SECTION 7

Friction: Sliding on the Moon

Section Overview

In this section, students investigate how the force of friction acts on objects, and how reduced gravity on the Moon affects the force of friction needed for sports. Students first observe the reaction force that pushes them forward as they walk as they walk is due to friction. To explore how friction depends upon the force holding two surfaces together, they measure the weight of a box in newtons by attaching it to a spring scale and then, using the spring scale, they pull that box horizontally, holding the scale parallel to the surface of the table. Students record the force required to pull the box at a constant speed and determine the net force acting on the box. They add sand to the box, successively increasing the weight to 4 N, 6 N, 8 N, and 10 N, and recording the force needed to pull each weight. Then they plot a graph of frictional force versus weight and sketch the line that best fits the data; that is, has an equal distribution of points above and below the straight line. Based on the data, students summarize the relationship between frictional force and weight. From their graph they also determine how the force of friction is reduced when an object's weight changes from 9 N on Earth to 1.5 N on the Moon. Students eventually discover that playing a sport on the Moon would mean that they will have to consider the reduced friction on the Moon.

Background Information

In general, the frictional force between the surfaces of two objects on the Moon is 1/6 of the amount that the frictional force between the same two objects would be in a similar situation on Earth. This is true because the frictional force is directly proportional to the normal force pushing the surfaces of the objects together. For similar situations on the Moon and on Earth, the normal force on the Moon is 1/6 the value of what it would be on Earth; therefore, the frictional force on the Moon is 1/6 of what it would be on Earth.

It is critical to recognize that the coefficient of sliding friction between a particular pair of surfaces does not change from Earth to the Moon. This is because the coefficient of sliding friction is determined by characteristics of the two surfaces in contact; changing the location of the surfaces does not affect the way in which the surfaces interact during sliding contact.

Crucial Physics

- The force of friction between two bodies depends upon the nature of the bodies and the force pressing the two bodies together (the normal force – F_N). The force of friction can be found using the equation $f = \mu F_N$, where μ is a dimensionless constant that describes the interaction between the surfaces.

Learning Outcomes	Location in the Section	Evidence of Understanding
Measure forces of sliding friction using a spring scale.	***Investigate*** Step 4	Students pull a box horizontally using a spring scale and record the amount of force needed to slide the box across the table.
Compare frictional forces on Earth and the Moon by applying the definition of the coefficient of sliding friction.	***Investigate*** Step 7	Students compare the force of friction on a sliding object of given mass for Earth, and when the weight is reduced by a factor of six on the Moon. By realizing that the nature of the surfaces sliding past each other hasn't changed on the Moon as compared to Earth, students realize that the frictional force depends upon both the weight and the surfaces involved.

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CHAPTER 9

Section 7 Materials, Preparation, and Safety

Materials and Equipment

PLAN A and PLAN B		
Materials and Equipment	**Group (4 students)**	**Class**
Spring scale, 0–10 N	1 per group	
Container, 32 oz (for sand)	1 per group	
Scissors	1 per group	
Sand, fine, 5 lb	1 per group	
Friction box	1 per group	
String, ball		1 per class
Paper, graph, pkg. of 50		1 per class
Access to a long table*	1 per group	

*Additional items needed not supplied

Time Requirements

- Allow two class periods or 90 minutes for the students to do the *Investigate* and other parts of the section.

Teacher Preparation

- In advance of the activity you will need to collect flat-bottomed containers for which the coefficient of sliding friction between the container and a tabletop will be measured at each station. A set of shoe boxes would work.
- Sand to be used for increasing the weight of the box may be obtained from hardware stores or lumber yards in 40-lb bags.

Safety

- Students must wear safety goggles for this *Investigate*.
- Clean up any sand spilled on the floor immediately to prevent slipping.

