# SECTION 6

# Forces Acting During Acceleration: Apparent Weight on a Roller Coaster

## Section Overview

Students simulate apparent weight changes in an ascending and descending elevator using a mass on a spring scale and use Newton's first and second laws to explain why changes in apparent weight take place. They hang a mass from a spring scale and record its weight as they move the mass up and then down at constant speed. To represent forces acting on the mass, students draw vector diagrams that indicate the magnitude and direction of forces acting on the mass. The use of force vectors helps visualize the relationship between net force and acceleration. They repeat this investigation for an accelerating mass, relate the direction of the net force to the acceleration direction and compare their findings to their experience of riding on an elevator. Students then compare elevator rides with the experience of a roller coaster. Finally, they learn that all objects fall with the same acceleration near the surface of Earth if no other forces than gravity act, but two objects released together may not hit the ground at the same time due to air resistance.

## Background Information

Newton's first law informs us that objects that are at rest remain at rest and objects in motion remain in motion with constant velocity unless acted upon by a force. This leads us to recognize that "at rest" and "constant velocity" are similar. Newton's first law tells us that there is no way to distinguish "at rest" from "constant velocity." This certainly mirrors our experiences in trains, cars, and planes that travel at high speeds. Except for the occasional bump, sway, or air turbulence, sitting in a moving vehicle is similar to sitting in that same vehicle while it is at rest.

A spring scale measures the upward force that the spring is exerting on the mass that is suspended on the spring. The force of gravity (the weight force) acting on the object pulls the object toward Earth. If the object remains stationary or is moving with constant velocity, the scale applies an equal magnitude of force upward. In equilibrium, the force of the spring acting upward on the object is equal in magnitude to the weight of force acting downward on the object.

As you step onto a bathroom scale, the scale begins to descend. You are compressing the spring in the scale. As you compress the spring, the restoring force that the spring can exert gets larger (Hooke's law). As you continue to descend, the spring gets more compressed and the spring's force gets larger. You may find that if you descend a bit too much the spring exerts a force larger than your weight, and you begin to ascend. You finally come to rest when the spring force is equal in magnitude to your weight.

The details of the motion would be easier to see if you stepped onto a trampoline. The trampoline would bend and you would descend. You would then move up and down until the trampoline came to rest. (Without friction, you would continue to move up and down forever.) Once you come to rest, the trampoline exerts an upward force on you that is equal in magnitude to the downward force exerted on you by gravity. On a scale, there are often magnetic brakes to allow the scale to come to rest quickly.

Newton's second law can also explain the relationship between the forces and your motion. Newton's second law states that $F_{net} = ma$. If there is zero acceleration (you are at rest or moving at a constant velocity), then the net force must be zero. In the case of the spring scale, the upward force provided by the scale must be equal in magnitude to the downward force provided by gravity (your weight).

For you to accelerate up or down while in an elevator while standing on a scale requires there to be a net force exerted on you. The only two forces acting on you, while in the elevator, are gravity pulling you down and the force of the scale pushing up. The gravitation force does not change significantly. For you to accelerate up, the force of the scale pushing up must be larger in magnitude than your weight. For you to accelerate down, the force of the scale pushing up must be less than the magnitude of your weight. These relationships are explored both in the section and in the mathematical analysis in the Student Edition.

When you say that you feel your weight, you are usually saying that you feel various contact forces acting on you. For example, if you sit in a chair, you feel the upward force of the seat of the chair acting on you. If only the seat is supporting you and you are at rest, the magnitude of the upward force due to the seat is equal to the magnitude of your weight. If you (and the chair) are accelerating upward (in a roller coaster, for example), the upward force on you due to the seat is larger than your weight, and you say that you feel "heavier." Of course, your actual weight (the gravitational force due to the Earth) is the same as it was before. But you feel the force due to the seat and that is what you interpret as your apparent weight. Similarly, when your car goes over the crest of a hill, the magnitude of the force on you due to the seat is less than the magnitude of your weight and you feel less heavy.

## Crucial Physics

- Objects traveling at constant velocity in any direction have no net force acting upon them. For an object travelling up or down at constant speed, the force required to keep the object from accelerating is equal to the object's weight.
- Apparent weight is the net force acting on you by a surface in the direction toward Earth. If you are accelerating toward Earth at less than "*g*" your apparent weight is less than your actual unaccelerated weight because there is less force between you and the surface you are in contact with. If you are accelerating upward then your apparent weight is greater than your "unaccelerated weight" because there is a greater force between you and the floor you are in contact with. If you are travelling with constant speed, your apparent weight is equal to your at rest weight.
- Air resistance is often ignored to make analysis of problems easier, however it also makes the analysis different from the real world.

| Learning Outcomes | Location in the Section | Evidence of Understanding |
|---|---|---|
| **Explore** the change in apparent weight as an object moves up or down with constant speed. | ***Investigate***<br>Part A, Steps 1-3 | Students hang a mass from a spring scale and record the weight of the mass by moving it up and then down at constant speed. |
| **Explore** the change in apparent weight as an object accelerates up or down. | ***Investigate***<br>Part A, Step 1 | Students accelerate the mass hanging from a spring up or down and record the readings on the scale. |
| **Analyze** the forces on a mass at rest, moving with constant velocity, or accelerating by drawing the appropriate force-vector diagram. | ***Investigate***<br>Part A, Steps 4-6<br>Part B, Steps 2-6<br><br>***Physics Talk*** | Students analyze the forces acting on a mass at rest and then moving up and down with constant velocity and constant acceleration. By drawing force-vector diagrams that show whether there is a net force acting on the mass or not they relate the motion to the associated vector diagram. |
| **Predict** mathematically the change in apparent weight as a mass accelerates up or down. | ***Investigate***<br>Part B, Steps 5-7 | Students raise and then lower the spring scale on which the mass is hung and predict the change in the value of the reading on the scale. |

# Section 6 Materials, Preparation, and Safety

## Materials and Equipment

| PLAN A | | |
|---|---|---|
| **Materials and Equipment** | **Group (4 students)** | **Class** |
| Mass, hanging, 100 g | 1 per group | |
| Spring scale, 0–10 N | 1 per group | |
| Weight, 500 g (w/ hook) | 1 per group | |
| Scale, bathroom | | 1 per class |
| Access to elevator* | | 1 per class |

*Additional items needed not supplied

## Time Requirements

Allow one class period or 45 minutes for this *Investigate*.

## Teacher Preparation

- Ensure that the mass provides a suitable reading with the spring scale (that is, the reading should be somewhere between 1/4 and 3/4 of the maximum).
- Adjust the spring scales so that they are zeroed prior to the students using them.
- For *Part A*, have sheets of cardboard or other material available to hide the scale reading when the mass starts to move or comes to rest.

## Safety

- Students should be aware that the mass might fall off the spring scale. Make certain that no feet are located below the spring where the masses may fall. Placing a soft surface underneath the area where the masses might fall will also protect the floor.

## Materials and Equipment

| PLAN B | | |
|---|---|---|
| **Materials and Equipment** | **Group (4 students)** | **Class** |
| Mass, hanging, 100 g | | 1 per class |
| Spring scale, 0–10 N | 1 per group | |
| Weight, 500 g (w/ hook) | 1 per group | |
| Scale, bathroom | | 1 per class |
| Access to elevator* | | 1 per class |

*Additional items needed not supplied

## Time Requirements

Allow one class period or 45 minutes for the *Investigate* of this section.

## Teacher Preparation

- Ensure that the mass provides a suitable reading with the spring scale (that is, the reading should be somewhere between 1/4 and 3/4 of the maximum).
- Adjust the spring scales so that they are zeroed prior to the students using them.
- For *Part B*, have sheets of cardboard or other material available to hide the scale reading when the mass starts to move or comes to rest.

## Safety

- Students should be aware that the mass might fall off the spring scale. Make certain that no feet are located below the spring where the masses may fall. Placing a soft surface underneath the area where the masses might fall will also protect the floor.

# Meeting the Needs of All Students

## Differentiated Instruction: Augmentation and Accommodations

| Learning Issue | Reference | Augmentation and Accommodations |
| --- | --- | --- |
| Activating prior knowledge | ***Investigate***<br><br>***Physics Talk*** | **Augmentation**<br>• Students with learning disabilities often have a difficult time retrieving the information stored in their brains partially because their thought process does not categorize and store information as efficiently as others.<br>• Help students activate their prior knowledge and open up the folder in their brains that is storing the information about Newton's laws, forces, and acceleration before beginning this activity. Brainstorm a class list of everything the group remembers about these topics. Seeing and hearing other students ideas and vocabulary will provide a frame of reference for the activity.<br>• This type of brainstorm also brings up student misconceptions. |
| Reading a spring scale | ***Investigate*** | **Augmentation**<br>• Model how to read a spring scale before students begin the *Investigate*.<br>• Provide a few opportunities to practice reading the spring scale when an object is stationary and when the object is moving. This guided practice will help students be more successful when collecting data to make predictions in the *Investigate*.<br>**Accommodation**<br>• If possible, paint the arrow/marker on the spring scale a bright color to help students see the marked spot more easily. |
| Following a series of directions<br><br>Reading comprehension | ***Investigate*** | **Augmentation**<br>• For students who struggle with reading and attention to task, there are a lot of steps required to complete this *Investigate*. When there are too many directions, students often skim over steps.<br>• Provide a photocopy of the directions to allow students to cross off each step as they complete it.<br>• Assign roles for each member of the lab group, such as recorder, tester, scale readers, direction reader, etc. The direction reader should be a student who has a relative strength in reading and is a leader. This person would read the directions aloud, make sure the group is following the directions, and keep the group on task.<br>• Allow some students to complete *Part A* and other students to complete *Part B*, and then provide an opportunity for students to share their observations.<br>• Provide reasonable time limits for each part of the *Investigate*, and give students time updates to help them self-monitor their own progress.<br>**Accommodation**<br>• For students with more severe reading struggles, pair the directions with as many pictures as possible. Take pictures of other students doing the activity and then put them in order for students to follow. |
| Recording observations | ***Investigate*** | **Augmentation**<br>• Remind students that the pencil icon indicates that they should be recording observations, data, or predictions for the corresponding step. |

| Learning Issue | Reference | Augmentation and Accommodations |
|---|---|---|
| Reading comprehension | ***Physics Talk***<br><br>***Active Physics Plus*** | **Augmentation**<br>• This section is filled with explanations and examples, but if students struggle with decoding and comprehension, they are going to miss many important concepts.<br>• One alternative to providing teacher-led direction instructions is to ask pairs of students to be responsible for certain sections. Students read a section of the text, put the information into their own words, and then present that information with some kind of visual aid to the class. This strategy allows for more student participation and differentiation. Students with higher-level math skills could present a math concept, and so on.<br>• Provide a set of guided reading questions that direct students to the information deemed most important by the curriculum. Ask students to read the questions before they begin reading *Physics Talk*.<br>**Accommodation**<br>• Provide a copy of the text. Instruct students to highlight one to three key points per paragraph. Tell students that they must be able to justify their choices if the teacher asks them why they highlighted something. |
| Synthesizing and applying new knowledge | ***Physics to Go***<br>Questions 3-9 | **Augmentation**<br>• At this point, students have spent a lot of time investigating and reading about the effects of acceleration on weight. Instruct students to refer back to their notes and observations in their *Active Physics* logs as well as the *Physics Talk* to help them accurately answer these questions. |

