SECTION 3

Newton's Second Law: Push or Pull

Section Overview

Students observe how acceleration is directly proportional to the force applied and inversely proportional to an object's mass. By applying a variable force to small and large masses, they obtain a kinesthetic feel for Newton's second law. The *Physics Talk* explains and defines Newton's second law. The use of the newton as a derived unit is emphasized by analyzing the equation for Newton's second law of motion. Students read about the importance of units and significant figures in measurements. Students explore applications of Newton's second law, particularly the force of gravity as a special case. Additionally, they explore scalar and vector quantities, and add forces acting in different directions to measure the resulting unbalanced force. Particular attention is given to the theory and application of significant figures when making experimental calculations.

Background Information

The unit of mass, or quantity of matter, in the International System of Units is the kilogram. One of seven base units from which all other units are derived, the kilogram originally was conceived as the quantity of matter represented by 1 L of water at the temperature of maximum density, 4°C. Today, the kilogram is defined by a carefully protected metal standard called the International Prototype Kilogram. When a balance which employs the force of gravity is used to measure the mass of an object by comparison to prototype masses, the resulting measurement is known as the "gravitational mass" of the object. Mass is also internationally recognized as a measure of the inertial resistance of an object to acceleration. When a standard force is used to compare an object's acceleration to the acceleration of a prototype mass as a means of measuring the mass of the object, the resulting measurement is known as the "inertial mass" of the object.

Extremely accurate measurements indicate that 1 kg of gravitationally determined mass is equivalent to 1 kg of inertial mass. A derived unit of force, the newton, is defined in terms of base units of mass, length, and time using Newton's second law of motion, $F = ma$. One newton is the force which will cause one kilogram to accelerate at one meter per second squared, or $1\ \text{N} = 1\ \text{kg} \cdot \text{m/s}^2$. The word "weight" denotes a force; the weight of an object is the product of its mass and a proportionality constant for objects on the surface of the Earth, 9.81 N/kg. Because weight is the force due to gravity, weight is measured in newtons. 1 N is roughly 1/4 lb, prompting the identification of the familiar 1/4 lb-burger as a "newton burger."

In summary, matter seems to have two distinct properties: it exhibits a resistance to acceleration (a property called "inertia") and it has the property of gravitation, which means that matter is attracted to other matter. All objects, no matter what their mass, have the same free-fall acceleration at a given location. The more mass, the more gravitational force; but the more mass, the more difficult it is to accelerate the object. These two factors exactly compensate to produce the same acceleration for every freely falling object at a given location. This acceleration is equal to the proportionality constant, 9.81 N/kg or 9.81 m/s^2, which is why this constant is often called "the acceleration due to gravity." By emphasizing that weight is equal to the mass times the proper proportionality constant, it will be easier for students to understand that the value of the proportionality constant depends on, for example, whether you are on Earth or the Moon. The acceleration of free-falling objects therefore also depends on whether you are on Earth or the Moon. Students who simply think of 9.81 m/s^2 as the acceleration due to gravity have little basis for understanding why this number is different on Earth and the Moon, because in their minds gravity is involved in both cases.

Crucial Physics

- Forces are "pushes" or "pulls" on an object. Forces on an object add as vectors and it is the total force or net force that determines the acceleration of the object.
- The total or net force on an object is related to its mass and acceleration by Newton's second law, $F = ma$.
- Weight is the force due to gravity on an object and is proportional to the object's mass. On the surface of Earth, the proportionality constant $g = 9.81$ N/kg, so $W = mg$.
- By Newton's second law, the acceleration of an object when the only force acting on it is gravity is $g = 9.81$ N/kg $= 9.81$ m/s^2.
- ***Active Physics Plus:*** Forces add as vectors.

Learning Outcomes	Location in the Section	Evidence of Understanding
Identify the forces on an object.	***Investigate, Physics Talk*** Steps 6-9	Students analyze the *Investigate* to identify forces on an object and learn the definition of a force.
Determine when the forces on an object are either balanced or unbalanced.	***Investigate, Physics Talk*** Steps 7-9	Students keep adding coins to the end of a ruler and learn how an unbalanced force causes the ruler to bend and the coins to drop.
Compare amounts of acceleration semi-quantitatively.	***Physics Talk, Physics to Go***	Students solve problems to compare how the amount of force applied affects acceleration.
Apply the definition of the newton as a unit of force.	***Physics Talk, Physics to Go*** Questions 3, 4, and 10-17	Students write the equivalent form of a newton and solve problems of acceleration and force using the newton as a unit of force.
Describe weight as the force due to gravity on an object.	***Physics Talk***	Students recall the experiment of the ruler and coins in the *Investigate* to describe weight.

Section 3 Materials, Preparation, and Safety

Materials and Equipment

PLAN A

Materials and Equipment	Group (4 students)	Class
Ruler, plastic, flexible, 30 cm	1 per group	
Cart, dynamics	1 per group	
Weights, slotted, set	1 per group	
C-clamp, steel, 3 in.	1 per group	
Tape, masking, 3/4 in. x 60 yds		6 per class
Access to a flat surface (such as a table, floor or other open space)*	1 per group	
Can or bottle (with less mass then the dynamics cart)*	1 per group	
Coins (pennies, nickels)*	5 per group	

*Additional items needed not supplied

PLAN B

Materials and Equipment	Group (4 students)	Class
Ruler, plastic, flexible, 30 cm	1 per group	
Cart, dynamics	1 per group	
Weights, slotted, set	1 per group	
C-clamp, steel, 3 in.	1 per group	
Tape, masking, 3/4 in. x 60 yds		6 per class
Access to a flat surface (such as a table, floor or other open space)*	1 per group	
Can or bottle (with less mass then the dynamics cart)*	1 per group	
Coins (pennies, nickels)*	5 per group	

*Additional items needed not supplied

Note: Time, Preparation, and Safety requirements are based on Plan A, if using Plan B, please adjust accordingly.

Time Requirement

To complete this requirement, one class period or 40 minutes are required.

Teacher Preparation

For best results, this *Investigate* should be done on a clear area of open floor.

Try to push the cart or can yourself with the ruler to maintain a constant force (bend of the ruler) to get a feel for how difficult this will be for the students. The students will often just give the cart a push to get it going over a short distance rather than chasing after the cart to maintain the force.

The students should discover that they must run faster and faster to keep up with the cart and maintain the same bend of the ruler. The chase is very important because it best demonstrates the acceleration that is taking place. If a large frictional force is present that causes the carts to travel with constant speed with the ruler bent, have the students use the bend of a large ruler until the cart or can accelerates.

If you are using carts, it is helpful if the cart has some additional mass on it for the first trial. When a “smaller” mass is required, mass may be removed from the cart, and later may be added to increase the cart’s mass.

Safety Requirements

Make certain that the area where the students will be pushing the carts is free from any obstructions.

Lab partners should watch for any potential problems where the students are pushing the carts so that the students my concentrate on keeping the ruler bent as they chase the cart.

Students should pick up the carts or cans from the floor and place them in a safe location immediately after finishing pushing to prevent anyone from slipping on them.

Meeting the Needs of All Students

Differentiated Instruction: Augmentation and Accommodations

Learning Issue	Reference	Augmentation and Accommodations
Describing motion qualitatively	***Investigate*** Steps 2-5	**Augmentation** • Assist students in brainstorming a list of words that could be used to describe motion (fast, slow, moderate speed, speeding up, slowing down, forward, etc.).
Creating a data table	***Investigate*** Step 5	**Augmentation** • Some students may struggle to create a table that includes all of the required information without seeing a sample. Tell students to decide in groups what kind of information needs to be recorded (object's name, relative mass, and motion). Then ask them how many columns and rows are needed. • Tell students to draw two vertical lines to divide their page into three equal sections. Remind them to record descriptions in the appropriate mass and motion columns, and ask them to make each row a few lines in height. • Pair the oral directions with a visual model of the data table. **Accommodation** • Give students a blank table to tape into their logs and complete.
Understanding qualitative vs. quantitative data	***Investigate***	**Augmentation** • Ask students if they know the meaning of *quantity*. Make an explicit connection between the words *quantity* and *quantitative*. Then ask students to help you create a list of quantities students can measure. Repeat this activity with *quality* and *qualitative*.
Understanding concepts of direct and inverse proportion	***Physics Talk*** ***Physics Essential Questions***	**Augmentation** • Students with reading-comprehension issues may not understand the written explanation. Show the students the relationship in a visual model while explaining the concept orally. Give clear and explicit explanations as in the examples below. • As force increases ($F \Uparrow$), what happens to the acceleration? Acceleration increases ($a\Uparrow$). This is a direct proportion. • This relationship can also be represented visually by increasing the font size of the variables. ($F \Rightarrow F$) causes ($a \Rightarrow a$) • As mass increases ($m\Uparrow$), what happens to acceleration? Acceleration decreases ($a\Downarrow$). This is an inverse proportion. • Provide direct instruction to draw the connection between these relationships to explain $a = F/m$.
Using the helpful circle	***Physics Talk***	**Augmentation** • Students may have forgotten how to use the helpful circle introduced in *Chapter 1*. Provide direct instruction and opportunities for guided practice to use/review the helpful circle.
Understanding key concepts	***Physics Talk***	**Augmentation** • Students with reading-comprehension issues may pass over the key concepts in this section. Students need to know that there are many kinds of forces and that unbalanced forces cause acceleration. • Ask students to brainstorm a list of forces with a partner. Then combine these lists into a class list. This *Investigate* will activate prior knowledge and also show the teacher if there are any misconceptions about kinds of forces. • Ask students if they can think of an example in which unbalanced forces cause acceleration.

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Learning Issue	Reference	Augmentation and Accommodations
Understanding the difference between mass and weight	***Physics Talk*** ***Inquiring Further***	**Augmentation** • The average person in society uses mass and weight interchangeably. These concepts can be very confusing. Ask students if they know the difference between mass and weight. Use adequate wait time to give everyone time to think about the answer. • Provide direct instruction to explain the difference. Give an example of the weight of a 1-kg mass on Earth versus the weight of a 1-kg mass on the Moon.
Solving word problems	***Physics to Go*** Questions 3-7, 15	**Augmentation** • Students with reading-comprehension, sequential, and executive-function issues may struggle to extract information from a word problem and follow the steps necessary to solve the problem. • Provide direct instruction to teach key words found in word problems, such as what is, how much, calculate, solve for, etc. • Model a think-aloud to make explicit the mental steps a good problem-solver takes to solve a problem. Pair the think-aloud with visual cues that show each step. **Accommodation** • Provide students with a sheet of blank problem-solving boxes.
Solving word problems that require unit conversions	***Physics Talk*** ***Physics to Go*** Question 14	**Augmentation** • Students with sequential-learning issues may need to see *Sample Problem 2* done as a two-step problem in which the conversion from grams to kilograms is done separately.
Understanding significant figures Using measurement in calculations	***Physics Talk***	**Augmentation** • Students with sequential-learning, executive-function, and attention issues may struggle to understand significant figures because they must follow a list of very specific rules. • Provide direct instruction to teach the rules for determining the number of significant figures. Keep a list of these rules posted in the classroom and provide students with a copy of these rules. • Provide opportunities for guided practice, during which students can receive feedback and ask questions.
Drawing free-body diagrams and finding resultant vectors	***Active Physics Plus*** ***Physics to Go*** Questions 10-13, 16-17	**Augmentation** • This is an opportunity to use differentiated instruction. Provide direct instruction to teach the explicit rules for drawing simple free-body diagrams that only include collinear forces. If students are able to find resultant vectors for collinear forces, introduce finding resultant vectors for forces using the Pythagorean theorem and then the tip-to-tail approach.
Copying tables	***Physics to Go,*** Question 1	**Accommodation** • Students with more significant graphomotor and visual-spatial issues struggle to copy written information accurately. Provide a copy of the table as it appears in the textbook. Then students can tape the table into their notebooks and complete the calculations.