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Meeting the Needs of All Students

Differentiated Instruction: Augmentation and Accommodations

Learning Issue	Reference	Augmentation and Accommodations
Creating a graph	***Investigate*** Step 6.a)	**Augmentation** • At this point, students should be much more independent with graphing than they were at the beginning of the *Active Physics* curriculum. Ask students to set up and label their axes. Remind students that their scale must be evenly spaced with the same number of blocks between each number. Then check in with students who have historically struggled with graphing or ask students to compare their graph with the person sitting next to them before they begin plotting points. It is very frustrating to finish a graph and be asked to start over, especially if the student struggles with graphing. • To practice drawing best-fit lines, provide a few sample graphs with the points already plotted. Then ask students to draw the best-fit line for each graph. Give students a few more minutes to compare their best-fit lines with group members. Then, go over the answers as a whole group. This quick activity will help students who struggle with graphing and are accustomed to drawing lines that connect all of the plotted points. • For long-term benefits and to improve technology skills, it may be worth their time to teach students to use a spreadsheet program that will graph the points and add a best-fit line. **Accommodation** • If a particular student is still struggling to set up a graph, provide a graph with the scale marked but not labeled with numbers. Help students decide what scale could be used to represent the data. Since the data increases by a factor of two, most students will recognize this pattern. Remember that independence is the goal, but students do need an accurate graph for *Step 7*.
Summarizing relationships from a graph	***Investigate*** Step 6.b)	**Augmentation** • Students who have a difficult time recognizing patterns may struggle to summarize a relationship based on the graph. Scaffold the activity by asking students specific questions to focus on. What happens to the frictional force as weight increases? Does the frictional force change by a similar amount each time the weight increases by 2 N? Ask students to provide evidence from the graph or data table to support their answers to these questions. **Accommodation** • Provide sentence starters for students who are unable to write a summary even with the scaffolding. For example, "As the weight increases…"
Reading comprehension Accessing prior knowledge	***Physics Talk*** ***Active Physics Plus***	**Augmentation** • Students have already learned about friction in an earlier chapter. Ask students to list at least two things they already know about friction before they begin reading. Activating prior knowledge will assist all students but will be especially helpful for students who struggle with reading. • Ask students to use their *Active Physics* logs to provide evidence for the two things they already know about friction. Citing evidence is an important skill that many students struggle with and requiring them to practice as much as possible is the best way to improve this skill. Also, referring back to earlier sections will also help students remember what they have learned about force vector diagrams.

Learning Issue	Reference	Augmentation and Accommodations
Applying knowledge to answer questions	***Physics to Go***	**Augmentation** • Students may be able to describe friction forces and give examples, but when those same students are asked to answer the *Physics to Go* questions, they get stuck. Some students struggle to apply or generalize knowledge to new situations. Ask students to generate a list of factors that affect frictional forces. Then develop a comprehensive list by asking students to share their answers with the class. Students can then reference the list when trying to apply the effects of frictional forces to difference sports.

Strategies for Students with Limited English-Language Proficiency

Learning Issue	Reference	Augmentation
Understanding concepts	***Investigate*** Step 4 ***Physics Talk***	Have volunteers explain for the class why a constant reading on the spring scale shows that the box is sliding with a constant speed. In *Step 4.a)*, check that students understand that the pulling force necessary to keep the box moving at a constant speed is equal to the sliding frictional force between the box and the surface. This point is revisited in *Physics Talk*.
Understanding concepts	***Investigate*** Step 6.b)	Explain that weight is plotted on the horizontal axis because it is the independent variable. In this context, discuss with students which would be more appropriate to write: "Frictional force is directly proportional to weight" or "Weight is directly proportional to frictional force."
Higher-order thinking	***Physics Talk*** Physics Words	Direct students' attention to the definition of friction. Ask: "Under what conditions might there be attempted motion?" Students should identify that attempted motion would occur when a force is applied to one of the two objects touching each other, but the force is not great enough to overcome the frictional force between the objects. This point is stated in different words in *Physics Talk*.
Designing experiments	***Active Physics Plus*** Step 2.c)	When students are designing their experiments, remind them to think of the characteristics of surfaces mentioned in *Step 1*, as well as the types of surfaces. Make sure you have on hand many options of surfaces for students to investigate.
Higher-order thinking	***Reflecting on the Section and the Challenge***	Challenge students to tell which is generally greater, the coefficient of sliding friction or the coefficient of static friction. [static friction]

Research skills are tremendously important in science. *Checking Up*, *Question 3*, the last paragraph in *Physics Talk*, and the *Inquiring Further* section all deal with the issues of traction and how to increase the friction of a lunar playing surface. Pair ELL students with native English speakers, and have them research traction and playing surfaces. You may wish to assign students specific surfaces or materials to look into, or let students choose for themselves. Make sure that some pairs investigate sliding friction.