CHAPTER 4

## Strategies for Students with Limited English-Language Proficiency

| Learning Issue | Reference | Augmentation |
|---|---|---|
| Vocabulary comprehension | ***Investigate*** Part A, Step 2 | Students may need some assistance in determining the meaning of "ingenuity" in context. |
| Understanding concepts | ***Investigate*** Part A, Step 4 | Students will benefit from a brief review of Newton's first and second laws from *Physics in Action*. |
| Comprehension | ***Investigate*** Part B, Step 8.a) | After students have recorded three similarities and three differences between riding in a roller coaster and riding in an elevator, hold a class discussion to compare thoughts. Different students will have different ideas, so all will benefit from hearing one another's thoughts. |
| Understanding concepts<br><br>Vocabulary comprehension | ***Investigate*** Part B, Steps 9.a) and b) | Make sure students realize that when dropped from the same height at the same time, a baseball and a bowling ball will hit the ground at the same time. A piece of paper and a baseball will not hit at the same time, however. The ball will hit first. The paper will be more affected by air resistance and so will take longer to fall, and it may not fall in a straight line. Students should be able to state that if crumpled into a ball shape, a piece of paper will then hit the ground at (nearly) the same time as the baseball.<br><br>If necessary, help students figure out the meaning of "simultaneously." Have them relate this term to other terms with the same root, such as "simulation" and "simulcast." |
| Higher-order thinking | ***Investigate*** Part B, Step 9 | Hold a class discussion about free fall. Have students explain what it means in their own words. Then ask: "Do you think objects often fall in free fall? Why or why not?" Introduce the topic of the Space Shuttle. Ask: "What keeps the Space Shuttle in orbit around Earth?" See whether students can figure out that in space, with no air or atmosphere, there is no air resistance acting on the Shuttle. When the thrusters are off, the only force acting on the Shuttle is the force of Earth's gravity, so the Shuttle is in free fall. (Students may wonder why the Shuttle doesn't crash into Earth. Explain that the Shuttle also has a horizontal component of motion which in fact tends to take it farther from Earth's curved surface.) |
| Vocabulary comprehension | ***Physics Talk*** Apparent Weight | ELL students may need some elaboration of the term "apparent weight." It may help to think of the bathroom scale as making the "apparent weight" visible. To clarify further, ask a volunteer to describe changes in apparent weight for a child swinging on a playground swing. These changes may be of greater magnitude than those in an elevator. Have another volunteer identify where in the arc a child would feel her body press harder against the swing seat and where the child might feel weightless. Encourage students to use the term "apparent weight" as they answer. |
| Vocabulary comprehension | ***Active Physics Plus*** | Students may benefit from a review of the term "inertia." |
| Researching skills | ***Active Physics Plus*** | ELL students benefit greatly from reading, writing, and speaking in English. If time allows, have ELL students or pairs of students look up Einstein and his general theory of relativity on the Internet, write up a short paper, and give an oral report to the class. |

# SECTION 6

# Teaching Suggestions and Sample Answers

## What Do You See?

Engage students in noticing the details of this illustration. Highlight the contrasting aspects of two persons standing on a bathroom scale and ask students what the artist is trying to convey. Consider asking the students why the two people are weighing themselves on a scale, why one person appears to be happy and the other person seems to be surprised. Accept all answers and post a few on the board. Ask students to connect their interpretations of the visuals to the concepts of force and acceleration. Emphasize that they will be revisiting this illustration to see how they would respond to the *What Do You Think?*

Chapter 4 Thrills and Chills

Section 6 Forces Acting During Acceleration: Apparent Weight on a Roller Coaster

What Do You See?

**Learning Outcomes**

In this section, you will

- **Explore** the change in apparent weight as an object moves up or down with constant speed.
- **Explore** the change in apparent weight as an object accelerates up or down.
- **Analyze** the forces on a mass at rest, moving with constant velocity, or accelerating by drawing the appropriate force-vector diagrams.
- **Predict** mathematically the change in apparent weight as a mass accelerates up or down.

**What Do You Think?**

As the roller coaster moves down that first hill, up the second hill, and then over the top, you feel as if your weight is changing. As you go over the top of the hill, you have the feeling of floating when your body rises up out of the seat. In roller coaster terms, this is called airtime.

- **Does your weight change when you are riding on a roller coaster?**
- **If you were sitting on a bathroom scale, would the scale give different readings at different places on the roller coaster?**

Record your ideas about these questions in your *Active Physics* log. Be prepared to discuss your responses with your small group and the class.

**Investigate**

In this experiment, you will investigate the apparent weight changes you feel when you are on a roller coaster. You will use the spring scale for your observations. However, you will explain what you observe with both the spring scale and the bathroom scale.

406

## Students' Prior Conceptions

You may elect to review the concept of normal force in *Section 6* of *Driving the Roads*. It builds on student belief that a force implies motion and if there is a force there must be a motion. The outcomes that they observed for Newton's third law provides insight into the concept of normal force and how apparent weight relates to the change in the normal force as an object accelerates up, down, or sideways.

1. **Students tend only to assign forces to animate objects, ignoring passive forces acting on inanimate objects.** Students often say that they "feel" changes in motion when they ride up and down in an elevator or that their "stomachs jump up" at certain times when they are riding coasters. However, conceptual alignment with how the changing acceleration interacts with the normal force to produce "weightlessness" or the "thrill" associated with roller-coaster rides can only emerge as students first analyze all of the forces acting on an object at rest, paying particular attention to the normal force, and then compare these forces with an object experiencing constant upward or downward accelerations. (A force acting toward the center of the curve is found in the *Section 7* on circular motion.) You should encourage students to draw force diagrams for situations involving moving up and down in an elevator and accelerating up or down while riding in a roller-coaster car. Understanding how weight changes in these situations is a principal element necessary for student modification of preconceived notions of weight and apparent weight.

questions, once they have gained more insight into the physics concepts investigated in this section.

## What Do You Think?

Students who have been on a roller coaster will probably say that they felt their weight change during different parts of a roller-coaster ride. Ask students whether they felt their weight change during the feeling of floating, as if they were rising up out of their seats. Remind students that they will be returning to the *What Do You Think?* questions at a later stage in the section. The purpose of these questions is to elicit what students know about weight and apparent changes in weight. Once again, it is important to elicit prior understandings, not to reach closure on the questions. It gives you an opportunity to uncover previous misconceptions. You should encourage students to share their ideas in class and not worry about whether their answers are correct or not. Involving students in a stimulating discussion will prepare them for the *Investigate* and they will be actively engaged in finding answers.

### What Do You Think?

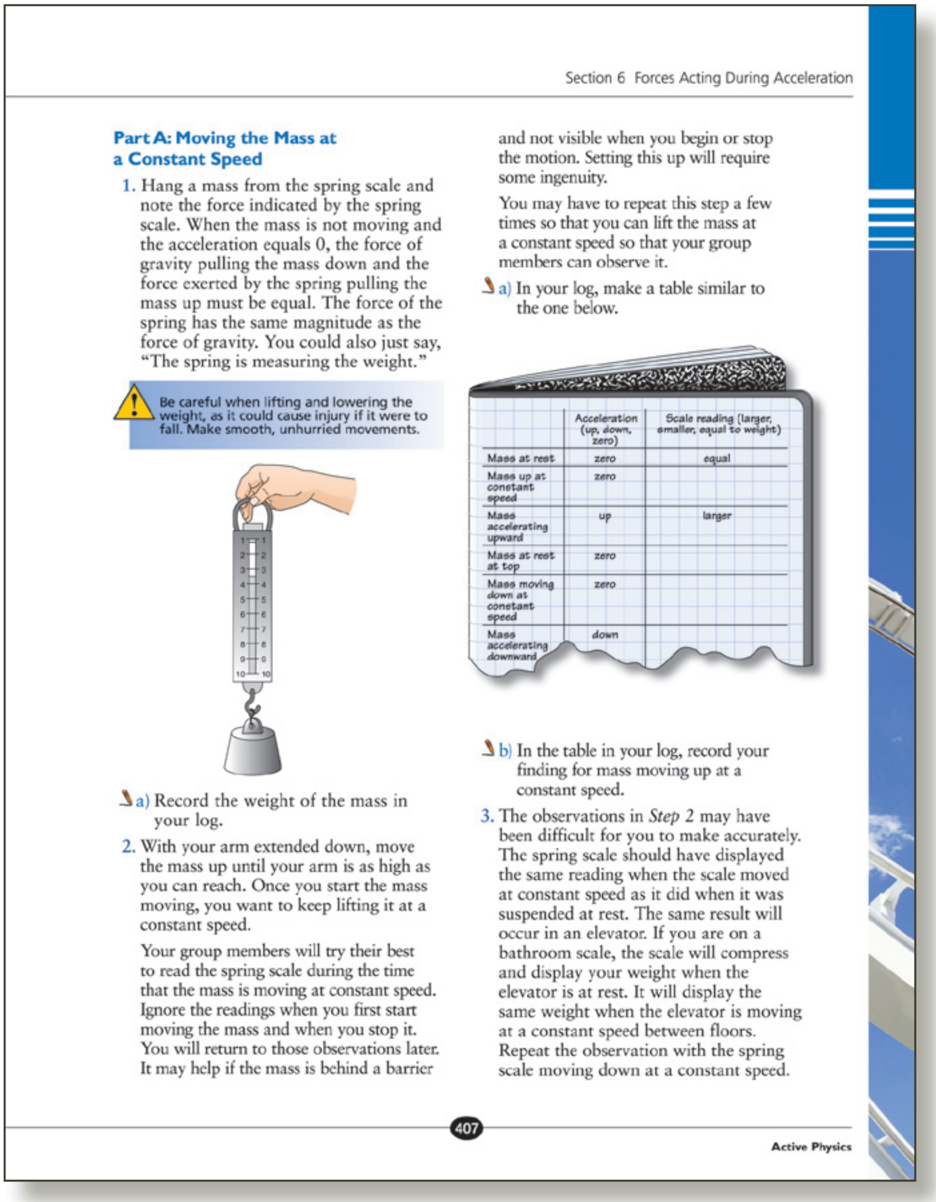
#### A Physicist's Response

Encourage your students to describe how they "feel" on a roller coaster. Some students may also compare this feeling to a car traveling at a high speed over the crest of a hill. When riding on a roller coaster, your weight doesn't change, but your apparent weight (really the normal force exerted on you to support your body) does change. It is this change in apparent weight that gives much of the thrill of a roller coaster. If you were sitting on a bathroom scale, which measures the normal force exerted on you, you would notice a different weight reading on the scale.



NOTES

# NOTES





**Part A: Moving the Mass at a Constant Speed**

1. Hang a mass from the spring scale and note the force indicated by the spring scale. When the mass is not moving and the acceleration equals 0, the force of gravity pulling the mass down and the force exerted by the spring pulling the mass up must be equal. The force of the spring has the same magnitude as the force of gravity. You could also just say, "The spring is measuring the weight."

Be careful when lifting and lowering the weight, as it could cause injury if it were to fall. Make smooth, unhurried movements.

a) Record the weight of the mass in your log.

2. With your arm extended down, move the mass up until your arm is as high as you can reach. Once you start the mass moving, you want to keep lifting it at a constant speed.

Your group members will try their best to read the spring scale during the time that the mass is moving at constant speed. Ignore the readings when you first start moving the mass and when you stop it. You will return to those observations later. It may help if the mass is behind a barrier and not visible when you begin or stop the motion. Setting this up will require some ingenuity.

You may have to repeat this step a few times so that you can lift the mass at a constant speed so that your group members can observe it.

a) In your log, make a table similar to the one below.

| | Acceleration (up, down, zero) | Scale reading (larger, smaller, equal to weight) |
|---|---|---|
| Mass at rest | zero | equal |
| Mass up at constant speed | zero | |
| Mass accelerating upward | up | larger |
| Mass at rest at top | zero | |
| Mass moving down at constant speed | zero | |
| Mass accelerating downward | down | |

b) In the table in your log, record your finding for mass moving up at a constant speed.

3. The observations in *Step 2* may have been difficult for you to make accurately. The spring scale should have displayed the same reading when the scale moved at constant speed as it did when it was suspended at rest. The same result will occur in an elevator. If you are on a bathroom scale, the scale will compress and display your weight when the elevator is at rest. It will display the same weight when the elevator is moving at a constant speed between floors. Repeat the observation with the spring scale moving down at a constant speed.