Strategies for Students with Limited English-Language Proficiency

Learning Issue	Reference	Augmentation
Following complex procedures	***Investigate***	Break down the *Investigate* into smaller chunks that allow students to comprehend each portion of the experiment before moving on to the next one. This approach will allow students to get comfortable following the procedures outlined within each step, and also to internalize the new concepts that are introduced. Lead a brief class discussion after each step to allow students the opportunity to demonstrate acquired knowledge and understanding.
Understanding concepts	***Investigate*** Qualitative and Quantitative Observations	It is vital in science that students understand the difference between the similar words "qualitative" and "quantitative." Tell students that qualitative observations discuss the quality of an object by using adjectives to describe the object: green, rough, loud. Quantitative observations involve quantities, or amounts, and often (but not always) are represented with numbers: 89 kg, 47°C, 5.3 m/s.
Vocabulary comprehension	***Physics Talk***	To help all students, especially kinesthetic learners, understand that a force is a push or a pull, and to help ELL students learn the meanings of "push" and "pull," demonstrate the movements of push and pull with your hands and then have students make the movements with you.
Understanding concepts Vocabulary comprehension	***Physics Talk***	All students may need guidance when trying to understand Newton's second law in his own words. To explain the meaning of "impressed" in this context, say: "The root of 'impressed' is press. Pressing on an object is like pushing on the object. When you push on an object, you apply a force to the object. So the force impressed means the force applied." Also, explain that in Newton's time, "right line" meant "straight line." Right after working through Newton's words may be a good time to have students write Newton's second law in their *Active Physics* logs in their own words. You can read the logs to check understanding. Be sure students grasp "unbalanced force" and "inversely proportional."
Understanding concepts	***Physics Talk*** (Gravity, Mass, Weight, and Newton's Second Law)	Students learn that the force of gravity is applied downward on all objects. Be sure students do not think that gravity pushes on objects from above. Gravity is a pulling force from below; Earth pulls objects toward it. Note that the term "on" or "downward on" may confuse ELL students because "on" has a connotation of "on top of" or "from above." In physics, we say "the force on" to mean "the force applied to," regardless of direction. Explain that we can talk about the force of gravity "on" a cinder block, and we also talk about the force the cinder block exerts "on" something under it. Both forces are in the same direction—toward Earth—but you can feel the weight of the block as a push or a pull, depending on where you stand. If you hold a cinder block over your head, you feel it push down on your arms. (Your arms are between the block and Earth.) But if you pick the cinder block up from the ground, it pulls down on your arms. (The block is between your arms and Earth.)
Cooperative learning	***Active Physics Plus*** (Balanced and Unbalanced Forces)	Draw a series of free-body diagrams on the board. Have students work in groups to identify whether the forces in each diagram are balanced or whether there is a net force. If there is a net force, students need to indicate the direction of the net force.
Reading comprehension	***Active Physics Plus***	Collaborate with the students' math teachers to determine what level of comprehension students have obtained for right triangles, the Pythagorean theorem, and tangents.

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SECTION 3

Teaching Suggestions and Sample Answers

What Do You See?

Here is yet another skilled representation of how the net force on an object is directly proportional to its acceleration. The three contrasting visuals of the girl pushing the ball with a stick are meant to evoke a response to the different predicaments faced by the girl. Consider asking your students why the girl appears to be so relaxed at first, then puzzled, and eventually so exhausted. Write down responses on the board and highlight key words and phrases that will be used later in the section to develop concepts. Ask questions that initiate a discussion on force and acceleration. This is the time that students might reveal prior misconceptions. Each idea that students present is significant. Keep encouraging them as they discuss the illustration. Emphasize that they will be returning to the *What Do You See?* illustration to discuss how earlier responses get altered with a better understanding of the artist's purpose in relating the physics of a section.

What Do You Think?

The *What Do You Think?* questions are designed to stimulate thinking about the section. Have students share their answers and accept all answers without correction. Encourage them to think of a time when they went bowling or played tennis. Prompt them to think of how a tennis ball is different from a bowling ball in terms of weight. Consider asking them if they can think of how weight and applied force are related. Remind them that they will be returning to these questions later in the section after they have explored the concepts of force and acceleration in relation to weight.

What Do You Think?

A Physicist's Response

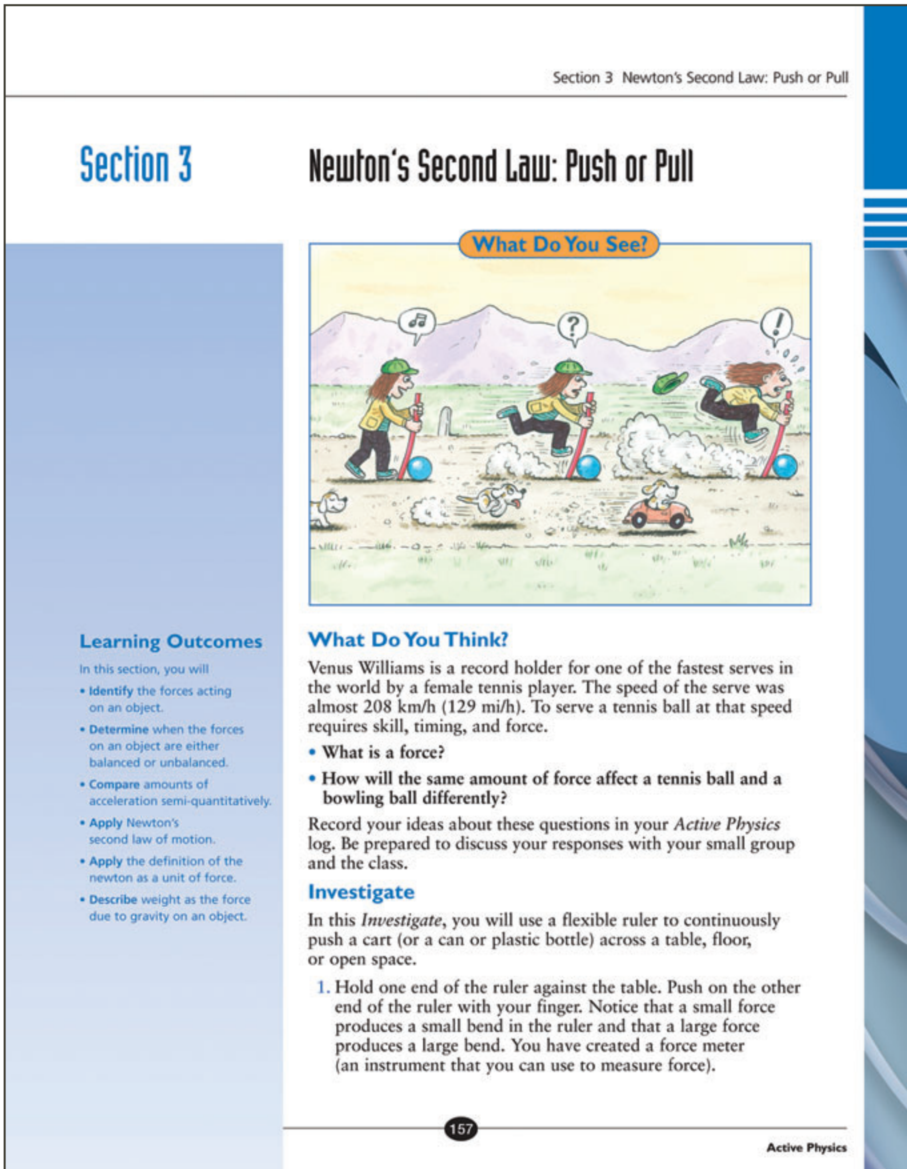
In simple terms, a force is a push or a pull. Some forces, such as gravitational and magnetic forces, can act on objects without having to be in contact with them. Many other forces, called mechanical forces, act when particles or objects touch each other. Forces are very important in physics because they determine how matter interacts with other matter.

The same force could be used to move both a bowling ball and a soccer ball, or even a table-tennis ball, as long as there is not much friction or other counteracting forces to interfere. The difference would be the amount by which each is accelerated by the force. The greater the mass, the lesser the acceleration experienced by an object when the same force is applied to it. Mass affects acceleration.

Students' Prior Conceptions

Students recognize that a force is a push or a pull. Forces have both magnitude and direction. When the forces acting on an object are unbalanced in one direction the object moves, either with acceleration or with steady motion, if the force applied equals the force of static friction. Students should grasp the meaning of Newton's second law to establish their foundation for the application of the laws of motion to all subsequent sections in the chapter. Some preconceptions are listed below:

1. **If an object is at rest, no forces are acting on the object.** It is necessary for students to identify all forces acting on an object so that they recognize balanced and unbalanced forces. Often, students overlook the forces acting in the vertical direction, for example, gravity pulling down on an object while the floor, chair, or table push up on the same object. Students might only consider the forces acting in the horizontal direction to affect motion in that direction.
2. **Only animate objects can exert a force.** Students have difficulty recognizing that all interactions involve equal forces acting in opposite directions on the separate interacting bodies. Thus, if an object is at rest on a table, students often say that there are no forces acting upon the object. Students need to identify all of the forces acting on an object, name the forces, discuss their directions, and identify their magnitudes, even if only relative to each other. Recognizing the nature of balanced and unbalanced forces acting on objects is paramount to learning how to apply Newton's second law to the interactions and motions of objects.



Section 3 Newton's Second Law: Push or Pull

Section 3 Newton's Second Law: Push or Pull

What Do You See?

Learning Outcomes

In this section, you will

- **Identify** the forces acting on an object.
- **Determine** when the forces on an object are either balanced or unbalanced.
- **Compare** amounts of acceleration semi-quantitatively.
- **Apply** Newton's second law of motion.
- **Apply** the definition of the newton as a unit of force.
- **Describe** weight as the force due to gravity on an object.

What Do You Think?

Venus Williams is a record holder for one of the fastest serves in the world by a female tennis player. The speed of the serve was almost 208 km/h (129 mi/h). To serve a tennis ball at that speed requires skill, timing, and force.

- **What is a force?**
- **How will the same amount of force affect a tennis ball and a bowling ball differently?**

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 *Investigate*, you will use a flexible ruler to continuously push a cart (or a can or plastic bottle) across a table, floor, or open space.

1. Hold one end of the ruler against the table. Push on the other end of the ruler with your finger. Notice that a small force produces a small bend in the ruler and that a large force produces a large bend. You have created a force meter (an instrument that you can use to measure force).

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Investigate

1.

Explain to the students that the ruler is behaving much like a spring. The bend of the ruler is indicative of the amount of force being applied in the same manner as the stretch of a spring indicates the amount of force. Although this force meter is not calibrated, the students will only be using it to obtain qualitative data on acceleration under an applied force.