Once the research is complete, have each pair of students prepare an oral report and give it to the class. Encourage ELL students to do as much of their presentation as possible, because ELL students benefit greatly from speaking in English.

At the end of the prepared presentation, encourage questions from the class. ELL students will also benefit from the opportunity to improve their listening skills and will be challenged to speak extemporaneously to answer the questions. Make sure the questions and responses include appropriate use of science vocabulary.

SECTION 7

Teaching Suggestions and Sample Answers

What Do You See?

The image of the person sliding while playing baseball on the Moon is bound to evoke many responses. You might want to initiate a class discussion through such an image to ask why the astronaut slides so much further on the Moon than he normally would on Earth to capture students' attention. To probe the illustration further, you might want to ask students: "How is one of the players able to catch the ball? Why did the astronaut slip? Or, why are the Aliens not wearing a spacesuit?" As students respond, point out that the artist has cleverly embedded important physics concepts in these images. A close analysis of this visual will enable students to appreciate how the artist has assembled these images to convey how physics is applied on the Moon.

What Do You Think?

When students are engaged in this question, ask them to recall what they know about friction. Prompt them to think of how friction might be related to weight and how this connection is likely to lead to a well thought-out response. It is important for students to realize that their answers will not be evaluated. However, students must show evidence of engagement and an earnest effort in recalling what they have learned in previous sections when they respond to *What Do You Think?* Encourage students to consider how this question might relate to *What Do You See?* and record their answers in their *Active Physics* logs.

This is also an opportunity for you to uncover students' misconceptions and address them at a later stage after students have carried out their investigations for this section.

What Do You Think?

A Physicist's Response

The force of gravity on an object on Earth is six times more than the force of gravity on the same object on the Moon. Therefore, frictional forces on the Moon are generally 1/6 the amount of frictional forces on Earth. However, the coefficient of friction is not affected by location, but only depends upon the surfaces in contact.

Students' Prior Conceptions

As students determine the coefficient of sliding friction between two surfaces, you have the opportunity to listen to the explanations of the causes of friction. The origin of the coefficient of friction is vital to students' understanding of why friction exists, and that the coefficient is a ratio of the weight of the object to the measured force needed to start the motion.

1. **Frictional forces are due to irregularities in surfaces moving past each other.** By doing the *Investigate*, students observe that that the applied force must be greater than the force of friction for motion to begin. Friction acts to resist the relative motion of objects that are touching each other. In addition, there is an adhesion between their surfaces, which must be broken before objects can slide past each other. The existence of friction affects walking, running, or standing on Earth and on the Moon.

2. **Students may confuse friction with inertia. They may say that the force required to accelerate an object at rest is working against friction, not inertia.** Students reason that it takes a larger force to move a larger object with more mass, hence more inertia, so a larger mass with more inertia must have more friction. Students confound friction, coefficient of friction, and applied force. This misconception can be addressed through mathematical reasoning while determining the coefficient of friction. Emphasize that the coefficient of friction is constant regardless of the mass of the object. Also, it is important for you to highlight the concepts of coefficient of friction as compared with the total applied force needed to start a motion. Encourage students to recognize the difference between the net force needed to put a mass into motion, which also overcomes friction, as opposed to the coefficient of friction between that mass and the surface upon which it rests, which is independent of the force and mass.

Section 7 Friction: Sliding on the Moon

What Do You See?

Learning Outcomes

In this section, you will

- **Measure** forces of sliding friction using a spring scale.
- **Compare** frictional forces on Earth and the Moon by applying the definition of the coefficient of sliding friction.

What Do You Think?

The Lunar Rover proved that there is enough frictional force on the Moon to operate a passenger-carrying wheeled vehicle.

- **How and why are frictional forces on Earth and the Moon different?**

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

Investigate

In this *Investigate*, you will determine the coefficient of sliding friction between two surfaces. You will find the force required to overcome friction for various weights as you pull a box across a level surface. By graphing the data, you will calculate the coefficient of sliding friction. You will then calculate the force of friction on the Moon and how it affects sports played there.