# Investigate

## Part A: Moving the Mass at a Constant Speed

**1.a)**

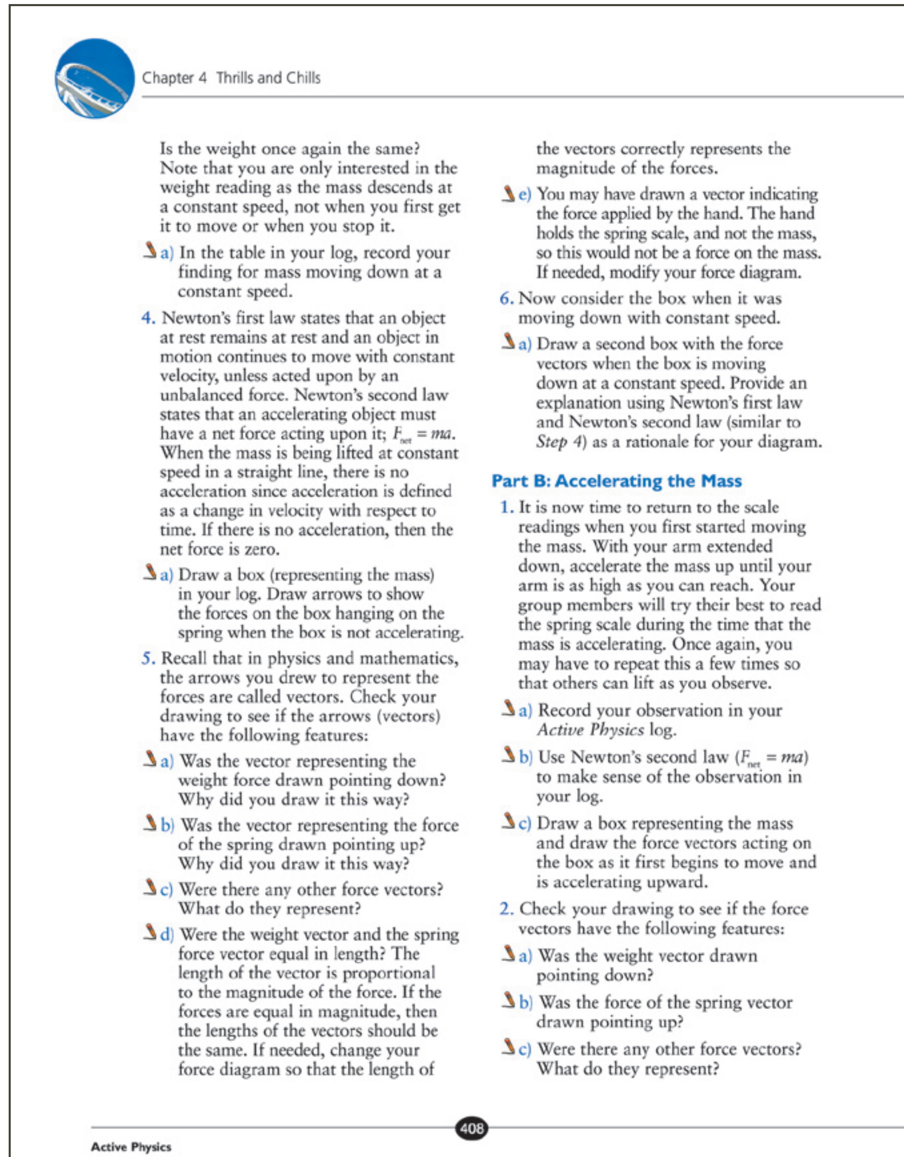
Let's assume that the student is hanging a 1-kg mass on the spring. The scale reading will be 9.8 N. Some spring scales are calibrated in grams, rather than newtons. Try to use the newton scales if possible.

**2.a)**

The students should copy the table in the text into their logs.

**2.b)**

When the mass is moving up at a constant speed, the scale reading is still 9.8 N.


Chapter 4 Thrills and Chills

Is the weight once again the same? Note that you are only interested in the weight reading as the mass descends at a constant speed, not when you first get it to move or when you stop it.

a) In the table in your log, record your finding for mass moving down at a constant speed.

4. Newton's first law states that an object at rest remains at rest and an object in motion continues to move with constant velocity, unless acted upon by an unbalanced force. Newton's second law states that an accelerating object must have a net force acting upon it; $F_{net} = ma$. When the mass is being lifted at constant speed in a straight line, there is no acceleration since acceleration is defined as a change in velocity with respect to time. If there is no acceleration, then the net force is zero.

a) Draw a box (representing the mass) in your log. Draw arrows to show the forces on the box hanging on the spring when the box is not accelerating.

5. Recall that in physics and mathematics, the arrows you drew to represent the forces are called vectors. Check your drawing to see if the arrows (vectors) have the following features:

a) Was the vector representing the weight force drawn pointing down? Why did you draw it this way?

b) Was the vector representing the force of the spring drawn pointing up? Why did you draw it this way?

c) Were there any other force vectors? What do they represent?

d) Were the weight vector and the spring force vector equal in length? The length of the vector is proportional to the magnitude of the force. If the forces are equal in magnitude, then the lengths of the vectors should be the same. If needed, change your force diagram so that the length of the vectors correctly represents the magnitude of the forces.

e) You may have drawn a vector indicating the force applied by the hand. The hand holds the spring scale, and not the mass, so this would not be a force on the mass. If needed, modify your force diagram.

6. Now consider the box when it was moving down with constant speed.

a) Draw a second box with the force vectors when the box is moving down at a constant speed. Provide an explanation using Newton's first law and Newton's second law (similar to *Step 4*) as a rationale for your diagram.

**Part B: Accelerating the Mass**

1. It is now time to return to the scale readings when you first started moving the mass. With your arm extended down, accelerate the mass up until your arm is as high as you can reach. Your group members will try their best to read the spring scale during the time that the mass is accelerating. Once again, you may have to repeat this a few times so that others can lift as you observe.

a) Record your observation in your *Active Physics* log.

b) Use Newton's second law ($F_{net} = ma$) to make sense of the observation in your log.

c) Draw a box representing the mass and draw the force vectors acting on the box as it first begins to move and is accelerating upward.

2. Check your drawing to see if the force vectors have the following features:

a) Was the weight vector drawn pointing down?

b) Was the force of the spring vector drawn pointing up?

c) Were there any other force vectors? What do they represent?

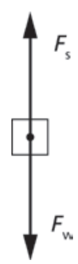
Active Physics 408

### 3.a)

When the mass is moving down at a constant speed, the scale reading is still 9.8 N.

### 4.

When the mass is at rest or the mass is moving at constant velocity, the weight force $F_w$ will be equal in magnitude but opposite in direction to the spring force $F_s$. The students' drawing should look like the one below.




### 5.a)

The weight-force vector should be drawn pointing down because Earth is pulling the mass down.

**Teaching Tip**

If the students are having trouble identifying the forces that act on the mass (the free-body diagram), have them draw a circle around the object for which they are trying to identify the forces. Anything that touches the circle is a source of force. The only other forces that can act on the object are forces like gravity that do not need to touch objects to exert a force. This will allow the students to identify the forces more easily.

### 5.b)

The spring-force vector is pointing up because the spring is applying a force upward on the mass.

### 5.c)

No, there are no other forces acting on the box. (A force may be applied to the spring to hold it in place, but this is not a force on the box—the spring applies the force to the box.)

### 5.d)

Yes, they are the same length because the forces are equal and opposite. If the students draw a hand holding the spring (or the box), have them remove it since this will only confuse the problem.

### 5.e)

Students' answers may vary.

### 6.a)

The diagram is identical to that in *Step 4*. Newton's second law states that when there is no acceleration $(a = 0)$, then there is no net force $(F_{net} = 0)$. For the net force (the sum of the forces) to be equal to zero, the weight down must be equal in magnitude to the spring's upward force.

CHAPTER 4

### Part B: Accelerating the Mass

**1.a)**

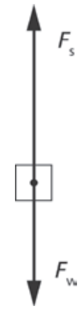
When the mass is first raised, the scale reads a higher reading. In the previous example, instead of reading 9.8 N, the scale might read 12.0 N.

**1.b)**

Because the mass is accelerating upward, Newton's second law informs us that there must be a net force acting upward. Because the weight of the object (the pull of Earth on the object) is identical to what it was before, the spring force must increase from what it was before. This increase in the spring force corresponds to a higher scale reading.

**1.c)**

Refer to the diagram below:




**2.a)**

The weight vector is down because Earth pulls the object down.

**2.b)**

The spring pulls the mass up.

**2.c)**

No, there are no other forces acting on the box.

NOTES

**2.d)**

The weight vector is smaller than the spring force vector because there is a net force acting upward due to the spring that provides the acceleration moving up.

**3.a)**

Students may need to modify their diagrams.

**4.a)**

The reading of the bathroom scale is the reading of the compressed spring, not your weight. While you are accelerating upward, the bathroom scale would read a number larger than your actual weight. If you weigh 700 N, the spring scale may read 750 N (your apparent weight during the acceleration). The spring in the bathroom scale is providing the force to accelerate you upward, so it must be larger than your weight to provide a net force.

**5.a)**

Make sure that students record their predictions before making their observations.

**5.b)**

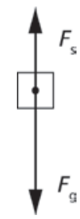
When you stop moving, the scale will read less than the original weight. This is because to stop, the mass will require a downward acceleration. A downward acceleration requires a net downward force. Thus, the spring-scale force will be less than the weight force.

**6.a)**

The scale will read a value less than the mass's weight. As you begin to lower the mass, the acceleration is down, so the downward force of the weight must be greater than the upward force of the spring scale.

**6.b)**

Refer to the diagram below:




**6.c)**

Students should predict that the scale will have a lower reading.

**6.d)**

The scale will have a smaller reading because the spring force is less than the weight force.

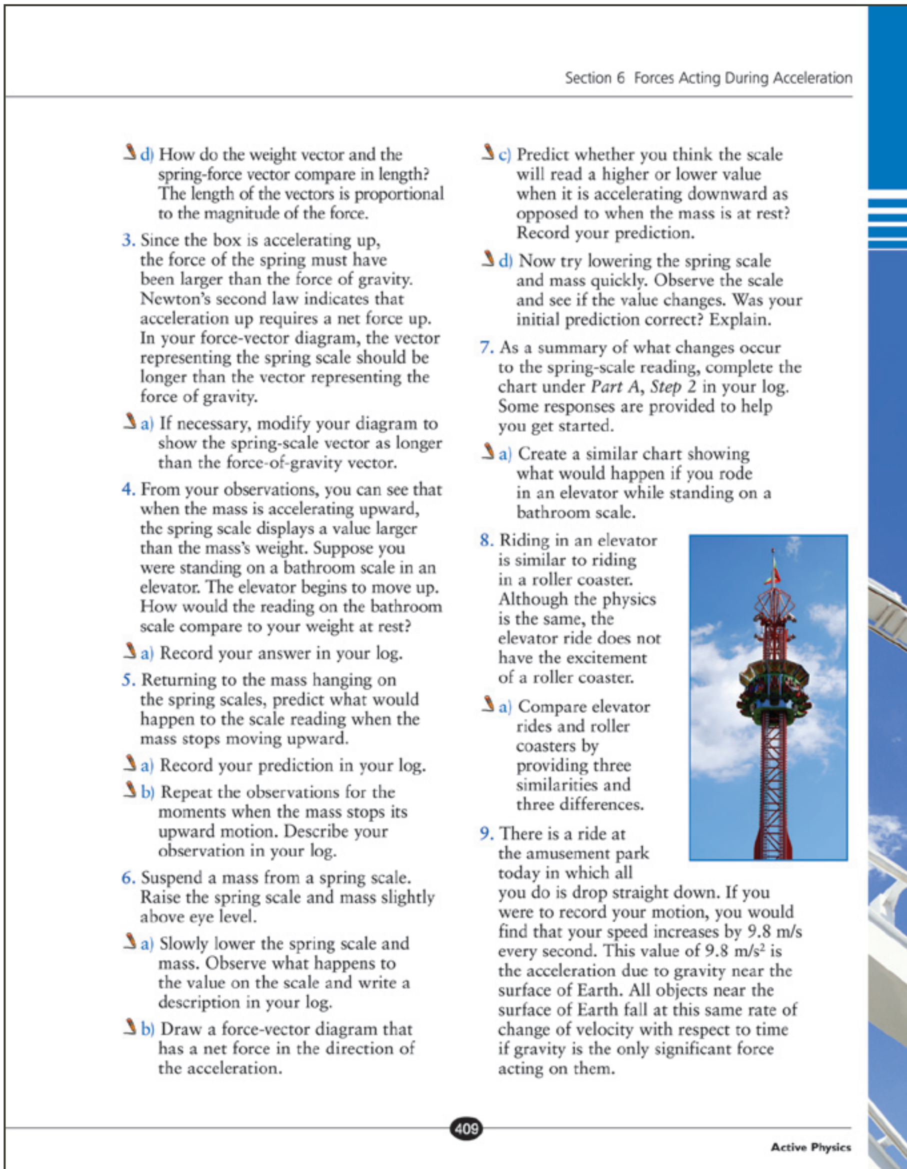
**7.a)**

Refer to the chart below. This chart is available as a Blackline Master at the end of this *Investigate*.