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3. **Force is a property of an object rather than a relation between objects.** Students may believe that an object has force and when the force runs out the object stops moving. Focus student attention on the concept of inertial mass to recognize that matter moves or stays at rest depending upon the nature of the balanced or unbalanced forces acting upon the object with that amount of matter. More matter requires a larger force to give the same type of motion.
4. **Large objects exert a greater force than small objects.** Students need to understand that force is defined as the product of a mass with its acceleration. A large mass can have a small acceleration and a small force whereas a small mass can have a large acceleration and therefore a large force. The equal nature of pairs of forces in interactions is considered in subsequent activities.
5. **Gravity is a property of an object rather than a force experienced by the object; weight is not a force–rather, the air exerts the force; gravity requires a medium to act through; weight is something that can be "felt"; if an object has no weight then it cannot be "felt"; and mass may not be differentiated from weight.** It is important for students to explore the relationship between mass and weight to recognize that weight is the product of the mass of an object and the acceleration due to the pull of Earth or another larger object or celestial body on an object.

These prior conceptions emerge in subsequent activities, too, as students apply the laws of motion to falling objects.

2.

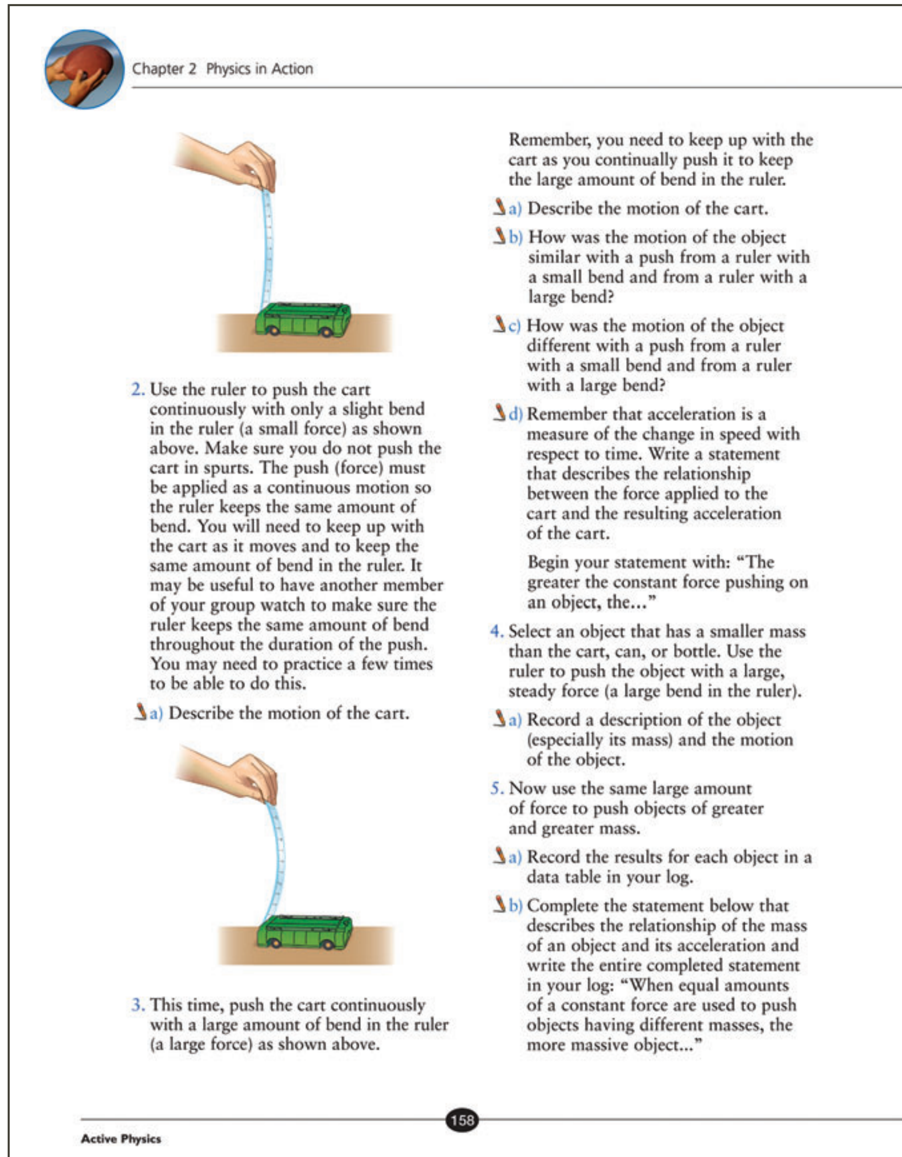
The students will have to accelerate as they chase the accelerating cart to maintain a constant bend in the ruler (a constant accelerating force).

2.a)

The students should indicate that the cart continually increases in speed as the force is applied. To make the acceleration more obvious to the students, have them apply the force to the cart while it is on the floor, so that the force can be maintained for a longer distance than a lab table, and the students will have to chase after the cart.

Teaching Tip

Try out the acceleration yourself first to determine if the students will have difficulty keeping up with the accelerating cart. If you determine that your carts accelerate too quickly for the students to effectively maintain a constant force, add mass to the cart to slow down the acceleration in these initial steps. Mass will also be added later to show the effect of increasing mass. If masses are added, they can be removed for *Step 4* to simplify that step.



Chapter 2 Physics in Action

2. Use the ruler to push the cart continuously with only a slight bend in the ruler (a small force) as shown above. Make sure you do not push the cart in spurts. The push (force) must be applied as a continuous motion so the ruler keeps the same amount of bend. You will need to keep up with the cart as it moves and to keep the same amount of bend in the ruler. It may be useful to have another member of your group watch to make sure the ruler keeps the same amount of bend throughout the duration of the push. You may need to practice a few times to be able to do this.

a) Describe the motion of the cart.

3. This time, push the cart continuously with a large amount of bend in the ruler (a large force) as shown above.

Remember, you need to keep up with the cart as you continually push it to keep the large amount of bend in the ruler.

a) Describe the motion of the cart.

b) How was the motion of the object similar with a push from a ruler with a small bend and from a ruler with a large bend?

c) How was the motion of the object different with a push from a ruler with a small bend and from a ruler with a large bend?

d) Remember that acceleration is a measure of the change in speed with respect to time. Write a statement that describes the relationship between the force applied to the cart and the resulting acceleration of the cart.

Begin your statement with: "The greater the constant force pushing on an object, the..."

4. Select an object that has a smaller mass than the cart, can, or bottle. Use the ruler to push the object with a large, steady force (a large bend in the ruler).

a) Record a description of the object (especially its mass) and the motion of the object.

5. Now use the same large amount of force to push objects of greater and greater mass.

a) Record the results for each object in a data table in your log.

b) Complete the statement below that describes the relationship of the mass of an object and its acceleration and write the entire completed statement in your log: "When equal amounts of a constant force are used to push objects having different masses, the more massive object..."

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The students should find they have difficulty keeping up with the cart, trying to maintain the constant larger bend in the ruler, as it accelerates at a greater rate.

3.a)

The cart accelerated in both trials.

3.b)

The students should note that the cart accelerates at a greater rate with a larger bend in the ruler (as it produces a larger force) than a smaller bend that produces a smaller force.

3.c)

The acceleration was greater in the second trial.

3.d)

"The greater the constant force pushing on an object, the greater the object's acceleration."

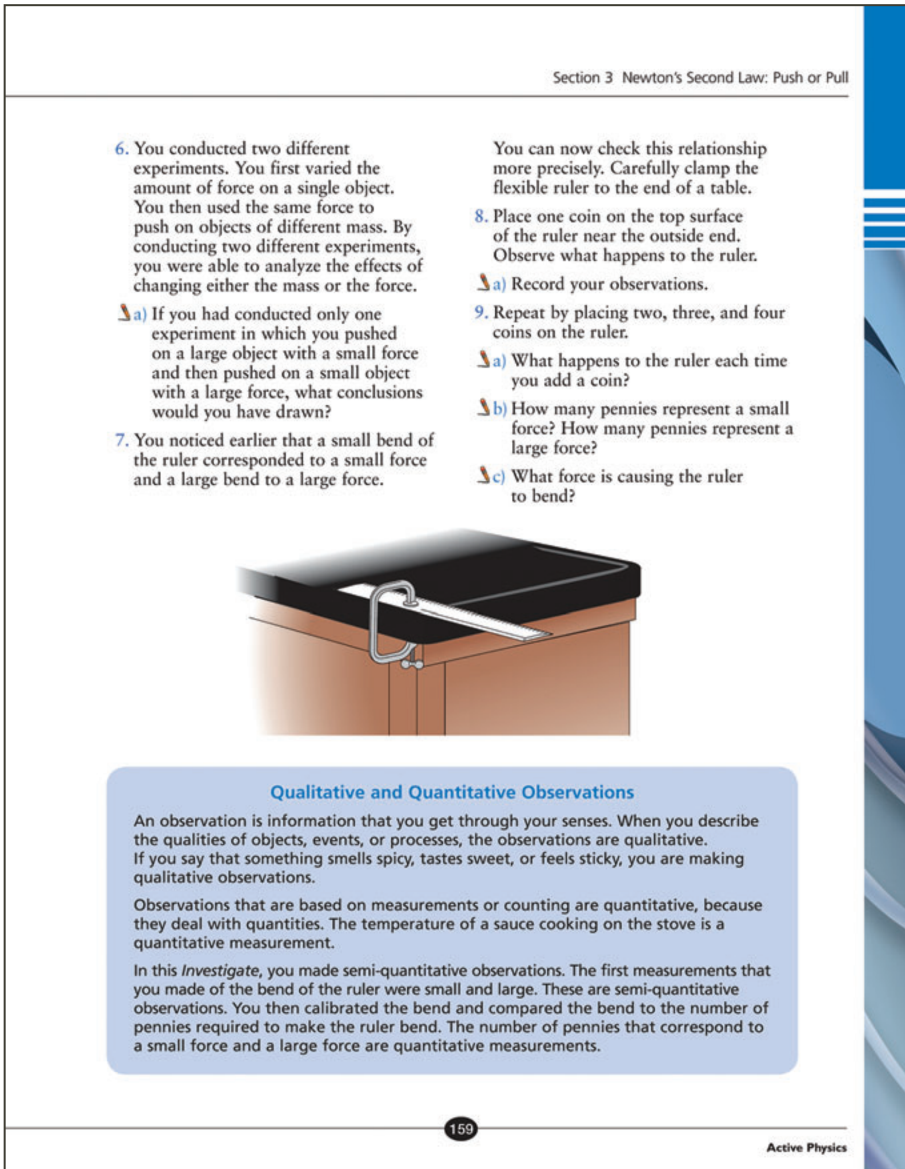
If the students used carts with masses for *Step 2*, they could remove the masses for this step. Otherwise use a smaller mass cart or object.

4.a)

The students should note that the large force on the smaller mass will give an acceleration greater than the previous trial with a large force.

5.a)

The students will see that as the mass becomes larger using the same force, the acceleration of the object will decrease.



Section 3 Newton's Second Law: Push or Pull

6. You conducted two different experiments. You first varied the amount of force on a single object. You then used the same force to push on objects of different mass. By conducting two different experiments, you were able to analyze the effects of changing either the mass or the force.

a) If you had conducted only one experiment in which you pushed on a large object with a small force and then pushed on a small object with a large force, what conclusions would you have drawn?