1. Walk forward for a few steps and then come to an abrupt stop. Make the observations needed to write answers to the following questions in your *Active Physics* log:

CHAPTER 9

Investigate

1.a)

You push your feet backward on the floor to go forward.

1.b)

The reaction force of the floor pushing on the feet uses friction to make the person move forward.

1.c)

Your feet try to push the floor forward to come to a stop.

1.d)

The reaction force of the floor using friction pushes backward on the feet to stop the person.

1.e)

On a surface like ice, the frictional reaction force the floor is able to provide is very small, so the person walking has a difficult time getting started or stopping, once in motion.

2.a)

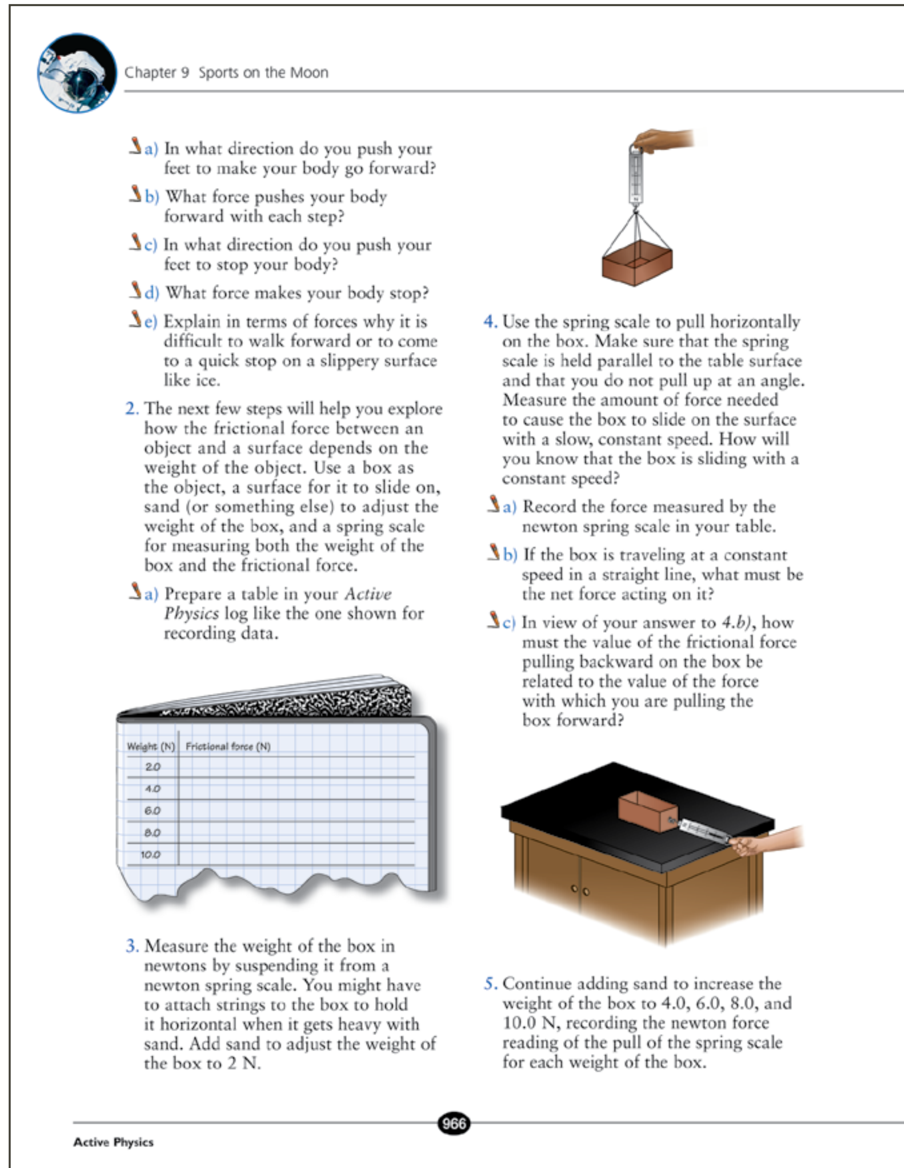
Students copy the table in the text into their logs.

Teaching Tip

To weigh the box with the sand, attach the string to the bottom of the box with tape, and then attach the ends of the string to the spring scale.

3.