**4-6a Blackline Master**

| | Acceleration (up, down, zero) | Scale reading (larger, smaller, equal to weight) |
|---|---|---|
| Mass at rest | zero | equal |
| Mass up at constant speed | zero | equal |
| Mass acceleration upward | up | larger |
| Mass coming to rest at the top | down | smaller |
| Mass at rest at top | zero | equal |
| Mass moving down at constant speed | zero | equal |
| Mass accelerating downward | down | smaller |
| Mass coming to rest at the bottom | up | larger |
| Mass at rest at the bottom | zero | equal |

Students complete a similar chart for the situation in which they are standing on a bathroom scale in an elevator. For the chart of riding in an elevator on a bathroom scale, the bathroom scale readings would be the same as in the chart above.




d) How do the weight vector and the spring-force vector compare in length? The length of the vectors is proportional to the magnitude of the force.

3. Since the box is accelerating up, the force of the spring must have been larger than the force of gravity. Newton's second law indicates that acceleration up requires a net force up. In your force-vector diagram, the vector representing the spring scale should be longer than the vector representing the force of gravity.

a) If necessary, modify your diagram to show the spring-scale vector as longer than the force-of-gravity vector.

4. From your observations, you can see that when the mass is accelerating upward, the spring scale displays a value larger than the mass's weight. Suppose you were standing on a bathroom scale in an elevator. The elevator begins to move up. How would the reading on the bathroom scale compare to your weight at rest?

a) Record your answer in your log.

5. Returning to the mass hanging on the spring scales, predict what would happen to the scale reading when the mass stops moving upward.

a) Record your prediction in your log.

b) Repeat the observations for the moments when the mass stops its upward motion. Describe your observation in your log.

6. Suspend a mass from a spring scale. Raise the spring scale and mass slightly above eye level.

a) Slowly lower the spring scale and mass. Observe what happens to the value on the scale and write a description in your log.

b) Draw a force-vector diagram that has a net force in the direction of the acceleration.

c) Predict whether you think the scale will read a higher or lower value when it is accelerating downward as opposed to when the mass is at rest? Record your prediction.

d) Now try lowering the spring scale and mass quickly. Observe the scale and see if the value changes. Was your initial prediction correct? Explain.

7. As a summary of what changes occur to the spring-scale reading, complete the chart under *Part A, Step 2* in your log. Some responses are provided to help you get started.

a) Create a similar chart showing what would happen if you rode in an elevator while standing on a bathroom scale.

8. Riding in an elevator is similar to riding in a roller coaster. Although the physics is the same, the elevator ride does not have the excitement of a roller coaster.

a) Compare elevator rides and roller coasters by providing three similarities and three differences.

9. There is a ride at the amusement park today in which all you do is drop straight down. If you were to record your motion, you would find that your speed increases by 9.8 m/s every second. This value of 9.8 $m/s^2$ is the acceleration due to gravity near the surface of Earth. All objects near the surface of Earth fall at this same rate of change of velocity with respect to time if gravity is the only significant force acting on them.



## 8.a)

Similarities between roller-coaster rides and elevators:

- Both roller coasters and elevators involve motion.
- Both roller coasters and elevators involve accelerations.
- Passengers on both roller coasters and elevators experience apparent weight changes.

Differences between roller-coaster rides and elevators:

- Elevators travel in one dimension (up and down), while roller coasters travel in three dimensions.
- Elevators are programmed to have small accelerations, while roller coasters are designed to have large accelerations.
- Elevators have accelerations in the vertical direction, while roller coasters have additional accelerations to the sides.
- You can remain vertical in elevators, while you can be upside down in roller coasters.

CHAPTER 4

**9.a)**

If you dropped a baseball and a bowling ball from the top of the Tower of Pisa at the same time, they would hit the ground at nearly the same time.

**9.b)**

If you dropped a baseball and a piece of paper at the same time, the baseball would hit the ground first. Air resistance is significant for the piece of paper and the paper is not in free-fall. Its acceleration is considerably less than 9.8 $m/s^2$. Modifying the sheet of paper by crumpling it up into a tight ball does not change its mass, but greatly reduces its air resistance. It allows the paper to fall with an acceleration much closer to that of the baseball.

**9.c)**

All objects fall with the same acceleration if gravity is the only significant force acting on them. In the case of a piece of paper, air resistance is quite significant and the piece of paper drifts downward under the influence of both gravity and air resistance. For the baseball, the force due to air resistance is much less than its weight, so it falls nearly at 9.8 $m/s^2$ unless it is moving really fast.

Chapter 4 Thrills and Chills

You have Galileo (1564-1642) to thank for this insight. As the story goes, he dropped two objects from the Leaning Tower of Pisa in Italy and observed them hitting the ground at the same time. The story may not be true, but Galileo did perform many experiments with balls rolling down inclined planes. The "dropping experiment" has been repeated many times with very precise equipment and with the effects of air resistance minimized or eliminated.

a) If you were at the Leaning Tower of Pisa and dropped a baseball and a bowling ball at the same time, which would hit the ground first? Explain your answer.

b) If you dropped a baseball and a piece of paper, which would hit the ground first? Explain your answer. Does the shape of the paper influence the way it drops? Do you think you could modify a sheet of paper to drop at the same time you drop a baseball? Try this and record your observations in your log.

c) How would you modify the statement, "All objects fall at the same acceleration" to account for your observation of a baseball and a sheet of paper?

The numerical value of the acceleration of falling objects, if gravity is the only significant force, is equal to the strength of the gravitational field (9.8 N/kg = 9.8 $m/s^2$ near the surface of Earth). That is why *g* is sometimes called "the acceleration due to gravity." But you should remember that in many cases, the object may experience other forces in addition to its weight. In these cases, the acceleration will not be equal to *g*. If you are falling under the influence of gravity alone, you are in "free fall."

**Physics Talk**

**FORCES ACTING DURING ACCELERATION**

**Using Newton's First and Second Law to Explain Forces Acting During Constant Speed and Acceleration**

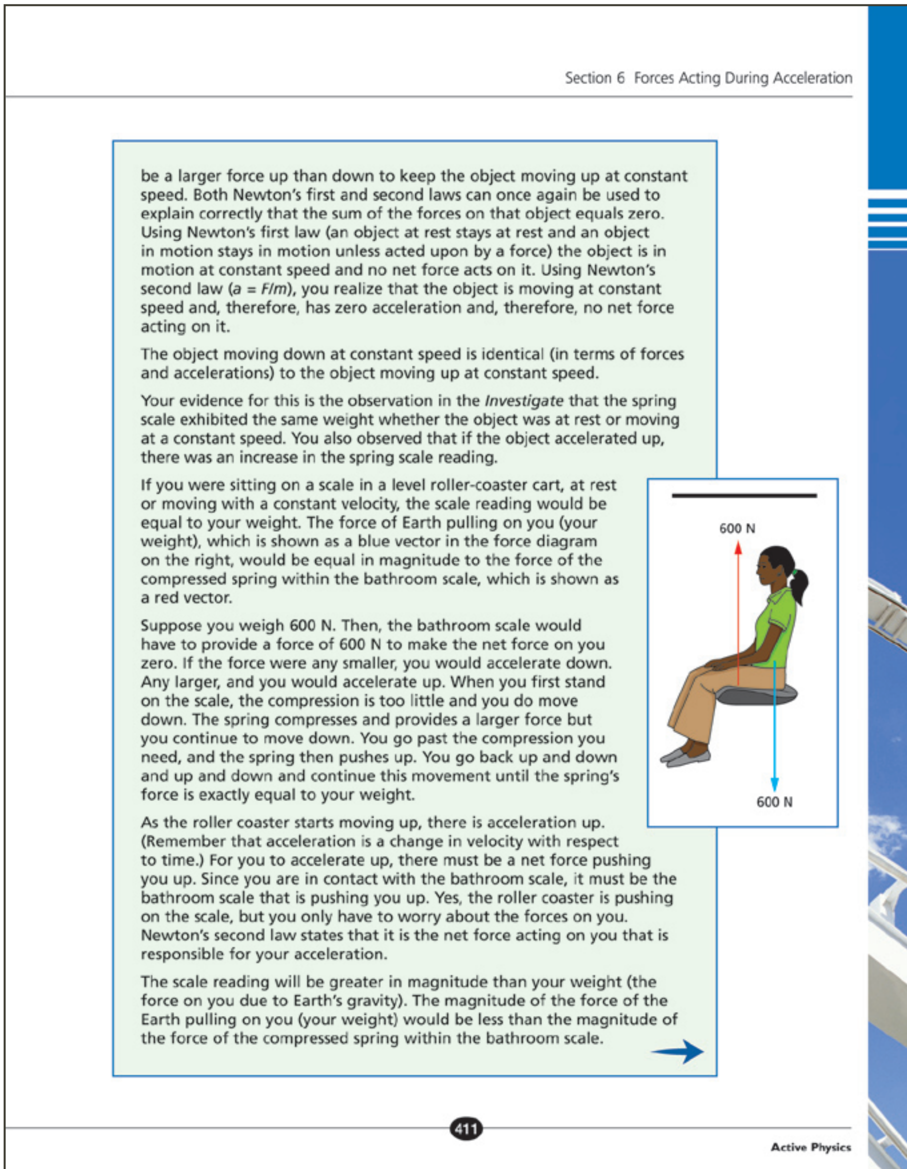
As the roller coaster moves you about, you feel funny things happening in your stomach. These, however, are more than just feelings. These changes can be measured. You can use physics to explain these feelings.

When an object is at rest, the sum of the forces on that object equal zero. Both Newton's first law and Newton's second law can be used to explain this. Using Newton's first law (an object at rest stays at rest and an object in motion stays in motion unless acted upon by a force), the object is at rest and no net force acts on it. Using Newton's second law ($a = F/m$), you realize that the object is at rest and, therefore, has zero acceleration and, therefore, no net force acting on it.

When the object moves up at constant speed, many people are too quick to jump to the wrong conclusion that there must

410

Active Physics




be a larger force up than down to keep the object moving up at constant speed. Both Newton's first and second laws can once again be used to explain correctly that the sum of the forces on that object equals zero. Using Newton's first law (an object at rest stays at rest and an object in motion stays in motion unless acted upon by a force) the object is in motion at constant speed and no net force acts on it. Using Newton's second law ($a = F/m$), you realize that the object is moving at constant speed and, therefore, has zero acceleration and, therefore, no net force acting on it.

The object moving down at constant speed is identical (in terms of forces and accelerations) to the object moving up at constant speed.

Your evidence for this is the observation in the *Investigate* that the spring scale exhibited the same weight whether the object was at rest or moving at a constant speed. You also observed that if the object accelerated up, there was an increase in the spring scale reading.

If you were sitting on a scale in a level roller-coaster cart, at rest or moving with a constant velocity, the scale reading would be equal to your weight. The force of Earth pulling on you (your weight), which is shown as a blue vector in the force diagram on the right, would be equal in magnitude to the force of the compressed spring within the bathroom scale, which is shown as a red vector.



Suppose you weigh 600 N. Then, the bathroom scale would have to provide a force of 600 N to make the net force on you zero. If the force were any smaller, you would accelerate down. Any larger, and you would accelerate up. When you first stand on the scale, the compression is too little and you do move down. The spring compresses and provides a larger force but you continue to move down. You go past the compression you need, and the spring then pushes up. You go back up and down and up and down and continue this movement until the spring's force is exactly equal to your weight.

As the roller coaster starts moving up, there is acceleration up. (Remember that acceleration is a change in velocity with respect to time.) For you to accelerate up, there must be a net force pushing you up. Since you are in contact with the bathroom scale, it must be the bathroom scale that is pushing you up. Yes, the roller coaster is pushing on the scale, but you only have to worry about the forces on you. Newton's second law states that it is the net force acting on you that is responsible for your acceleration.