7. You noticed earlier that a small bend of the ruler corresponded to a small force and a large bend to a large force. You can now check this relationship more precisely. Carefully clamp the flexible ruler to the end of a table.

8. Place one coin on the top surface of the ruler near the outside end. Observe what happens to the ruler.

a) Record your observations.

9. Repeat by placing two, three, and four coins on the ruler.

a) What happens to the ruler each time you add a coin?

b) How many pennies represent a small force? How many pennies represent a large force?

c) What force is causing the ruler to bend?

Qualitative and Quantitative Observations

An observation is information that you get through your senses. When you describe the qualities of objects, events, or processes, the observations are qualitative. If you say that something smells spicy, tastes sweet, or feels sticky, you are making qualitative observations.

Observations that are based on measurements or counting are quantitative, because they deal with quantities. The temperature of a sauce cooking on the stove is a quantitative measurement.

In this *Investigate*, you made semi-quantitative observations. The first measurements that you made of the bend of the ruler were small and large. These are semi-quantitative observations. You then calibrated the bend and compared the bend to the number of pennies required to make the ruler bend. The number of pennies that correspond to a small force and a large force are quantitative measurements.

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5.b)

"When equal amounts of a constant force are used to push objects having different masses, the more massive object the less the acceleration of that object."

6.

The results of the student's experiments are the essence of Newton's second law.

6.a)

Pushing on a large object with a small force would have produced a small acceleration, and pushing on a small object with a large force would have produced a very large acceleration. The results of these two experiments might have led the students to the correct conclusion about the relationship between force and acceleration. However, they might equally conclude that large forces always mean large accelerations, and small forces always mean small accelerations, regardless of mass. If the experiment had been a large force on a large mass and a small force on a small mass, the conclusion would have been that all masses accelerate at the same rate!

7.

The ruler should be clamped with most of the ruler hanging over the edge of the table.

The coin may need a small piece of tape on the side touching the ruler to keep it from sliding off the ruler.

8.a)

The ruler bends under the weight of the coin.

9.a)

As more coins are added, the bend of the ruler increases.

9.b)

One or two coins would represent a small force, while four coins represent a large force.

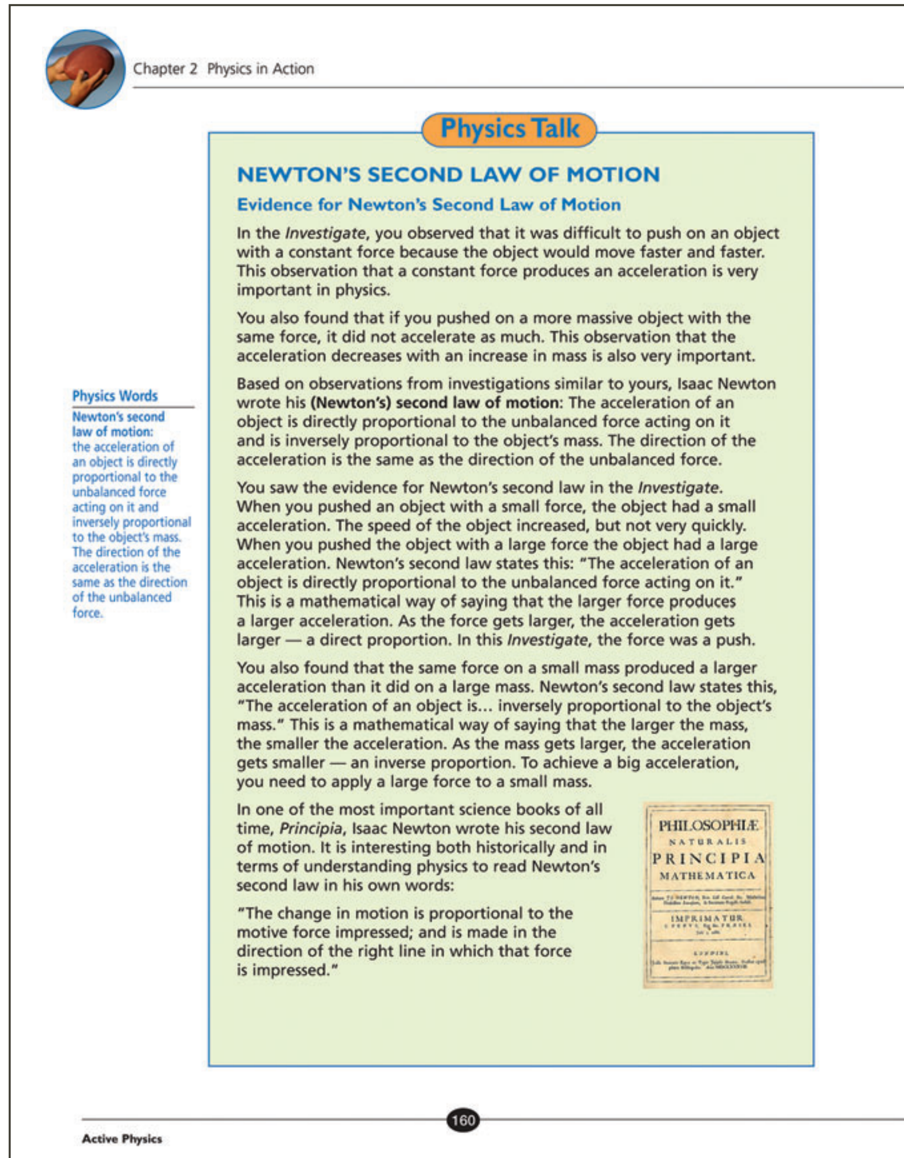
9.c)

In this case it is the weight of the coins causing the bend, rather than the force applied by the hand. You might want to point out to the students that equal bends in the ruler imply that equal forces are needed.

CHAPTER 2

Physics Talk

This *Physics Talk* explores Newton's second law of motion qualitatively as well as quantitatively. It would be useful to the students to make connections with the different steps in their *Investigate* and see how each step can be explained through their reading of the *Physics Talk*. To check for student understanding, have students summarize the findings of their *Investigate* as evidence for Newton's second law. Emphasize that an unbalanced force is needed for an object to accelerate, and that although a force may be acting, if it is not unbalanced, the object will not accelerate. In addition, point out that the force of gravity or weight is really only a special case of Newton's second law, where it is the ratio of force to mass that gives the constant acceleration we call "*g*." As students learn about force, make sure they also understand the meaning of derived units. You might want to ask them where they have used these before. You could also ask them to write and discuss the units of force and weight and illustrate Newton's second law with diagrams. While students are working through the sample problems, have them discuss the solution of each problem with their peers. To verify whether students are comfortable determining significant figures in a measurement, ask them to give a few examples of significant figures in their logs. Doing several sample calculations using measurements with different numbers of significant figures will improve their understanding of the role of significant figures in science.


Chapter 2 Physics in Action

Physics Talk

NEWTON'S SECOND LAW OF MOTION

Evidence for Newton's Second Law of Motion

In the *Investigate*, you observed that it was difficult to push on an object with a constant force because the object would move faster and faster. This observation that a constant force produces an acceleration is very important in physics.

You also found that if you pushed on a more massive object with the same force, it did not accelerate as much. This observation that the acceleration decreases with an increase in mass is also very important.

Based on observations from investigations similar to yours, Isaac Newton wrote his **(Newton's) second law of motion**: The acceleration of an object is directly proportional to the unbalanced force acting on it and is inversely proportional to the object's mass. The direction of the acceleration is the same as the direction of the unbalanced force.

Physics Words

Newton's second law of motion: the acceleration of an object is directly proportional to the unbalanced force acting on it and inversely proportional to the object's mass. The direction of the acceleration is the same as the direction of the unbalanced force.

You saw the evidence for Newton's second law in the *Investigate*. When you pushed an object with a small force, the object had a small acceleration. The speed of the object increased, but not very quickly. When you pushed the object with a large force the object had a large acceleration. Newton's second law states this: "The acceleration of an object is directly proportional to the unbalanced force acting on it." This is a mathematical way of saying that the larger force produces a larger acceleration. As the force gets larger, the acceleration gets larger — a direct proportion. In this *Investigate*, the force was a push.

You also found that the same force on a small mass produced a larger acceleration than it did on a large mass. Newton's second law states this, "The acceleration of an object is... inversely proportional to the object's mass." This is a mathematical way of saying that the larger the mass, the smaller the acceleration. As the mass gets larger, the acceleration gets smaller — an inverse proportion. To achieve a big acceleration, you need to apply a large force to a small mass.

In one of the most important science books of all time, *Principia*, Isaac Newton wrote his second law of motion. It is interesting both historically and in terms of understanding physics to read Newton's second law in his own words:

"The change in motion is proportional to the motive force impressed; and is made in the direction of the right line in which that force is impressed."

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Active Physics

Section 3 Newton's Second Law: Push or Pull

An Equation for Newton's Second Law of Motion

Newton's second law can be written as an equation:

$$\text{Acceleration} = \frac{\text{force}}{\text{mass}}$$

$$a = \frac{F}{m}$$

where a is acceleration expressed in meters per second squared (m/s²),

F is force expressed in newtons (N), and

m is mass expressed in kilograms (kg).

With a bit of algebra, Newton's second law can be arranged so that it is easier to find the unknown quantity of F, m, or a.

$$a = \frac{F}{m} \qquad F = ma \qquad m = \frac{F}{a}$$

Some students like to use a helpful circle:

If you want to find:

- force, F, cover it up and you see m next to a (or $F = m \times a$).
- acceleration, a, cover it up and you see F over m (or $a = F \div m$).
- mass, m, cover it up and you see F over a (or $m = F \div a$).

Newton: A Derived SI Unit with a Special Name

When you measured speed and acceleration, you used derived units with compound names. You measured speed in meters per second (symbol, m/s) and acceleration in meters per second per second, or meters per second squared (symbol, (m/s)/s or m/s²). These are derived units. They are made up of one or more base SI units.

In the equation for Newton's second law, force is expressed in newtons (symbol, N). What is a newton? A newton is a derived SI unit with a special name. A newton is the force required to make one kilogram of mass accelerate at one meter per second squared.

CHAPTER 2

Chapter 2 Physics in Action

With this definition, the unit newton can be written in its equivalent form: 1 kg • m/s^2.

$$1\ \text{N} = 1\ \text{kg} \cdot \text{m/s}^2$$

Knowing the equivalent form for a newton will be important when using Newton's second law to do calculations to find mass and acceleration. Mathematically, the dot represents multiplication.

$$1\ \text{kg} \cdot \text{m/s}^2 \text{ means } 1\ \text{kg} \times \frac{\text{m}}{\text{s}^2} \text{ or } 1\ \text{kg} \times \frac{\text{m}}{\text{s} \times \text{s}}$$

Where There's Acceleration, There Must Be an Unbalanced Force

There are lots of different everyday forces. There is the force of the bent ruler in this investigation. There is also the force of a spring, the force of a rubber band, the force of a magnet, the force of your hand, the force of a bat hitting a ball, the force of friction, the buoyant force of water, and many more. Newton's second law tells you that accelerations are caused by unbalanced forces. It does not matter what kind of force it is or how it originates. If you observe an acceleration (a change in velocity), then there must be an unbalanced force causing the acceleration. When you apply a force to an object that has a small mass, the acceleration may be quite large. If the object has a large mass, the acceleration will be smaller for the same force. Occasionally, the mass is so large that you cannot measure the acceleration because it is so small.