Students' results will vary with the type of box used. The box should weigh less than 2 N so that additional mass (like sand) may be added to the box to bring the weight up to 2 N.



Chapter 9 Sports on the Moon

a) In what direction do you push your feet to make your body go forward?

b) What force pushes your body forward with each step?

c) In what direction do you push your feet to stop your body?

d) What force makes your body stop?

e) Explain in terms of forces why it is difficult to walk forward or to come to a quick stop on a slippery surface like ice.

2. The next few steps will help you explore how the frictional force between an object and a surface depends on the weight of the object. Use a box as the object, a surface for it to slide on, sand (or something else) to adjust the weight of the box, and a spring scale for measuring both the weight of the box and the frictional force.

a) Prepare a table in your *Active Physics* log like the one shown for recording data.

Weight (N)	Frictional force (N)
2.0	
4.0	
6.0	
8.0	
10.0	

3. Measure the weight of the box in newtons by suspending it from a newton spring scale. You might have to attach strings to the box to hold it horizontal when it gets heavy with sand. Add sand to adjust the weight of the box to 2 N.

4. Use the spring scale to pull horizontally on the box. Make sure that the spring scale is held parallel to the table surface and that you do not pull up at an angle. Measure the amount of force needed to cause the box to slide on the surface with a slow, constant speed. How will you know that the box is sliding with a constant speed?

a) Record the force measured by the newton spring scale in your table.

b) If the box is traveling at a constant speed in a straight line, what must be the net force acting on it?

c) In view of your answer to *4.b)*, how must the value of the frictional force pulling backward on the box be related to the value of the force with which you are pulling the box forward?

5. Continue adding sand to increase the weight of the box to 4.0, 6.0, 8.0, and 10.0 N, recording the newton force reading of the pull of the spring scale for each weight of the box.

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Active Physics

4.a)

Students record the force measured by the Newton spring scale. The reading will depend upon the natural surface of the box and the surface the box is being pulled across.

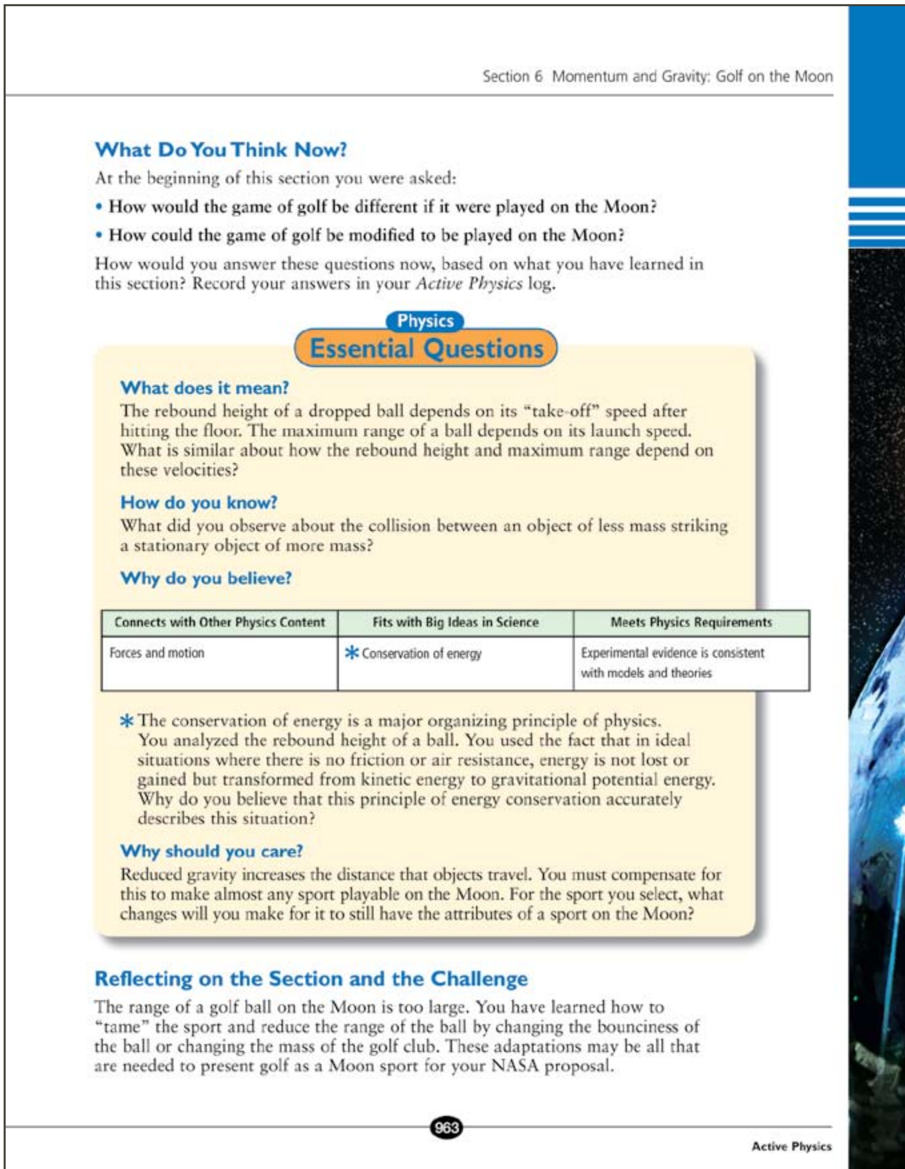
4.b)