The scale reading will be greater in magnitude than your weight (the force on you due to Earth's gravity). The magnitude of the force of the Earth pulling on you (your weight) would be less than the magnitude of the force of the compressed spring within the bathroom scale.



## Physics Talk

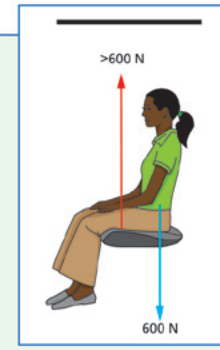
This *Physics Talk* draws on Newton's first and second laws to explain why people feel lighter when they are accelerating down or heavier when they are moving up on an elevator or roller coaster. Students learn to associate the direction of the net force with the direction of the acceleration, and how this affects their apparent weight on a roller coaster.

Students can gain a thorough understanding of how forces act on objects that move up or down if they draw vector diagrams and compare their experiments in the *Investigate* to the explanation in *Physics Talk*.

Discuss the relationship between Newton's first and second laws and the weight of an object at rest. Then ask students how they would contrast this with an object moving at constant velocity. Review the *Investigate* steps in which students recorded the weight of a mass they moved up and then down at constant speed. Have them review the diagrams they drew before that explained the direction and magnitude of forces acting on the mass. Determine if students understand why the net force on an object moving at constant speed should be zero.

Once students have grasped why their weight would read the same on a spring scale, when they are at rest or moving with constant velocity, steer the discussion toward the net force acting on a person riding an elevator or roller coaster that is accelerating. Ask students to use Newton's first and second laws to describe why they feel that a change in their weight is taking place when they accelerate up or down in a roller coaster. To help students realize the connections between the physics concepts they are gradually acquiring, draw a concept map on the board and invite students to fill it in with important ideas they have learned that explain the physics of forces acting on an object in motion. Make sure that they include the connection of weight to the concept of gravity and how air resistance affects the speed of objects falling on Earth.

Chapter 4 Thrills and Chills




If your weight is 600 N (blue vector), then the bathroom scale would have to be providing a force of greater than 600 N (red vector).

Another way of looking at the situation is to look first at the forces. According to the vector diagram, the force of the scale is larger than the force of gravity. The net force is, therefore, up and according to Newton's second law, the object will accelerate up, $F_{net} = ma$. You observed this in the *Investigate* when you accelerated the mass up and observed the increased scale reading.

### Calculating Acceleration

Suppose you are standing on a bathroom scale in an elevator. You can calculate the acceleration of the elevator if you know your weight and measure the force as read on the spring scale during the acceleration. Assume you weigh 600.0 N and the force of the scale on you is 700.0 N up.

$$F_{net} = 700.0 \text{ N} - 600.0 \text{ N}$$
$$= 100.0 \text{ N (upward)}$$

To find the acceleration, you need to know your mass. If your weight is 600.0 N ($F_w$ = 600.0 N), you can calculate your mass.

$$F_w = mg, \text{ where } g = 9.8 \text{ N/kg}$$
$$m = \frac{F_w}{g}$$
$$= \frac{600.0 \text{ N}}{9.8 \text{ N/kg}} \quad \left(\text{units: } \cancel{\text{N}} \times \frac{\text{kg}}{\cancel{\text{N}}}\right)$$
$$= 61 \text{ kg}$$

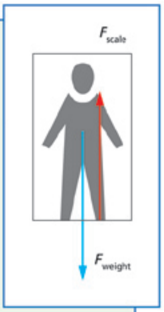
Knowing the mass and the net force, you can calculate the acceleration using Newton's second law.

$$F_{net} = ma$$
$$a = \frac{F}{m}$$
$$= \frac{100.0 \text{ N}}{61 \text{ kg}} \quad \left(\text{units: } \frac{\cancel{\text{kg}} \times \text{m/s}^2}{\cancel{\text{kg}}}\right)$$
$$= 1.6 \text{ m/s}^2$$

Similarly, you can calculate the reading of the spring scale if you know the acceleration of the elevator.

### Sample Problem

An elevator at the top floor begins to descend with an acceleration of 2.0 m/s² downward. What will a bathroom scale read if a 50.0-kg person is standing on the scale while the elevator is accelerating?




***Strategy:*** Since the elevator and the person are accelerating down, the net force on the person must be down. The force vectors are shown in the diagram on the right.

Newton's second law states that

$$F_{net} = ma$$

where $F_{net}$ is the net force.

Since the weight is greater than the force of the spring and in the opposite direction, you can write this as

Weight − force due to bathroom scale = $ma$ (downward)

***Given:***

$m = 50.0$ kg
$a = 2.0$ m/s²

***Solution:***

First find the person's weight:

$$\text{Weight} = mg = (50.0 \text{ kg})(9.8 \text{ N/kg}) = 490 \text{ N}$$

Using Newton's second law,

$$\text{Weight} - \text{force due to scale} = ma$$

$$490 \text{ N} - F_{scale} = (50.0 \text{ kg})(2.0 \text{ m/s}^2)$$

Solve for the force due to the scale.

$$F_{scale} = 490 \text{ N} - (50.0 \text{ kg})(2.0 \text{ m/s}^2) = 390 \text{ N}$$

The scale would read 390 N instead of the person's weight, which is 490 N.

If the elevator accelerates up, the scale reads a value higher than the person's weight of 490 N. There is really no limit to the upward acceleration although the person would become unconscious if the acceleration were greater than about nine times the acceleration due to gravity. This has been experimentally determined by test pilots.

If the elevator accelerates down, the scale reads a value lower than the weight of 490 N. There is a lower limit on the scale reading. If the elevator accelerates down at 9.8 m/s² (For example, the cable broke and the elevator is in free fall.), the scale would not push up at all and its reading would be 0 N.

Using Newton's second law,

$$F_{scale} = ma$$

$$\text{Weight} - \text{Force by spring} = ma$$

Substitute the numerical values.

$$(50.0 \text{ kg})(9.8 \text{ N/kg}) - F_{scale} = (50.0 \text{ kg})(9.8 \text{ N/kg})$$

$$490 \text{ N} - F_{scale} = 490 \text{ N}$$

Solve for the force due to the scale.

$$F_{scale} = 0 \text{ N}$$

This is what you experience when you jump off a diving board. It is also felt for a few moments in the amusement park ride where you are in free fall.

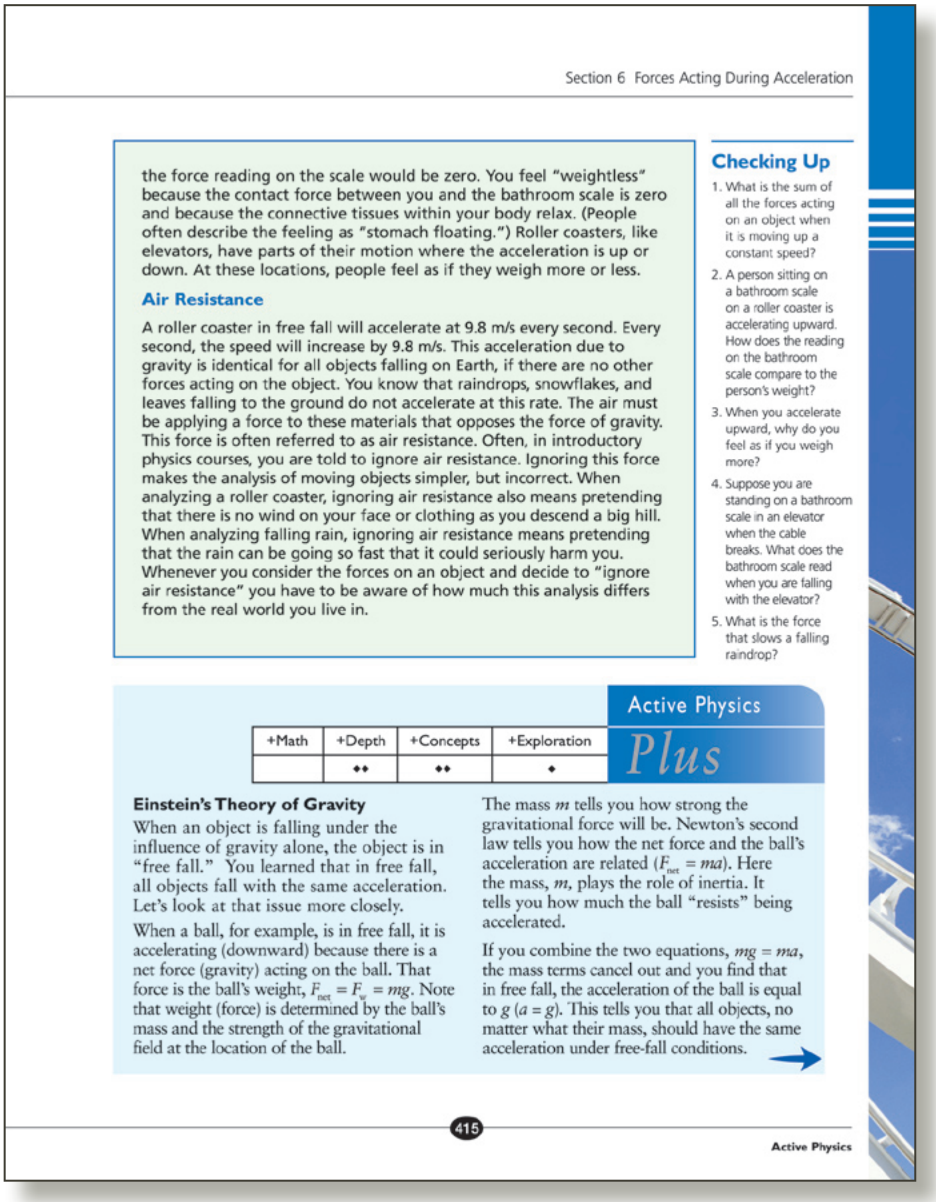
### Apparent Weight

When the elevator is at rest or moving up or down at constant velocity, your weight readings are identical. That's because at rest or moving at a constant velocity requires no net force. The force of the scale up on you is equal to the weight force down. The bathroom scale denotes the value of the force up on you.

When an object accelerates (changes its velocity), you know there must be a net force acting on the object. When the elevator accelerates up, you also accelerate up. This is because Earth pulls down on you with a force that is smaller than the force that the scale exerts on you upward. The scale reads a larger force than before.

You also feel as if you weigh more. Why is that? You feel your weight because of the contact forces between your body and other objects. When you stand on the floor, you feel the floor pushing up on you. Also, some parts of your body are only loosely connected to other parts. For example, when you are standing straight up, your stomach moves down a bit until the connective tissues in your body (acting like springs) exert a large enough force upward to hold your stomach in place against the force due to gravity. Nerve endings in those tissues allow you to feel that stretching. When the elevator accelerates upward, you feel the larger contact force between you and the bathroom scale. Also, the connective tissues have to stretch more to get your stomach to accelerate. All of this leads to a feeling of larger apparent weight.

When the elevator accelerates down, you also accelerate down. This is because the force of the scale up on you is less than the force of your weight down. The scale reads a smaller force than before. You also feel as if you weigh less because the contact force with the bathroom scale is smaller and because the connective tissues stretch a bit less. If the elevator cable were to break, you would have only the force of your weight pulling you down. The scale would not push up and you and



Section 6 Forces Acting During Acceleration

the force reading on the scale would be zero. You feel "weightless" because the contact force between you and the bathroom scale is zero and because the connective tissues within your body relax. (People often describe the feeling as "stomach floating.") Roller coasters, like elevators, have parts of their motion where the acceleration is up or down. At these locations, people feel as if they weigh more or less.

**Air Resistance**

A roller coaster in free fall will accelerate at 9.8 m/s every second. Every second, the speed will increase by 9.8 m/s. This acceleration due to gravity is identical for all objects falling on Earth, if there are no other forces acting on the object. You know that raindrops, snowflakes, and leaves falling to the ground do not accelerate at this rate. The air must be applying a force to these materials that opposes the force of gravity. This force is often referred to as air resistance. Often, in introductory physics courses, you are told to ignore air resistance. Ignoring this force makes the analysis of moving objects simpler, but incorrect. When analyzing a roller coaster, ignoring air resistance also means pretending that there is no wind on your face or clothing as you descend a big hill. When analyzing falling rain, ignoring air resistance means pretending that the rain can be going so fast that it could seriously harm you. Whenever you consider the forces on an object and decide to "ignore air resistance" you have to be aware of how much this analysis differs from the real world you live in.