If you push on a small cart with the largest force you can, the cart will accelerate a great deal. If you push on a car with that same force, the acceleration will be much smaller. If you were to push on a truck, the acceleration would be too small to measure. Can you convince someone that a push on a truck accelerates the truck? Why should you believe something that you cannot measure? If you were to assume that the truck does not accelerate when you push on it, then you would have to believe that Newton's second law stops working when the mass gets too big. If that were so, you would want to determine how big is "too big." When you conduct such experiments, you find that the acceleration gets less and less as the mass gets larger and larger. Eventually, the acceleration gets so small that it is difficult to measure. Your inability to measure it does not mean that it is zero. It just means that it is smaller than your best measurement. In this way, you can assume that Newton's second law is always valid.

Section 3 Newton's Second Law: Push or Pull

Calculations Using Newton's Second Law of Motion

Since Newton's second law relates force, mass, and acceleration, you can use the equations for Newton's second law to solve a variety of problems.

Sample Problem I

As the result of a serve, a tennis ball (m_t = 58 g) accelerates at 430 m/s^2 for the very brief time it is in contact with the racket.

a) What force is responsible for this acceleration?

b) Could an identical force accelerate a 5.0-kg bowling ball at the same rate?

Strategy: Newton's second law states that the acceleration of an object is directly proportional to the applied force and inversely proportional to the mass ($F = ma$).

Given:

$a = 430\ \text{m/s}^2$

$m_t = 58\ \text{g} = 0.058\ \text{kg}$

$m_b = 5.0\ \text{kg}$

Solution:

a) $F = m_t a$

$= (0.058\ \text{kg})(430\ \text{m/s}^2)$

$= 24.94\ \text{kg} \cdot \text{m/s}^2$ or $25\ \text{kg} \cdot \text{m/s}^2$

$= 25\ \text{N}$

Recall that $1\ \text{N} = 1\ \text{kg} \cdot \text{m/s}^2$

b) Since the mass of the bowling ball has a much greater mass than the tennis ball, an identical force will result in a smaller acceleration. (You can calculate the acceleration.)

$$a = \frac{F}{m_b}$$

$$= \frac{25\ \text{N}}{5.0\ \text{kg}}$$

$$= \frac{25\ \cancel{\text{kg}} \cdot \text{m/s}^2}{5.0\ \cancel{\text{kg}}}$$

$$= 0.5\ \text{m/s}^2$$

This is much smaller than the acceleration of the tennis ball.

Calculations and Units

In physics, when you do calculations, it is very important to pay close attention to the units in your answer. Notice how in the calculation above you can write the unit N as kg • m/s^2. Then the units kg in the top and bottom of the equation cancel out, leaving m/s^2, the unit for acceleration that you need for your answer.

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Active Physics

CHAPTER 2

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Sample Problem 2

A tennis racket hits a sand-filled tennis ball with a force of 4.0 N. While the 275-g ball is in contact with the racket, what is its acceleration? (Notice that here "g" stands for grams of mass. You have to really pay attention in physics!)

Strategy: Newton's second law relates the force acting on an object, the mass of the object, and the acceleration given to it by the force. Use the form of the equation that solves for acceleration. The force unit, the newton, is defined as the amount of force needed to give a mass of 1.0 kg an acceleration of 1.0 m/s². Therefore, you will need to change the grams to kilograms.

Given:

$F = 4.0 \text{ N}$

$m = 275 \text{ g}$

Remember: 1000 g equals 1 kg

Solution:

$$m = (275 \text{ g})\left(\frac{1 \text{ kg}}{1000 \text{ g}}\right)$$

$$m = 0.275 \text{ kg}$$

$$a = \frac{F}{m}$$

$$= \frac{4.0 \text{ N}}{0.275 \text{ kg}}$$

$$= \frac{4.0 \cancel{\text{kg}} \cdot \text{m/s}^2}{0.275 \cancel{\text{kg}}}$$

$$= 14.5 \text{ m/s}^2$$

Using Measurements in Calculations

When you perform calculations using measurements, you need to express the result of your calculations in a way that makes sense of the precision of the measurements you used. You must look at the number of significant figures (or digits) in the number. The number of significant figures represents how carefully, and with what level of accuracy or precision, the measurement was taken. A calculation will never add significant figures. If one value from measurements has two significant figures and all your other values were from more precise measurements and had four significant figures, your calculation using these values can have no more than two significant figures.

Section 3 Newton's Second Law: Push or Pull

Determining the Number of Significant Figures in a Measurement

There are guidelines that you can use to determine the number of significant figures in a measurement.

All nonzero numbers are considered to be significant figures. In the measurement 152.5 m, all the digits are significant. The measurement has four significant figures.

Zeros may or may not be significant, depending on their place in a number.

- A zero between nonzero digits is a significant figure. In the measurement 308 g, the zero is significant. The measurement has three significant figures.
- A zero at the end of a decimal number is considered significant. In the measurement 1.50 N, the zero is significant. The measurement has three significant figures.
- A zero at the beginning of a decimal number is not significant. In the measurement 0.023 kg, the zeros are not significant. The measurement has two significant figures.
- In a large number without a decimal point, the zeros are not significant. In the measurement 2000 kg, the zeros are not significant. The measurement has one significant figure.

Significant Figures in Calculations

There are also guidelines that you can use when making your calculations.

Adding and Subtracting

When adding or subtracting, the final result should have the same number of decimal places as the measurement with the fewest decimal places.

Multiplying and Dividing

When multiplying or dividing, the result should have no more significant digits than the factor having the fewest number of significant digits.

CHAPTER 2

Gravity, Mass, Weight, and Newton's Second Law

In the *Investigate*, you observed another type of force — the force of gravity. As you added coins to the ruler attached to the end of the table, the ruler began to bend. Earlier, you saw the ruler bend when you applied a force from your arm to push the cart. You know that if you observe the ruler bending there must be a force acting. When you drop a ball, you notice that it accelerates to the floor. Newton's second law informs you that if there is an acceleration, there must be an unbalanced force acting.

In both cases, you cannot see the force, but you know it is there from the observations you make. In the case of the force bending the ruler, this is the force due to gravity.

You know that if you apply a force of 1.0 N to a 1.0-kg mass, the mass will accelerate at a rate of 1.0 m/s². That means that if you observe a 1.0-kg mass accelerate at 1.0 m/s², there must be a 1.0 N force acting on it.

If you drop a 1.0-kg mass on Earth, you will observe that the mass accelerates toward Earth at 9.8 m/s². That means that there must be a force of 9.8 N acting downward on the mass. This is the force of gravity acting on the mass. You will have an opportunity to measure the acceleration due to gravity yourself in a later section.

Physics Words

weight: the vertical, downward force exerted on a mass as a result of gravity.

If you put a backpack on your back, you can feel the force you must exert so that the pack does not fall to the ground due to the force of gravity. This force of gravity on the backpack is also called its weight. **Weight** is the force of gravity acting on an object, and it depends on the mass of the object and the acceleration due to gravity.

Using Newton's second law, you can calculate the weight of an object.

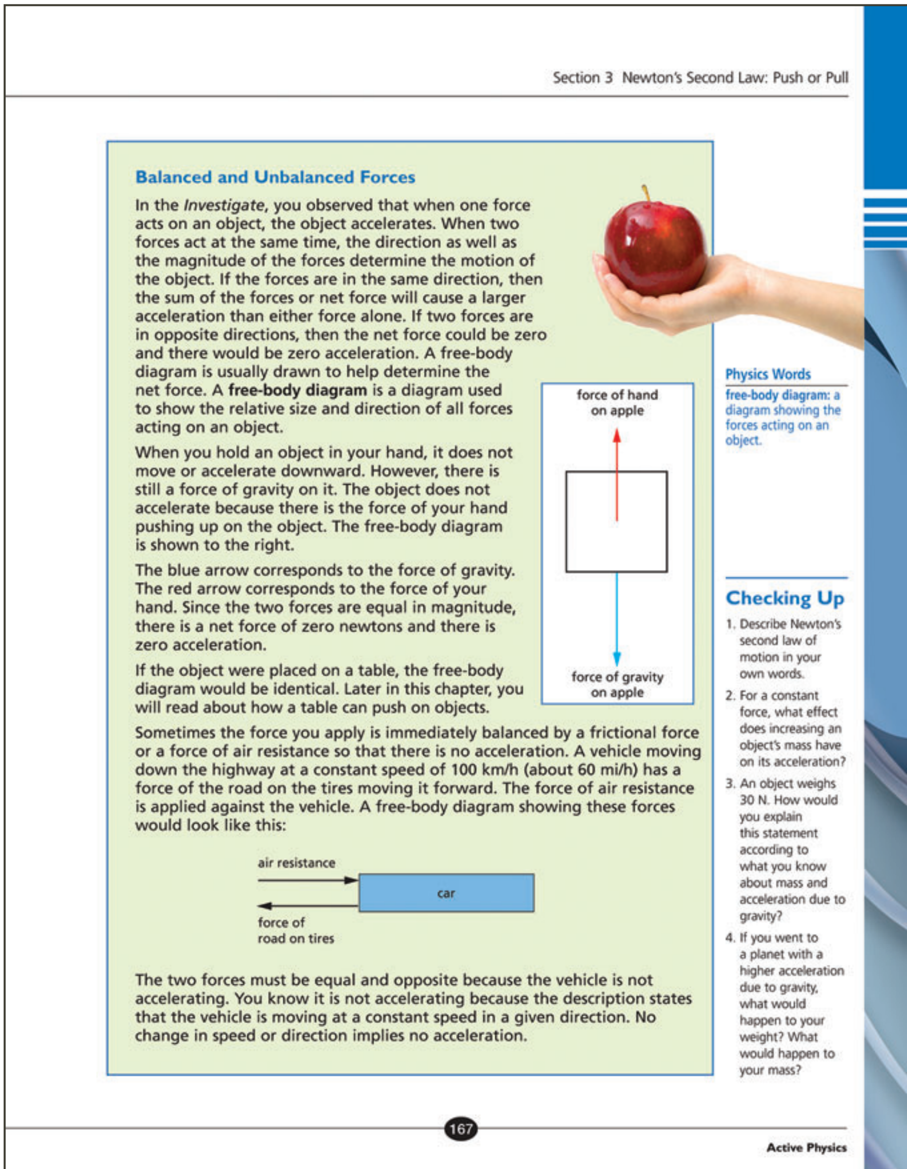
$$F_{gravity} = ma_{gravity}$$

$$w = mg$$

where w is the weight (by definition, the force of gravity),

m is the mass in kilograms, and

g is the acceleration due to gravity (9.8 m/s²)



Balanced and Unbalanced Forces

In the *Investigate*, you observed that when one force acts on an object, the object accelerates. When two forces act at the same time, the direction as well as the magnitude of the forces determine the motion of the object. If the forces are in the same direction, then the sum of the forces or net force will cause a larger acceleration than either force alone. If two forces are in opposite directions, then the net force could be zero and there would be zero acceleration. A free-body diagram is usually drawn to help determine the net force. A **free-body diagram** is a diagram used to show the relative size and direction of all forces acting on an object.

