and crazy roller coaster design. Remember that the roller coaster begins on the top of the Prudential building in Boston and ends on the ground. It can include drops, loop-di-loops, or upside-down adventure, as long as it follows the laws of physics.

The following requirements *must* be on your poster. You may include additional information of your choosing.

- Basics
 - Diagram of roller coaster that you have tested
 - Title – name of roller coaster
 - Name of the engineer – you!
- Scale
 - Measure length of your roller coaster in cm
 - Estimate length in meters
 - Divide them (example: 1 cm = 20 meters)
- Labels
 - Where there is the most momentum
 - Where there is the most GPE
 - Where there is the most KE
- State how Newton's three laws are demonstrated in your roller coaster
 - Newton's First Law: inertia
 - Newton's Second Law: $F=ma$
 - Newton's Third Law: action/reaction
- Professionalism
 - Ink, colored pencil, or marker only (no pencil)
 - Use a ruler!
 - Color it
 - Correct spelling

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Grading Rubric

Student name: _____ Date: _____

Requirement	Points Awarded/Points Possible
Basics	
• Title (name of roller coaster)	___/5
• Name of engineer	___/5
• Roller coaster design	___/10
Scale	
• Scale is present	___/5
• Scale is mathematically correct	___/5
Labels	
• Most momentum (p)	___/10
• Most kinetic energy (KE)	___/10
• Most potential energy (GPE)	___/10
Newton's Laws	
• First law – inertia	___/10
• Second law – $F=ma$	___/10
• Third law – action/reaction	___/10
Professionalism	
• Neatness, ink, color, spelling	___/5
• Creativity	___/5
TOTAL	___/100