**Checking Up**

1. What is the sum of all the forces acting on an object when it is moving up a constant speed?
2. A person sitting on a bathroom scale on a roller coaster is accelerating upward. How does the reading on the bathroom scale compare to the person's weight?
3. When you accelerate upward, why do you feel as if you weigh more?
4. Suppose you are standing on a bathroom scale in an elevator when the cable breaks. What does the bathroom scale read when you are falling with the elevator?
5. What is the force that slows a falling raindrop?

**Active Physics Plus**

| +Math | +Depth | +Concepts | +Exploration |
|---|---|---|---|
| | ◆◆ | ◆◆ | ◆ |

**Einstein's Theory of Gravity**

When an object is falling under the influence of gravity alone, the object is in "free fall." You learned that in free fall, all objects fall with the same acceleration. Let's look at that issue more closely.

When a ball, for example, is in free fall, it is accelerating (downward) because there is a net force (gravity) acting on the ball. That force is the ball's weight, $F_{net} = F_w = mg$. Note that weight (force) is determined by the ball's mass and the strength of the gravitational field at the location of the ball.

The mass $m$ tells you how strong the gravitational force will be. Newton's second law tells you how the net force and the ball's acceleration are related ($F_{net} = ma$). Here the mass, $m$, plays the role of inertia. It tells you how much the ball "resists" being accelerated.

If you combine the two equations, $mg = ma$, the mass terms cancel out and you find that in free fall, the acceleration of the ball is equal to $g$ ($a = g$). This tells you that all objects, no matter what their mass, should have the same acceleration under free-fall conditions.

415 Active Physics

## Checking Up

**1.**

When an object is moving up at constant speed, the sum of all the forces acting on the object is zero.

**2.**

The reading on the bathroom scale is more than the person's weight when the person is riding a roller coaster that is accelerating upward.

**3.**

In an upward accelerating elevator, the force provided by the scale pushing you upward is more than the force of gravity pulling you down. You feel that you weigh more because of the contact forces between you and the bathroom scale are what you interpret as your weight.

**4.**

When you are falling with the elevator, you are accelerating downward at exactly the same rate as the elevator $(9.8\ \text{m/s}^2)$. To fall at this rate, the only force acting on you is the force of your weight, so the reading on the bathroom scale is zero.

**5.**

The force of air resistance slows down a falling raindrop.

## Active Physics Plus

Students test Einstein's theory of gravity by answering questions that probe how balls will fall to the floor on Earth and a spaceship moving up with no net gravitational force.

They are led to think about the remarkable coincidence between inertial mass and gravitational mass that led Einstein to develop his famous geometric theory of gravity (General Relativity).

CHAPTER 4

**1.**

$F_w = m_{\text{gravitational}}(g)$

$F_{\text{net}} = m_{\text{inertial}}(a)$

**2.a)**

The student sees both balls accelerate toward the ground and strike the ground simultaneously.

**2.b)**

$9.8\ \text{m/s}^2$

**3.a)**

The astronaut sees both balls accelerate toward the floor and strike the floor simultaneously.

**3.b)**

If the astronaut was unaware that the rocket was accelerating in space, it would appear to the astronaut that gravity accelerated the balls to the floor.

**3.c)**

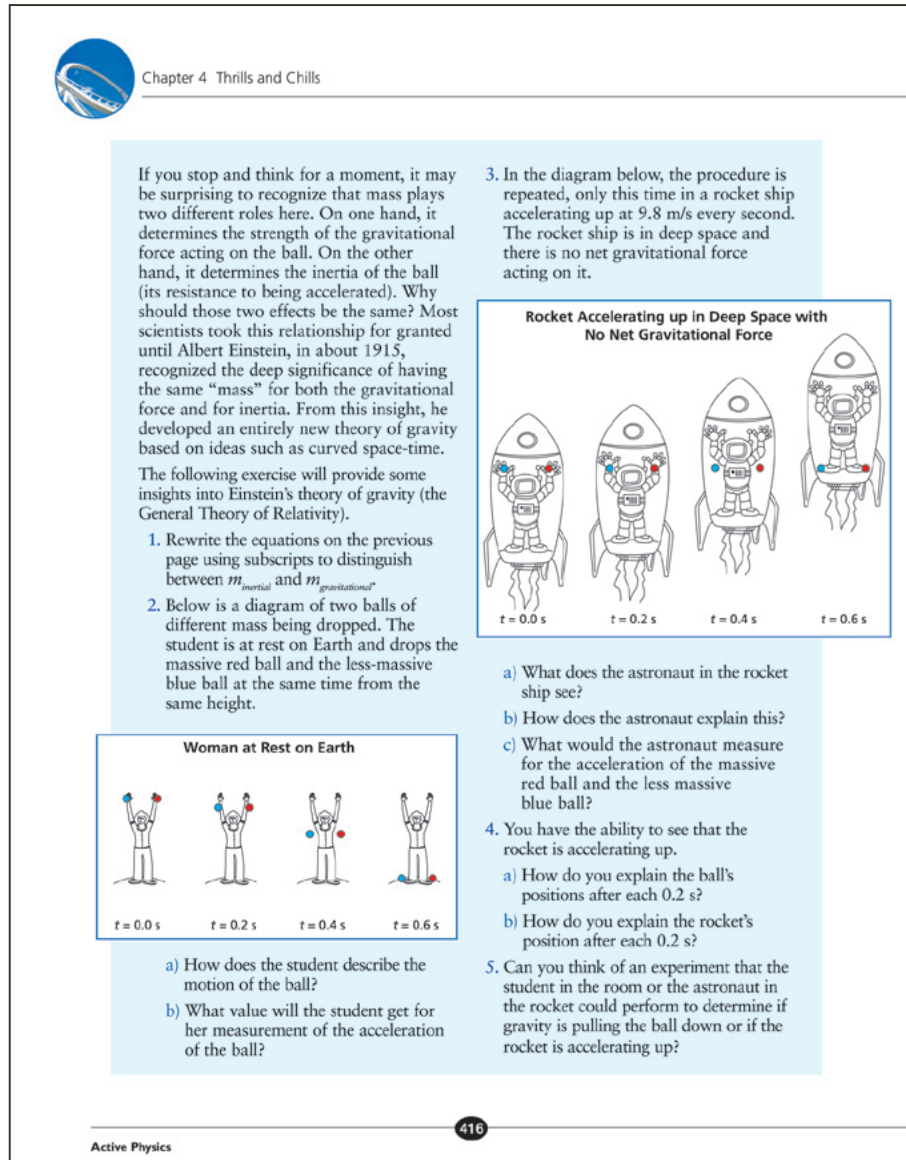
The astronaut would measure the acceleration of the massive red ball and the blue ball to be $9.8\ \text{m/s}^2$.

**4.a)**

To an outside observer, because there is no net force acting (with no gravitational force), the balls' positions after each 0.2 s would not change.

**4.b)**

To an outside observer, the rocket's position after each 0.2 s is accelerating up to meet the balls' consistent position.


Chapter 4 Thrills and Chills

If you stop and think for a moment, it may be surprising to recognize that mass plays two different roles here. On one hand, it determines the strength of the gravitational force acting on the ball. On the other hand, it determines the inertia of the ball (its resistance to being accelerated). Why should those two effects be the same? Most scientists took this relationship for granted until Albert Einstein, in about 1915, recognized the deep significance of having the same "mass" for both the gravitational force and for inertia. From this insight, he developed an entirely new theory of gravity based on ideas such as curved space-time.

The following exercise will provide some insights into Einstein's theory of gravity (the General Theory of Relativity).

1. Rewrite the equations on the previous page using subscripts to distinguish between $m_{\text{inertial}}$ and $m_{\text{gravitational}}$.
2. Below is a diagram of two balls of different mass being dropped. The student is at rest on Earth and drops the massive red ball and the less-massive blue ball at the same time from the same height.



   a) How does the student describe the motion of the ball?
   b) What value will the student get for her measurement of the acceleration of the ball?
3. In the diagram below, the procedure is repeated, only this time in a rocket ship accelerating up at 9.8 m/s every second. The rocket ship is in deep space and there is no net gravitational force acting on it.



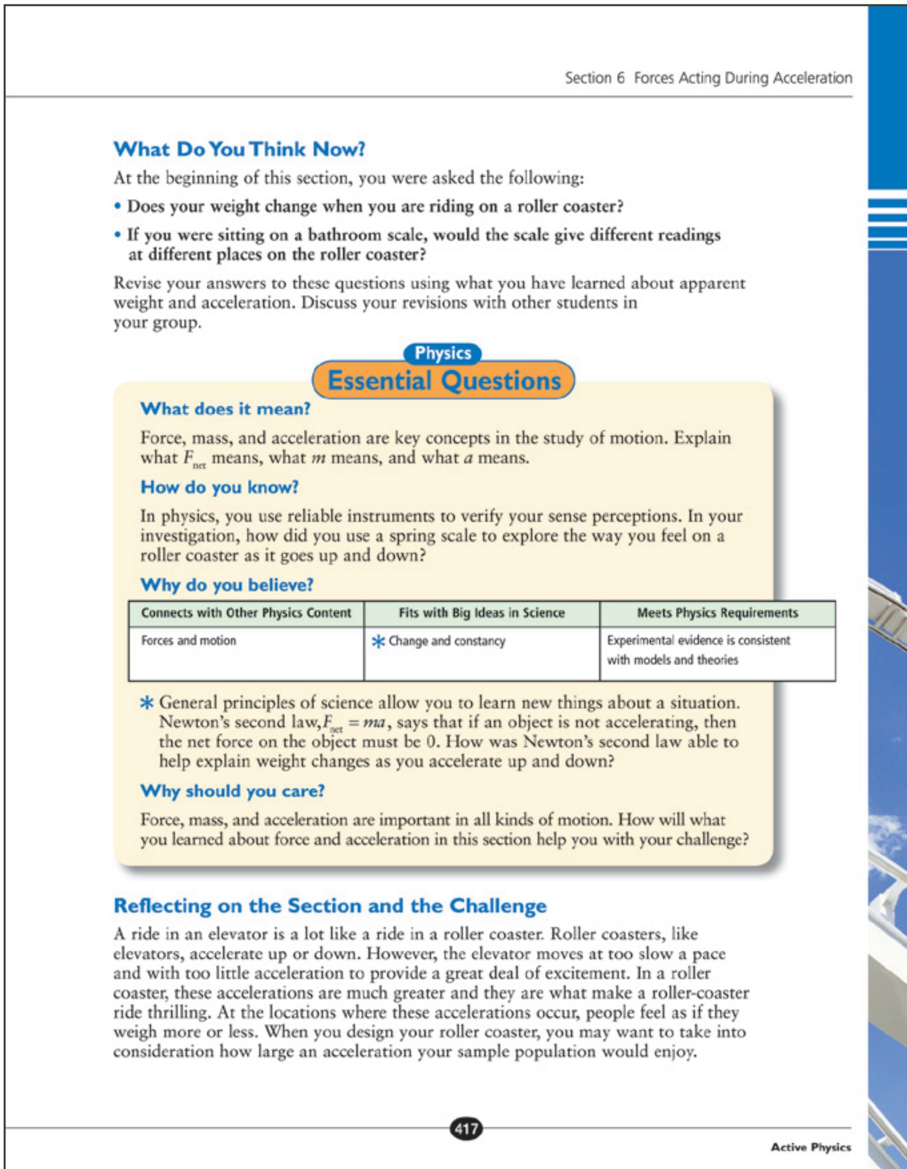
   a) What does the astronaut in the rocket ship see?
   b) How does the astronaut explain this?
   c) What would the astronaut measure for the acceleration of the massive red ball and the less massive blue ball?
4. You have the ability to see that the rocket is accelerating up.
   a) How do you explain the ball's positions after each 0.2 s?
   b) How do you explain the rocket's position after each 0.2 s?
5. Can you think of an experiment that the student in the room or the astronaut in the rocket could perform to determine if gravity is pulling the ball down or if the rocket is accelerating up?