When you hold an object in your hand, it does not move or accelerate downward. However, there is still a force of gravity on it. The object does not accelerate because there is the force of your hand pushing up on the object. The free-body diagram is shown to the right.

The blue arrow corresponds to the force of gravity. The red arrow corresponds to the force of your hand. Since the two forces are equal in magnitude, there is a net force of zero newtons and there is zero acceleration.

If the object were placed on a table, the free-body diagram would be identical. Later in this chapter, you will read about how a table can push on objects.

Sometimes the force you apply is immediately balanced by a frictional force or a force of air resistance so that there is no acceleration. A vehicle moving down the highway at a constant speed of 100 km/h (about 60 mi/h) has a force of the road on the tires moving it forward. The force of air resistance is applied against the vehicle. A free-body diagram showing these forces would look like this:

The two forces must be equal and opposite because the vehicle is not accelerating. You know it is not accelerating because the description states that the vehicle is moving at a constant speed in a given direction. No change in speed or direction implies no acceleration.

Physics Words

free-body diagram: a diagram showing the forces acting on an object.

Checking Up

1. Describe Newton's second law of motion in your own words.
2. For a constant force, what effect does increasing an object's mass have on its acceleration?
3. An object weighs 30 N. How would you explain this statement according to what you know about mass and acceleration due to gravity?
4. If you went to a planet with a higher acceleration due to gravity, what would happen to your weight? What would happen to your mass?

Checking Up

1.

When an unbalanced force acts on an object, the acceleration of the object is directly proportional to the magnitude of the force and occurs in the same direction that force was applied.

2.

For a constant force, increasing the mass of an object will reduce its acceleration.

3.

The statement means that there will be a force of 30 N acting downward on the mass due to force of Earth's gravity.

4.

Your weight would increase while your mass would remain the same.

2-3a **Blackline Master**

Active Physics Plus

Encourage your students to draw vectors showing the direction of unbalanced forces. Having them define scalar and vector quantities in their logs will help reinforce their learning. To provide a visual focus, drawing examples of vectors on the board will help students to see how two forces create a net resultant force.

Active Physics **Plus**

+Math	+Depth	+Concepts	+Exploration
◆◆	◆		

Adding Vectors

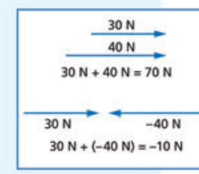
Many of the numbers you use every day are scalars. Scalars are numbers defining quantities that do not have any specific direction associated with them. They only have sizes or magnitudes. Some examples of scalars include temperature, prices, time, mass, lengths, and widths.

Unlike a scalar quantity, a vector is a quantity that has both magnitude and direction. The velocity of an object is a vector. Its magnitude is the speed of the object and its direction is the direction the object is moving.

Force is also a vector because you can measure how big it is (its magnitude) and its direction. Acceleration is also a vector. Newton's second law reminds you that the force and the acceleration must be in the same direction. Mass is not a vector — it has no direction associated with it, so it is a scalar. Weight, however, is a force and does have direction associated with it. All forces are vectors. The direction of the weight vector is down (toward the center of Earth).

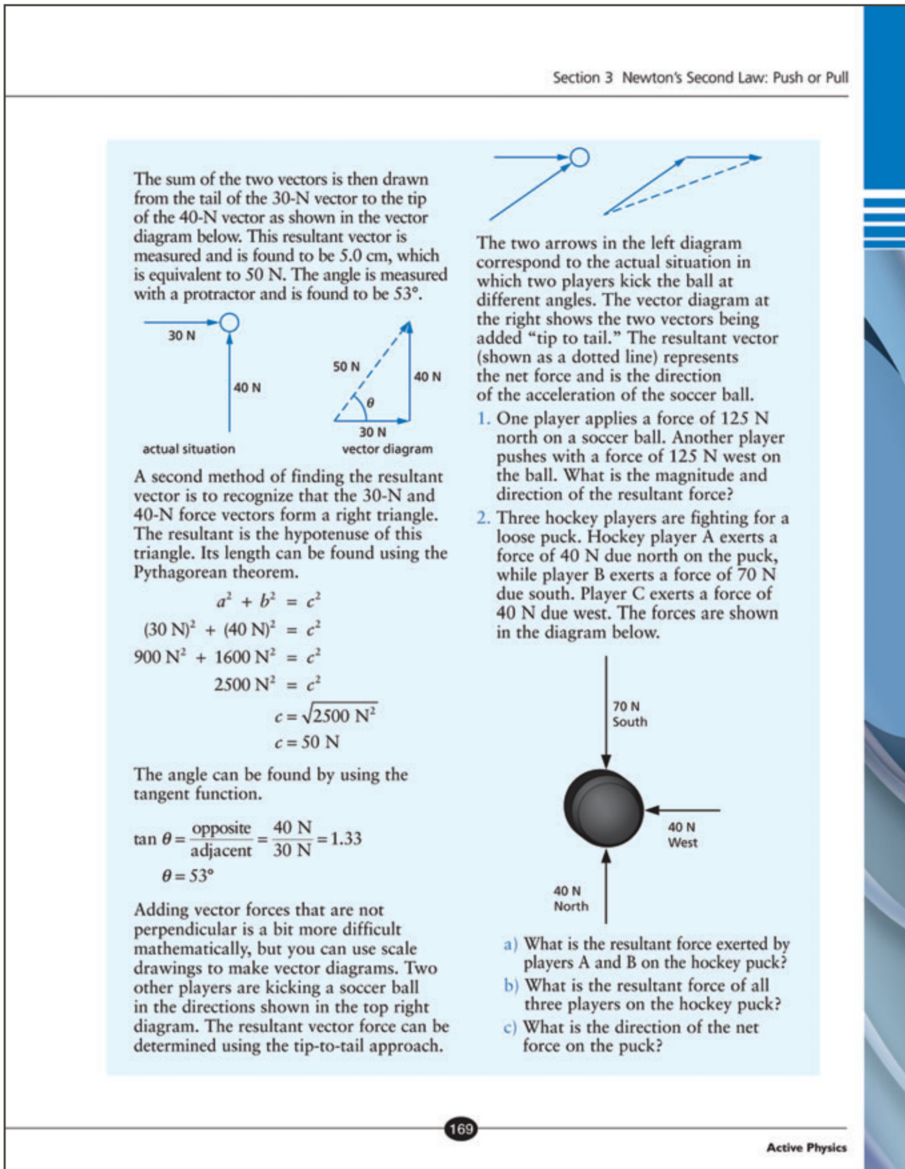
Often, more than one force acts on an object. If the two forces are in the same direction, the sum of the forces is simply the algebraic addition of the two forces. A 30-N force by one person and a force of 40 N by a second person (pushing in the same direction) on the same desk provide a 70-N force on the desk. If the two forces are in opposite directions, then you give one of the forces a negative value and one a positive value to show that they act opposite to each other. Then you add them algebraically.

If one student pushes on a desk to the right with a force of 30 N and a second student pushes on the same desk to the left with a force of 40 N, the net force on the desk (also called the total force or the unbalanced force) will be 10 N to the left. Mathematically, you would state that 30 N + (– 40 N) = – 10 N where the negative sign denotes "to the left." Choosing left as the negative direction is an arbitrary choice.



Occasionally, the two forces acting on an object are at right angles. For instance, one student may be kicking a soccer ball with a force of 30 N ahead toward the goal, while the second student kicks the same soccer ball with a force of 40 N toward the sideline. To find the net force on the ball and the direction the ball accelerates, you must use vector addition. You can do this by using a vector diagram or the Pythagorean theorem.

In the actual situation shown on the next page, the two force vectors are shown as arrows acting on the soccer ball. The magnitudes of the vectors are drawn to scale. If you were to draw this using the scale that 10 N = 1.0 cm, then the 30-N force would be 3.0 cm long and the 40-N force would be 4.0 cm long. To add the vectors, slide them so that the tip of the 30-N vector can be placed next to the tail of the 40-N vector (tip to tail method).



The sum of the two vectors is then drawn from the tail of the 30-N vector to the tip of the 40-N vector as shown in the vector diagram below. This resultant vector is measured and is found to be 5.0 cm, which is equivalent to 50 N. The angle is measured with a protractor and is found to be 53°.

A second method of finding the resultant vector is to recognize that the 30-N and 40-N force vectors form a right triangle. The resultant is the hypotenuse of this triangle. Its length can be found using the Pythagorean theorem.

$$a^2 + b^2 = c^2$$
$$(30\ \text{N})^2 + (40\ \text{N})^2 = c^2$$
$$900\ \text{N}^2 + 1600\ \text{N}^2 = c^2$$
$$2500\ \text{N}^2 = c^2$$
$$c = \sqrt{2500\ \text{N}^2}$$
$$c = 50\ \text{N}$$

The angle can be found by using the tangent function.

$$\tan\theta = \frac{\text{opposite}}{\text{adjacent}} = \frac{40\ \text{N}}{30\ \text{N}} = 1.33$$
$$\theta = 53°$$

Adding vector forces that are not perpendicular is a bit more difficult mathematically, but you can use scale drawings to make vector diagrams. Two other players are kicking a soccer ball in the directions shown in the top right diagram. The resultant vector force can be determined using the tip-to-tail approach.

The two arrows in the left diagram correspond to the actual situation in which two players kick the ball at different angles. The vector diagram at the right shows the two vectors being added "tip to tail." The resultant vector (shown as a dotted line) represents the net force and is the direction of the acceleration of the soccer ball.

1. One player applies a force of 125 N north on a soccer ball. Another player pushes with a force of 125 N west on the ball. What is the magnitude and direction of the resultant force?
2. Three hockey players are fighting for a loose puck. Hockey player A exerts a force of 40 N due north on the puck, while player B exerts a force of 70 N due south. Player C exerts a force of 40 N due west. The forces are shown in the diagram below.

a) What is the resultant force exerted by players A and B on the hockey puck?
b) What is the resultant force of all three players on the hockey puck?
c) What is the direction of the net force on the puck?

1.