416

Active Physics

**5.**

In this situation, there is no test the astronaut could do to distinguish between gravity accelerating the balls downward, or the rocket accelerating upward to meet the balls. This is the basis for Einstein's general theory of relativity that equates acceleration and gravity.



Section 6 Forces Acting During Acceleration

### What Do You Think Now?

At the beginning of this section, you were asked the following:

- **Does your weight change when you are riding on a roller coaster?**
- **If you were sitting on a bathroom scale, would the scale give different readings at different places on the roller coaster?**

Revise your answers to these questions using what you have learned about apparent weight and acceleration. Discuss your revisions with other students in your group.

Physics **Essential Questions**

**What does it mean?**

Force, mass, and acceleration are key concepts in the study of motion. Explain what $F_{net}$ means, what $m$ means, and what $a$ means.

**How do you know?**

In physics, you use reliable instruments to verify your sense perceptions. In your investigation, how did you use a spring scale to explore the way you feel on a roller coaster as it goes up and down?

**Why do you believe?**

| Connects with Other Physics Content | Fits with Big Ideas in Science | Meets Physics Requirements |
|---|---|---|
| Forces and motion | * Change and constancy | Experimental evidence is consistent with models and theories |

* General principles of science allow you to learn new things about a situation. Newton's second law, $F_{net} = ma$, says that if an object is not accelerating, then the net force on the object must be 0. How was Newton's second law able to help explain weight changes as you accelerate up and down?

**Why should you care?**

Force, mass, and acceleration are important in all kinds of motion. How will what you learned about force and acceleration in this section help you with your challenge?

### Reflecting on the Section and the Challenge

A ride in an elevator is a lot like a ride in a roller coaster. Roller coasters, like elevators, accelerate up or down. However, the elevator moves at too slow a pace and with too little acceleration to provide a great deal of excitement. In a roller coaster, these accelerations are much greater and they are what make a roller-coaster ride thrilling. At the locations where these accelerations occur, people feel as if they weigh more or less. When you design your roller coaster, you may want to take into consideration how large an acceleration your sample population would enjoy.

417 Active Physics

## What Do You Think Now?

Students now have an opportunity to review their previous answers to the *What Do You Think?* section. Students should recall what they have learned about apparent weight and acceleration and apply it in updating their answers. Highlight the main features of *A Physicist's Response* to elaborate why riders feel a thrill when they go up and down a roller coaster. Encourage students to share their ideas with each other and have them discuss their revisions in class. Have them revisit the *What Do You See?* illustration and determine how their earlier responses relate to their present knowledge of apparent weight and acceleration. Students should now be able to identify the features they missed before. Through this process of updating and reviewing prior information, students will gain self-confidence in their answers and appreciate the purpose behind the *What Do You Think?* questions.

## Physics Essential Questions

### What does it mean?

The net force is the sum of all forces acting on the mass ($m$). Any time you observe acceleration, you know that a net force must be present. All accelerations are due to net forces.

### How do you know?

The spring scale was able to show the weight of a mass as it accelerated up and down just as your stomach feels changes during accelerations.

### Why do you believe?

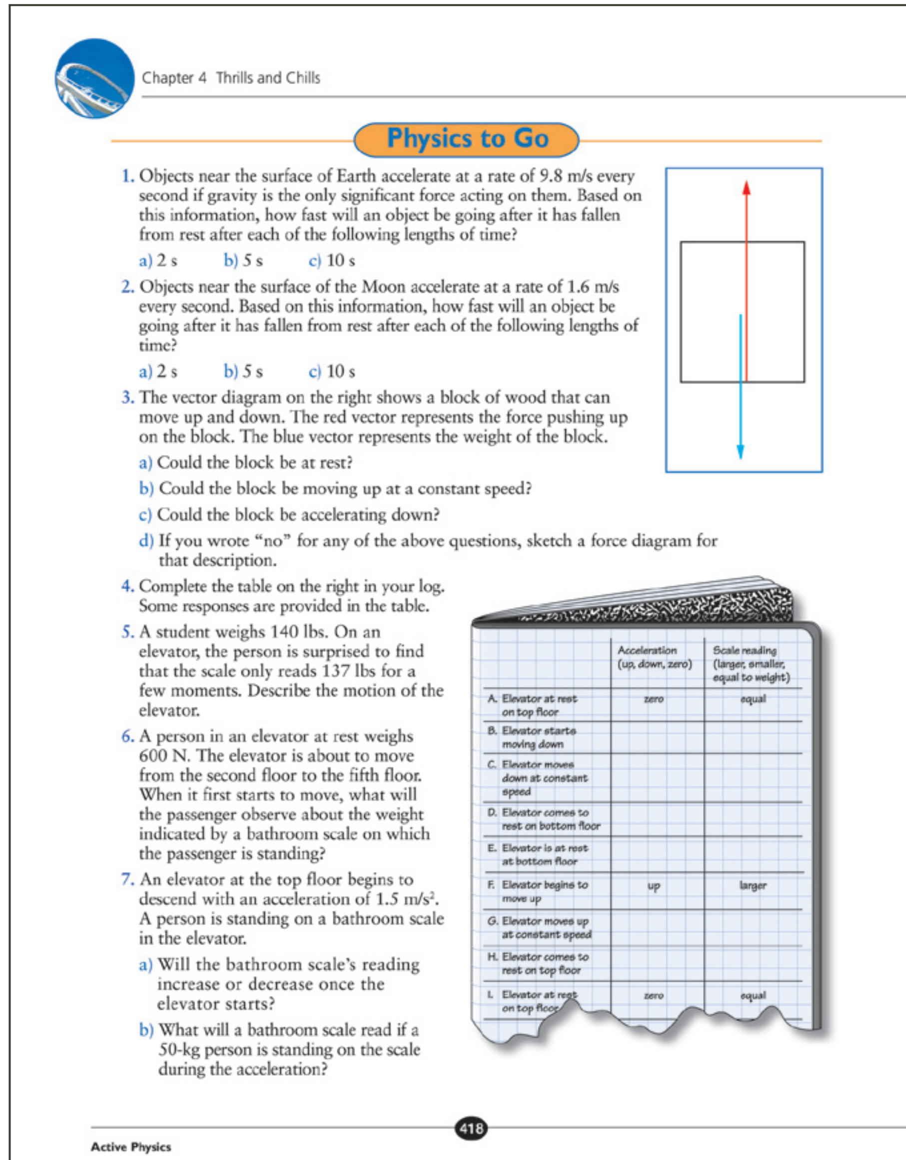
The force of gravity is always acting upon you. As you sit on a chair with no acceleration (whether you are at rest or moving with a constant velocity), the net force is zero and the normal force of the chair is equal to your weight. If you are accelerating up, the normal force on the chair will be larger than the force of gravity.

### Why should you care?

You will now be able to identify the net forces in all locations on the roller coaster where you experience accelerations.

## Reflecting on the Section and the Challenge

Ask students to reflect on how rollers coasters are different from elevators and how they are similar. Students should reflect on the problems that they have solved, in which they calculated the net force on an object when it moved up or down at constant acceleration or constant speed in an elevator. Point out that they need to focus on the velocity changes in roller coasters and modify the design of the roller coaster they have chosen for their target group. This is time for students to think about their *Chapter Challenge* and determine what they need to do meet the criteria of their *Goal*.



Chapter 4 Thrills and Chills

**Physics to Go**

1. Objects near the surface of Earth accelerate at a rate of 9.8 m/s every second if gravity is the only significant force acting on them. Based on this information, how fast will an object be going after it has fallen from rest after each of the following lengths of time?
   a) 2 s b) 5 s c) 10 s
2. Objects near the surface of the Moon accelerate at a rate of 1.6 m/s every second. Based on this information, how fast will an object be going after it has fallen from rest after each of the following lengths of time?
   a) 2 s b) 5 s c) 10 s
3. The vector diagram on the right shows a block of wood that can move up and down. The red vector represents the force pushing up on the block. The blue vector represents the weight of the block.
   a) Could the block be at rest?
   b) Could the block be moving up at a constant speed?
   c) Could the block be accelerating down?
   d) If you wrote "no" for any of the above questions, sketch a force diagram for that description.
4. Complete the table on the right in your log. Some responses are provided in the table.
5. A student weighs 140 lbs. On an elevator, the person is surprised to find that the scale only reads 137 lbs for a few moments. Describe the motion of the elevator.
6. A person in an elevator at rest weighs 600 N. The elevator is about to move from the second floor to the fifth floor. When it first starts to move, what will the passenger observe about the weight indicated by a bathroom scale on which the passenger is standing?
7. An elevator at the top floor begins to descend with an acceleration of 1.5 $m/s^2$. A person is standing on a bathroom scale in the elevator.
   a) Will the bathroom scale's reading increase or decrease once the elevator starts?
   b) What will a bathroom scale read if a 50-kg person is standing on the scale during the acceleration?

| | Acceleration (up, down, zero) | Scale reading (larger, smaller, equal to weight) |
|---|---|---|
| A. Elevator at rest on top floor | zero | equal |
| B. Elevator starts moving down | | |
| C. Elevator moves down at constant speed | | |
| D. Elevator comes to rest on bottom floor | | |
| E. Elevator is at rest at bottom floor | | |
| F. Elevator begins to move up | up | larger |
| G. Elevator moves up at constant speed | | |
| H. Elevator comes to rest on top floor | | |
| I. Elevator at rest on top floor | zero | equal |

418

Active Physics

## Physics to Go

### 1.a)

Given:

$g = 9.8\,\text{m/s}^2$

$v = at = (9.8\text{ m/s}^2)(2\text{ s}) = 19.6\text{ m/s} \approx 20\text{ m/s}$

### 1.b)

$v = at = (9.8\text{ m/s}^2)(5\text{ s}) = 49\text{ m/s} \approx 50\text{ m/s}$

### 1.c)

$v = at = (9.8\text{ m/s}^2)(10\text{ s}) = 98\text{ m/s} \approx 100\text{ m/s}$

### 2.a)

Given:

$g = 1.6\text{ m/s}^2$

$v = at = (1.6\text{ m/s}^2)(2\text{ s}) = 3.2\text{ m/s} \approx 3\text{ m/s}$

### 2.b)

$v = at = (1.6\text{ m/s}^2)(5\text{ s}) = 8.0\text{ m/s}$

### 2.c)

$v = at = (1.6\text{ m/s}^2)(10\text{ s}) = 16\text{ m/s} \approx 20\text{ m/s}$

### 3.a)

Because the upward (red) force is greater in magnitude than the downward (blue) force, the block could not be at rest.

### 3.b)

No, the block cannot be traveling at constant speed. Newton's first law states that for an object to be traveling at constant speed in a straight line, the net force must be zero. In this case, there is a net force in the upward direction.

**3.c)**

Because there is a net upward force, the block cannot be accelerating downward.

**3.d)**

For the description in *3.a)* and *b)*, the force diagram would need to have an upward force arrow equal to the magnitude of the downward force. For the description in *3.c)*, the force diagram would need to have a greater force in the downward direction.

**7.a)**

As the elevator begins to descend, the acceleration is down. The scale reading will decrease.

**7.b)**

Given:

$a = 1.5\ \text{m/s}^2$

Newton's second law $F_{net} = ma$

$\text{Weight} - (\text{force by spring}) = ma$

$(50.0\ \text{kg})(9.8\ \text{m/s}^2) - F_s =$

$(50.0\ \text{kg})(1.5\ \text{m/s}^2)$

$490\ \text{N} - F_s = 75\ \text{N}$

Solve for $F_s$

$F_s = 415\ \text{N}$

**4.**

| | Acceleration (up, down, zero) | Scale reading (larger, smaller, equal to weight) |
|---|---|---|
| A. Elevator at rest on top floor | zero | equal |
| B. Elevator starts moving down | down | smaller |
| C. Elevator moves down at constant speed | zero | equal |
| D. Elevator comes to rest on bottom floor | up | larger |
| E. Elevator is at rest on bottom floor | zero | equal |
| F. Elevator begins to move up | up | larger |
| G. Elevator moves up at constant speed | zero | equal |
| H. Elevator comes to rest on top floor | down | smaller |
| I. Elevator is at rest on top floor | zero | equal |

**5.**

The elevator is accelerating down. The spring scale force (the reading on the scale) is less than the student's weight.

**6.**

The acceleration will be up. The passenger will feel heavier and the scale will read a larger value.