Given:

$a = b = 125$ N

Solution:

Using the Pythagorean theorem, the resultant would be determined by the formula

$$a^2 + b^2 = c^2$$

$$(125\ \text{N})^2 + (125\ \text{N})^2 = c^2$$

$$c = \sqrt{(125\ \text{N})^2 + (125\ \text{N})^2} = 177\ \text{N}$$

To find the direction use tan

θ= opposite/adjacent =

$(125\ \text{N})/(125\ \text{N}) = 1^\circ$

$\theta = 45^\circ$ North of West

2.a)

Adding the two opposite vertical forces

$$40\ \text{N} + (-70\ \text{N}) = -30\ \text{N}$$

30 N downward or South

2.b)

$$F_{\text{vertical}} = -30\ \text{N}$$
$$F_{\text{horizontal}} = -40\ \text{N}$$

Using the Pythagorean theorem, the resultant force would be determined by the formula

$$F_{\text{resultant}} = \sqrt{\left(F_{\text{vertical}}\right)^2 + \left(F_{\text{horizontal}}\right)^2} = \sqrt{(-30\ \text{N})^2 + (-40\ \text{N})^2} = 50\ \text{N}$$

2.c)

To find the direction use tan

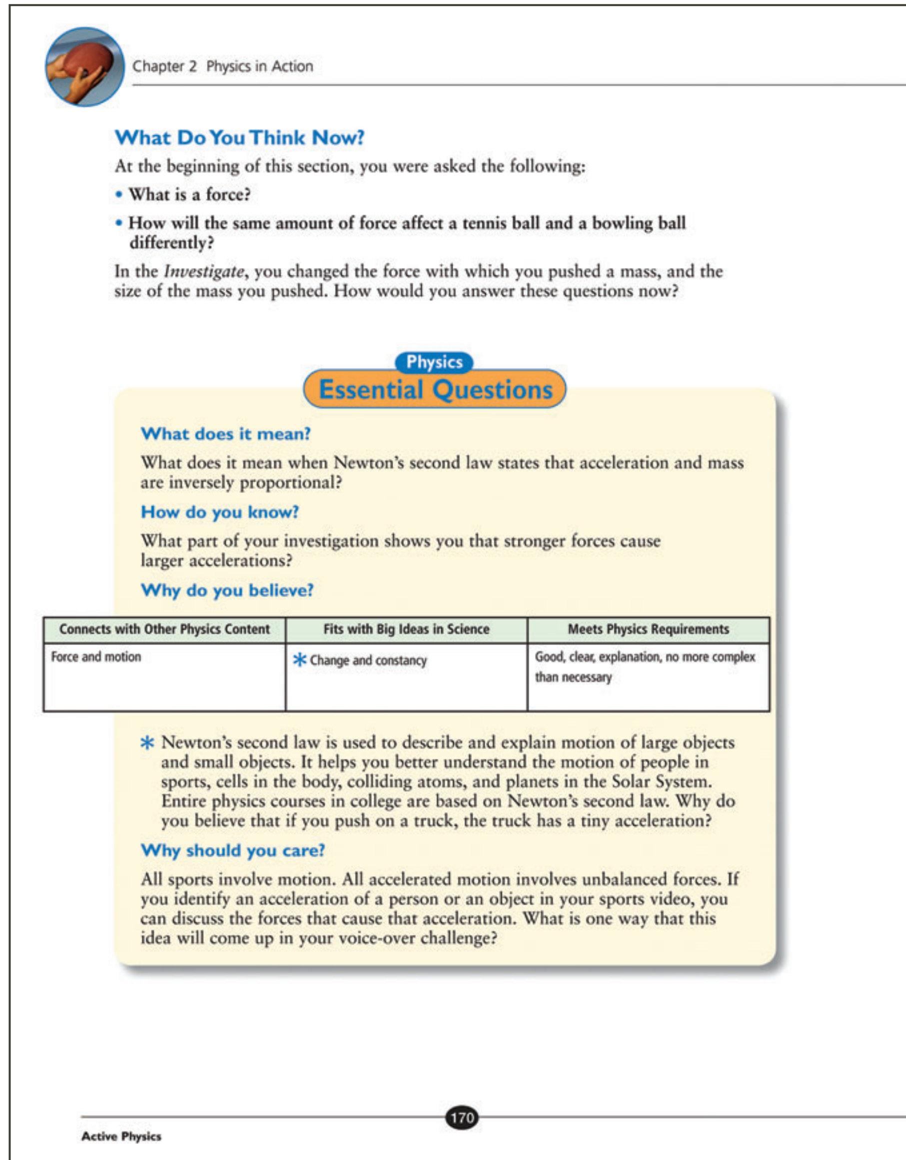
$$\theta = \left(\frac{F_{\text{vertical}}}{F_{\text{horizontal}}}\right) = \tan^{-1}\left(\frac{-30\ \text{N}}{-40\ \text{N}}\right) = 37^\circ$$

37° South of West

CHAPTER 2

What Do You Think Now?

Most students will by now have an understanding of Newton's second law and should be well equipped to answer the *What Do You Think Now?* questions with ease. As you discuss their responses, make sure that they have a good understanding of Newton's second law. You might want to touch on certain aspects of the *Investigate* and *Physics Talk*. Recalling previous learning should help them see why it essential for them to revisit questions asked in *What Do You See?*



Chapter 2 Physics in Action

What Do You Think Now?

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

- **What is a force?**
- **How will the same amount of force affect a tennis ball and a bowling ball differently?**

In the *Investigate*, you changed the force with which you pushed a mass, and the size of the mass you pushed. How would you answer these questions now?

Physics
Essential Questions

What does it mean?

What does it mean when Newton's second law states that acceleration and mass are inversely proportional?

How do you know?

What part of your investigation shows you that stronger forces cause larger accelerations?

Why do you believe?

Connects with Other Physics Content	Fits with Big Ideas in Science	Meets Physics Requirements
Force and motion	* Change and constancy	Good, clear, explanation, no more complex than necessary

* Newton's second law is used to describe and explain motion of large objects and small objects. It helps you better understand the motion of people in sports, cells in the body, colliding atoms, and planets in the Solar System. Entire physics courses in college are based on Newton's second law. Why do you believe that if you push on a truck, the truck has a tiny acceleration?

Why should you care?

All sports involve motion. All accelerated motion involves unbalanced forces. If you identify an acceleration of a person or an object in your sports video, you can discuss the forces that cause that acceleration. What is one way that this idea will come up in your voice-over challenge?

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Active Physics

Physics Essential Questions

What does it mean?

If the same force pushed a series of masses, the larger masses would have the smallest accelerations. This is an inverse proportion.

How do you know?

By applying a larger force (more bend in the ruler), you can observe a greater change in speed in a given time interval.

Why do you believe?

Newton's second law states that if the push is the only force acting on the truck, then the truck would have a very tiny acceleration. To assume that there would be no acceleration would require us to then find out why Newton's second law does not apply for either small forces or large masses. It makes more sense to conclude the acceleration is too small to see.

Why should you care?

A baseball leaving the bat has acceleration. Newton's second law states that if there is acceleration, there must be a force. The force is the bat on the ball.

Section 3 Newton's Second Law: Push or Pull

Reflecting on the Section and the Challenge

What you learned in this activity really increases the possibilities for interpreting sports events in terms of physics, particularly when events have motions along straight paths. Now you can explain why accelerations occur in terms of the masses and forces involved. You know that unbalanced forces are the only things that produce accelerations. Therefore, if you see an acceleration occur, you know to look for unbalanced forces. In soccer and baseball, the ball accelerates. In soccer, the force to increase its speed or change the direction of the ball is the player's foot or head. In baseball, one force is the bat hitting the ball. In football, one player tries to accelerate another player by pushing on him. If the player being pushed is small, the acceleration can be quite large. If the player being pushed is quite massive, the acceleration is much smaller. You can apply Newton's second law to the sport you will describe.

You can also discuss the weight of players and objects in the sports by recognizing that weight is a force that is equal to the mass of the object multiplied by g, acceleration due to gravity, which is 9.8 m/s² on Earth.

Physics to Go

1. Copy the following table in your log. Use Newton's second law of motion to calculate the missing values in the table. Be sure to include the unit of measurement for each missing item (examples: kg, N, m/s²).

Newton's second law:	F =	m ×	a
sprinter beginning 100-m dash	?	70 kg	5 m/s²
long jumper in flight	800 N	?	10 m/s²
shot-put ball in flight	70 N	7 kg	?
ski jumper going downhill before jumping	400 N	?	5 m/s²
hockey player "shaving ice" while stopping	–1500 N	100 kg	?
running back being tackled	?	100 kg	–30 m/s²

2. The following items refer to the table in *Question 1*.
   a) In which cases in the table does the acceleration match g (the acceleration due to gravity, 9.8 m/s²)? Are the matches to g coincidences or not? Explain your answer.
   b) The force on the hockey player stopping is given in the table as a negative value. Should the player's acceleration also be negative? What do you think it means for a force or an acceleration to be negative?
   c) The acceleration of the running back being tackled also is given as negative. Should the unbalanced force acting on the running back also be negative? Explain your answer.

Newton's second law	F =	m x	a
sprinter beginning 100-meter dash	350 N	70 kg	5 m/s²
long jumper in flight	800 N	80 kg	10 m/s
shot-put ball in flight	70 N	7 kg	10 m/s²
ski jumper going down hill before jumping	400 N	80 kg	5 m/s²
hockey player "shaving ice" while stopping	–1500 N	100 kg	–15 m/s²
running back being tackled	–3000 N	100 kg	–30 m/s²

Reflecting on the Section and the Challenge

Students should read this section so that they can begin to form specific connections with the *Chapter Challenge*. A discussion of different sports, especially the ones mentioned in the *Reflecting on the Section and the Challenge*, will help students to see how Newton's second law affects the decisions that are made by players. You might want to provide some time for your students to read this section aloud.

Physics to Go

1.

See chart below.

2.a)

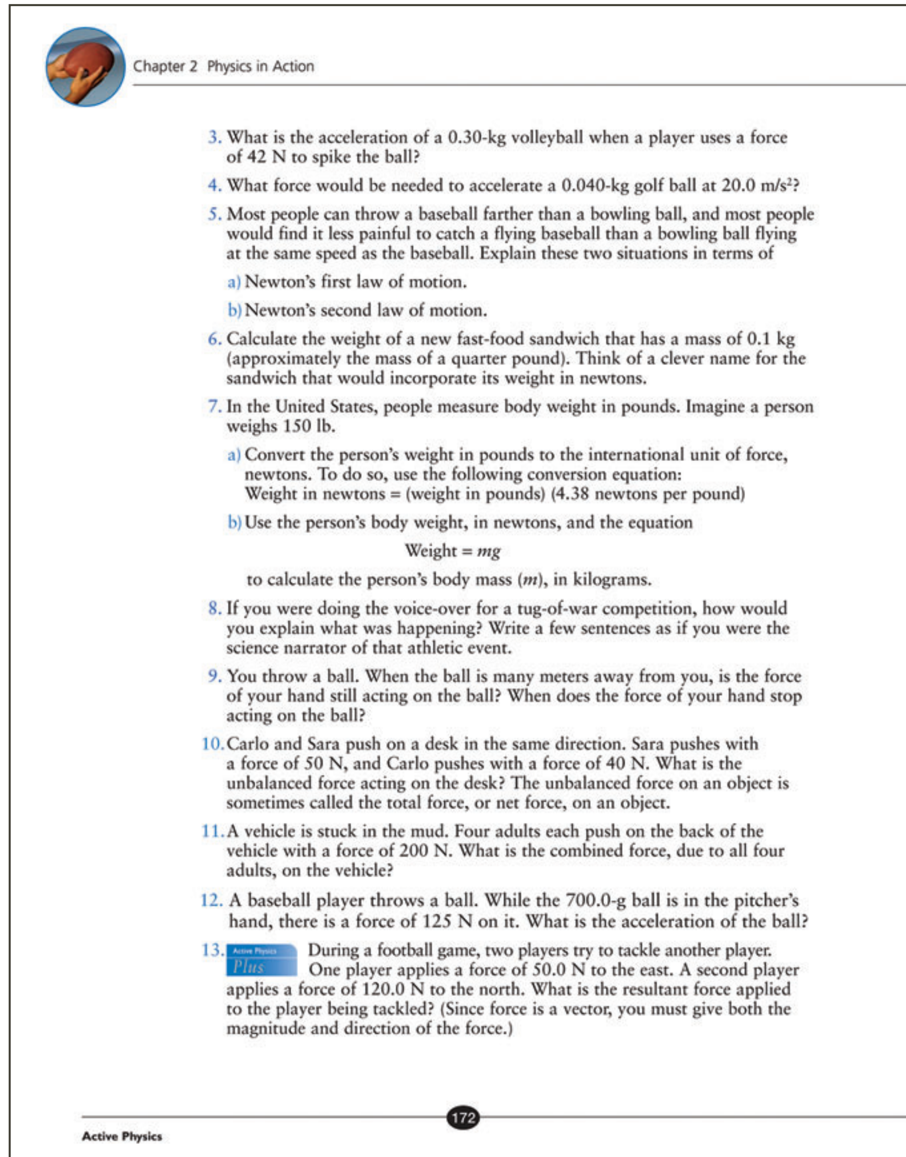
The long jump and the shot put are both cases of free fall; therefore the acceleration is g, the acceleration due to gravity.

2.b)

The negative sign is used to denote that the force and acceleration are in a direction opposite the motion.

2.c)

Because acceleration occurs in the direction of the causal force, yes, the force should be shown as negative.



Chapter 2 Physics in Action

3. What is the acceleration of a 0.30-kg volleyball when a player uses a force of 42 N to spike the ball?

4. What force would be needed to accelerate a 0.040-kg golf ball at 20.0 m/s^2?

5. Most people can throw a baseball farther than a bowling ball, and most people would find it less painful to catch a flying baseball than a bowling ball flying at the same speed as the baseball. Explain these two situations in terms of

   a) Newton's first law of motion.

   b) Newton's second law of motion.

6. Calculate the weight of a new fast-food sandwich that has a mass of 0.1 kg (approximately the mass of a quarter pound). Think of a clever name for the sandwich that would incorporate its weight in newtons.

7. In the United States, people measure body weight in pounds. Imagine a person weighs 150 lb.

   a) Convert the person's weight in pounds to the international unit of force, newtons. To do so, use the following conversion equation:
   Weight in newtons = (weight in pounds) (4.38 newtons per pound)

   b) Use the person's body weight, in newtons, and the equation

   $$\text{Weight} = mg$$

   to calculate the person's body mass (m), in kilograms.

8. If you were doing the voice-over for a tug-of-war competition, how would you explain what was happening? Write a few sentences as if you were the science narrator of that athletic event.

9. You throw a ball. When the ball is many meters away from you, is the force of your hand still acting on the ball? When does the force of your hand stop acting on the ball?

10. Carlo and Sara push on a desk in the same direction. Sara pushes with a force of 50 N, and Carlo pushes with a force of 40 N. What is the unbalanced force acting on the desk? The unbalanced force on an object is sometimes called the total force, or net force, on an object.

11. A vehicle is stuck in the mud. Four adults each push on the back of the vehicle with a force of 200 N. What is the combined force, due to all four adults, on the vehicle?

12. A baseball player throws a ball. While the 700.0-g ball is in the pitcher's hand, there is a force of 125 N on it. What is the acceleration of the ball?

13. Active Physics Plus During a football game, two players try to tackle another player. One player applies a force of 50.0 N to the east. A second player applies a force of 120.0 N to the north. What is the resultant force applied to the player being tackled? (Since force is a vector, you must give both the magnitude and direction of the force.)

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3.

$42\,N/0.30\,kg = 140\,m/s^2$

4.

$0.040\ kg \times 20\ m/s^2 = 0.8\ N$

5.a)

A bowling ball has greater inertia (mass) than a baseball; therefore, a bowling ball has a greater tendency to either remain at rest or remain in motion than does a baseball.

5.b)

More force is required to cause a bowling ball to accelerate than a baseball; therefore, throwing (accelerating) or catching (decelerating) a bowling ball involves much greater forces than throwing or catching a baseball when equal speeds are involved.

6.

The sandwich would weigh $0.1\ kg \times 10\ m/s^2 = 1\ N$. Names such as "newtonburger" might work.

7.a)

Example:
$\text{Weight} = 150\ lb \times 4.38\ N/lb = 657\ N$

7.b)

$\text{Mass} = 657\ N/10\ m/s^2 = 65.7\ kg$

8.

Students provide voice-over for tug of war.

9.

No. The force of your hand stops acting on the ball the moment the two are no longer in contact.

10.

The resultant is
$40\ N + 50\ N = 90\ N$.

11.

The total or combined force is $4 \times 200\ N = 800\ N$. But there may also be forces due to the mud, acting in the opposite direction.

12.

$F = ma$

$a = F/m = (125\ N)/(0.7\ kg) =$

$179\ m/s^2$

13.

Application of the Pythagorean theorem yields:

$(50\ N)^2 + (120\ N)^2 = F^2$

$F = 130\,N$

Using the tangent button on the calculator or a vector diagram, the angle is 23° East of North.

Section 3 Newton's Second Law: Push or Pull

14. Active Physics Plus In auto racing, a crash occurs. A red car hits a blue car from the front with a force of 4000 N. A yellow car also hits the blue car from the side with a force of 5000 N. What is the resultant force on the blue car? (Since force is a vector, you must give both the magnitude and direction of the force.)

15. The acceleration due to gravity at the surface of Earth is approximately 9.8 m/s^2. What force does the gravitational attraction of Earth exert on a 12.8-kg object, such as a toolbox loaded with tools?

16. Active Physics Plus A force of 30.0 N acts on an object. At right angles to this force, another force of 40.0 N acts on the same object.

a) What is the net force on the object?

b) What acceleration would this object have if it is a 5.6-kg wagon?

17. Active Physics Plus Bob exerts a 30.0-N force to the left on a box (m = 100.0 kg). Carol exerts a 20.0-N force on the same box, perpendicular to Bob's force.

a) What is the net force on the box?

b) Determine the acceleration of the box.

c) At what rate would the box accelerate if both forces were to the left instead of perpendicular to each other?

18. *Preparing for the Chapter Challenge*
Using a sport of your choice, write a script for a voice-over that deals with accelerated motion and forces.

Inquiring Further

Gaining and losing weight

The acceleration due to gravity is different at the surface of the Moon and the other planets in the Solar System. Where would you choose to "live" if you wanted to lose weight? What would be the weight of a 150-lb person on the Moon and on each of the planets?

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14.

Application of the Pythagorean theorem yields:

$$(4000\ \text{N})^2 + (5000\ \text{N})^2 = F^2$$

$$F = 6403\ \text{N}$$

Using the tangent button on the calculator or a vector diagram, the angle is 39°.

15.

$$F = ma = (12.8\ \text{kg})(9.8\ \text{m/s}^2) = 125\ \text{N}$$

16.a)

Application of the Pythagorean theorem yields:

$$(40\ \text{N})^2 + (30\ \text{N})^2 = F^2$$

$$F = \sqrt{(40\ \text{N})^2 + (30\ \text{N})^2} = 50\ \text{N}$$

Using the tangent button on the calculator or a vector diagram, the angle is 53°.

16.b)

$$a = F/m = 50\ \text{N}/5.6\ \text{kg} = 8.9\ \text{m/s}^2$$

17.a)

Application of the Pythagorean theorem yields:

$$(30\ \text{N})^2 + (20\ \text{N})^2 = F^2$$

$$F = \sqrt{(30\ \text{N})^2 + (20\ \text{N})^2} = 36\ \text{N}$$

Using the tangent button on the calculator or a vector diagram, the angle is 34°.

17.b)

$$a = F/m = 36\ \text{N}/100\ \text{kg} = 0.36\ \text{N/kg} = 0.36\ \text{m/s}^2$$

17.c)

If both boxes were pushed toward the right, the new force would be 50 N.

$$(30\ \text{N} + 20\ \text{N} = 50\ \text{N})$$

The acceleration can then be calculated:

$$a = F/m = 50\ \text{N}/100\ \text{kg} = 0.5\ \text{N/kg} = 0.5\ \text{m/s}^2$$

18.

Preparing for the Chapter Challenge

Student responses will vary, but should include a description of how Newton's second law will determine the acceleration of an object that is acted upon by one or more forces. The forces should be appropriate for the sports example being illustrated.

CHAPTER 2

Inquiring Further

Because your weight depends upon your mass times the acceleration of gravity, the best place to go to "lose weight" would be the planet with the lowest gravity. Unfortunately, although you would weigh less, your mass would still be the same so you would not look appreciably different.

The acceleration of gravity on the Moon is approximately 1.6 m/s^2 or about one-sixth that of Earth. If you went to the Moon, your new weight would be one-sixth your weight on Earth. A person who weighed 150 lbs on Earth would only weigh 25 lbs on the Moon!

The acceleration of gravity varies greatly from planet to planet, with a high of about 26 m/s^2 for Jupiter, and a low of 0.6 m/s^2 for Pluto. The weight of a 60-kg person would vary from

1560 N (about 350 lbs) on Jupiter to 36 N (about 8 lbs) on Pluto.

NOTES

SECTION 3 QUIZ

2-3b Blackline Master

1. The force required to accelerate a 2-kg mass at 4 m/s^2 is

   a) 6 N. b) 2 N.
   c) 8 N. d) 16 N.

2. A force of *F* newtons will give an object with a mass of *M* an acceleration of *A*. The same force will give a mass of 2 *M* an acceleration of

   a) A/2. b) 2A.
   c) A. d) A/4.

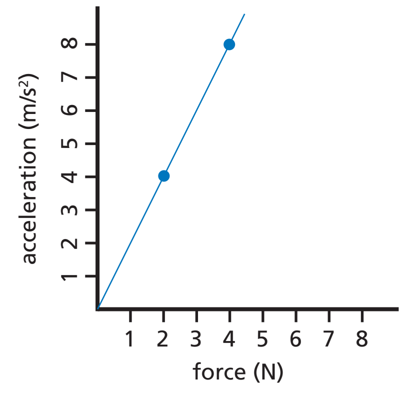
3. On the planet Gamma a 4.0-kg mass experiences a gravitational force of 24 N. What is the acceleration due to gravity on Gamma?

   a) 0.17 m/s^2 b) 6 m/s^2
   c) 9.8 m/s^2 d) 96 m/s^2

4. A cart is uniformly accelerating from rest. The force on the cart must be

   a) decreasing. b) zero.
   c) constant. d) increasing.

5. In the graph below, the acceleration of an object is plotted against the unbalanced force applied. What is the mass of the object?



   a) 0.5 kg b) 2 kg
   c) 4 kg d) 0.2 kg

CHAPTER 2

SECTION 3 QUIZ ANSWERS

1. b) Using $F = ma = (2\ \text{kg})(4\ \text{m/s}^2) = 8\ \text{N}$.

2. a) $a = F/M$, then $F/2M = \frac{1}{2}A$

3. b) Using $W = mg$ gives $24\ \text{N} = (4\ \text{kg})(g)$ Solving for $g = 6\ \text{m/s}^2$.

4. c) A constant acceleration requires a constant net force.

5. a) Using values from the graph, when the force is 4 N, the acceleration is $8\ \text{m/s}^2$. Substituting these values in the equation $F = ma$ yields $4\ \text{N} = m(8\ \text{m/s}^2)$, or $m = 0.5\ \text{kg}$.

NOTES

NOTES