NOTES

**8.a)**

Given:
$m = 50$ kg

The weight is taken as being in the positive direction (down) and the force of the scale (up) as negative.

Newton's second law $F_{net} = ma$

$\text{Weight} - (\text{force by spring}) = ma$

$(50.0 \text{ kg})(9.8 \text{ m/s}^2) - F_s =$

$(50.0 \text{ kg})(0 \text{ m/s}^2)$

$490 \text{ N} - F_s = 0 \text{ N}$

Solve for $F_s$

$F_s = 490$ N

**8.b)**

Given:
$a = 2 \text{ m/s}^2$

Acceleration is up, so it is negative.
Newton's second law $F_{net} = ma$

$\text{Weight} - (\text{force by spring}) = ma$

$(50.0 \text{ kg})(9.8 \text{ m/s}^2) - F_s =$

$(50.0 \text{ kg})(-2.0 \text{ m/s}^2)$

$490 \text{ N} - F_s = -100 \text{ N}$

Solve for $F_s$

$F_s = 590$ N

**8.c)**

Newton's second law $F_{net} = ma$

$\text{Weight} - (\text{force by spring}) = ma$

$(50.0 \text{ kg})(9.8 \text{ m/s}^2) - F_s =$

$(50.0 \text{ kg})(0 \text{ m/s}^2)$

$490 \text{ N} - F_s = 0 \text{ N}$

Solve for $F_s$

$F_s = 490$ N

**9.**

In the first diagram, there is no acceleration of the elevator and the forces are equal. The scale reading (the apparent weight) is 500 N.

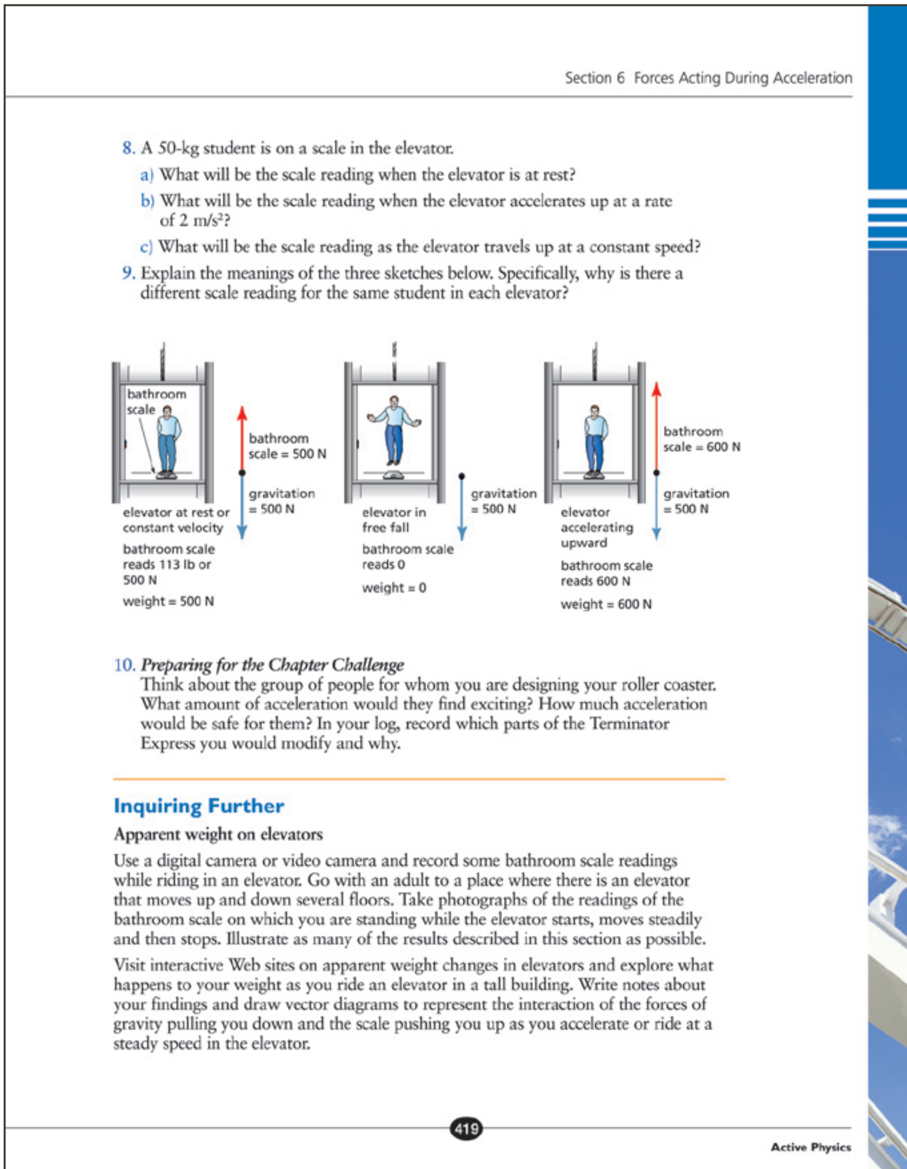
In the middle diagram, the elevator is in free fall. There is no force up. Therefore, the spring scale (that provides the force up) reads zero.

In the last diagram, the elevator is accelerating up. To have an upward acceleration, the scale must be providing a larger force up than in the first diagram. Therefore, the scale will read 600 N.

**10.**

***Preparing for the Chapter Challenge***

Students' answers will vary. Those that choose to make the roller coaster for thrill seekers will suggest aggressive, sharp turns, high velocities, loops, etc. This roller coaster will have the apparent weight of the riders increase and decrease dramatically. Students choosing a roller coaster for the less adventurous will suggest more moderate turns, lower speeds and smaller shifts in apparent weight.





8. A 50-kg student is on a scale in the elevator.
   a) What will be the scale reading when the elevator is at rest?
   b) What will be the scale reading when the elevator accelerates up at a rate of 2 m/s²?
   c) What will be the scale reading as the elevator travels up at a constant speed?
9. Explain the meanings of the three sketches below. Specifically, why is there a different scale reading for the same student in each elevator?



10. *Preparing for the Chapter Challenge*
    Think about the group of people for whom you are designing your roller coaster. What amount of acceleration would they find exciting? How much acceleration would be safe for them? In your log, record which parts of the Terminator Express you would modify and why.

**Inquiring Further**

**Apparent weight on elevators**

Use a digital camera or video camera and record some bathroom scale readings while riding in an elevator. Go with an adult to a place where there is an elevator that moves up and down several floors. Take photographs of the readings of the bathroom scale on which you are standing while the elevator starts, moves steadily and then stops. Illustrate as many of the results described in this section as possible.

Visit interactive Web sites on apparent weight changes in elevators and explore what happens to your weight as you ride an elevator in a tall building. Write notes about your findings and draw vector diagrams to represent the interaction of the forces of gravity pulling you down and the scale pushing you up as you accelerate or ride at a steady speed in the elevator.



## Inquiring Further

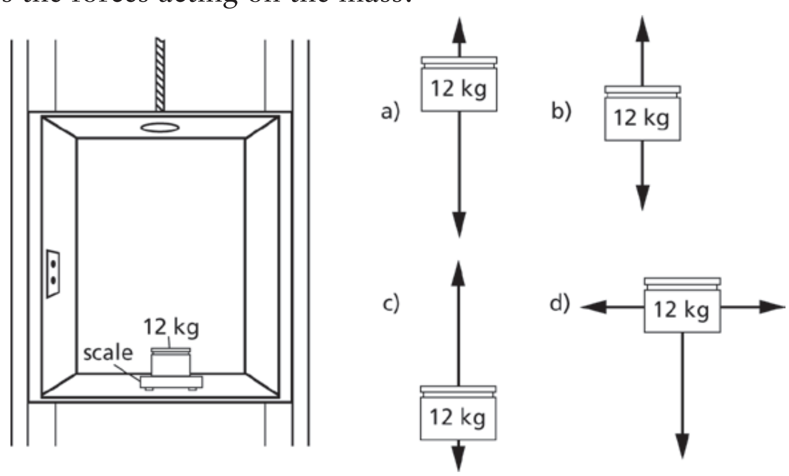
This is a student investigation. For best results, a high-speed elevator is recommended that will have a measurable acceleration for the starts and stops. Freight elevators generally do not meet this criterion, although slight changes in the scale are detectable. With a high-speed elevator, it is often surprising to the students that when the speed is maximum and constant, the scale reading is the same as when it is at rest. The digital camera or video camera can be used to record the readings on a bathroom scale while the elevator starts to move upward, while it is moving upward at constant velocity and while it comes to a stop. The student should correlate the acceleration of the elevator with the changes in the bathroom scale readings.

For this *Inquiring Further*, the students may have to search a bit to find the appropriate interactive physics site. Java applets are available on numerous sites on the Internet that allow students to test their knowledge of what is occurring during various physical situations. The students' diagrams for the site should look quite similar to those that they developed in the *Investigate* of this section. Similar pictures can be taken while the elevator moves downward.

# SECTION 6 QUIZ

**4-6b** **Blackline Master**

1. A mass of 12 kg is resting on a bathroom scale sitting in an elevator as shown in the diagram below. If the elevator is accelerating downward at 4 $m/s^2$, which force diagram correctly shows the forces acting on the mass?




2. In *Question 1*, what is the apparent weight of the 12-kg mass when the elevator is accelerating downward?

   a) 40 N    b) 48 N    c) 72 N    d) 120 N

3. A 750-N man is standing on a bathroom scale in an elevator. When the elevator is moving, the man notices that the scale is reading 780 N. Which statement below correctly describes the motion of the elevator?

   a) The elevator is moving upward with constant velocity.

   b) The elevator is moving upward with constant acceleration.

   c) The elevator is moving downward with constant velocity.

   d) The elevator is moving downward with constant acceleration.

4. A student is standing in an elevator while holding a spring scale that is attached to a 2-kg mass. The student notices that spring scale reads exactly 20 N. Which motion below is not possible for the elevator?

   a) The elevator is at rest.

   b) The elevator is travelling upward with constant velocity.

   c) The elevator is moving downward with constant velocity.

   d) The elevator is accelerating downward.

5. A woman is standing on a bathroom scale in an elevator that is accelerating upward at 1.5 $m/s^2$. The bathroom scale reads 600 N. What is the woman's mass?

   a) 75 kg    b) 90 kg    c) 52 kg    d) 48 kg

## SECTION 6 QUIZ ANSWERS

1. a) For the mass to accelerate downward, there must be a net force in the down direction, which is shown in diagram *a)*. Diagram *d)* is incorrect, since the scale would exert an upward force on the mass less than its weight, which is not shown. In addition, there would be no sideways force on the mass.

2. c) To find the apparent weight, use Newton's second law, $\Sigma F = ma$. The forces acting on the mass are the weight acting down $\left(F_w\right)$, and the scale pushing upward to provide a normal force $\left(F_N\right)$. The sum of the forces then is $\Sigma F = F_w - F_N = ma$. Solving for the normal force gives $mg - F_N = ma$ or $(12\text{ kg})(10\text{ m/s}^2) - F_N = (12\text{ kg})(4\text{ m/s}^2)$ or $F_N = 72\text{ N}$. The apparent weight is equal the normal force.

3. b) Since the upward force of the scale is greater than the downward force of the man's weight, the man has a net upward force acting on him, so the elevator must be accelerating upward.

4. d) The weight of a 2-kg mass is found using the equation $F_w = mg$, or $F_w = (2\text{ kg})(10\text{ m/s}^2) = 20\text{ N}$.
The force exerted by the spring scale upward is exactly equal to the downward force of the 2-kg weight. This means that the object cannot be accelerating in any direction. The object can either be travelling with constant velocity (either up or down) or at rest.

5. c) The apparent weight is equal to the normal force. Using Newton's second law, $\Sigma F = ma$. the forces acting on the woman are the weight acting down $\left(F_w\right)$, and the scale pushing upward to provide a normal force $\left(F_N\right)$. The sum of the forces then is $\Sigma F = F_N - F_w = ma$ which becomes $F_N - mg = ma$. Solving for the woman's mass gives $600\text{ N} - (m)(10\text{ m/s}^2) = (m)(1.5\text{ m/s}^2)$ or $m = 52\text{ kg}$.