If the box is traveling at constant speed in a straight line, then by Newton's first law, the box must have zero net force acting on it.

4.c)

To have a result of zero net force, the frictional force pushing backward must exactly equal the force of the spring scale pulling forward.

9-7a Blackline Master



Section 6 Momentum and Gravity: Golf on the Moon

What Do You Think Now?

At the beginning of this section you were asked:

- How would the game of golf be different if it were played on the Moon?
- How could the game of golf be modified to be played on the Moon?

How would you answer these questions now, based on what you have learned in this section? Record your answers in your *Active Physics* log.

Physics

Essential Questions

What does it mean?

The rebound height of a dropped ball depends on its "take-off" speed after hitting the floor. The maximum range of a ball depends on its launch speed. What is similar about how the rebound height and maximum range depend on these velocities?

How do you know?

What did you observe about the collision between an object of less mass striking a stationary object of more mass?

Why do you believe?

Connects with Other Physics Content	Fits with Big Ideas in Science	Meets Physics Requirements
Forces and motion	* Conservation of energy	Experimental evidence is consistent with models and theories

* The conservation of energy is a major organizing principle of physics. You analyzed the rebound height of a ball. You used the fact that in ideal situations where there is no friction or air resistance, energy is not lost or gained but transformed from kinetic energy to gravitational potential energy. Why do you believe that this principle of energy conservation accurately describes this situation?

Why should you care?

Reduced gravity increases the distance that objects travel. You must compensate for this to make almost any sport playable on the Moon. For the sport you select, what changes will you make for it to still have the attributes of a sport on the Moon?

Reflecting on the Section and the Challenge

The range of a golf ball on the Moon is too large. You have learned how to "tame" the sport and reduce the range of the ball by changing the bounciness of the ball or changing the mass of the golf club. These adaptations may be all that are needed to present golf as a Moon sport for your NASA proposal.

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Active Physics

5.a)

Student results will depend upon the surfaces, but should increase in approximately uniform steps if the weight of the box is increased in uniform steps.

6.a)

The "best-fit line" should be a straight line, but this might not be completely consistent with the students' data. Discuss the possible conclusions from their data (straight line, curved line) and other considerations (accuracy of data).

6.b)

As the weight increases, so does the frictional force.

7.a)

Students find the weight of 9 N on their graph and read the corresponding value of the frictional force as shown in the graph for *Step 7.b)*. Students should not expect the force of friction to equal the weight as it does in the graph shown in the student text.

7.b)

Students repeat the procedure from *Step 7.a)* for 1.5 N

7.c)

The weight will be 1/6 of 9 N, or 1.5 N.

7.d)

The frictional force on the Moon for a box that weighs 9 N on Earth would be the same as the frictional force on a box that weighs 1.5 N on the Moon.

7.e)

The frictional force on the Moon will be 1/6 the frictional force on Earth. This means people walking on the Moon will have a harder time getting started (lower acceleration) than on Earth, and will not stop as easily (lower negative acceleration).

8.a)

Getting started, walking or running or stopping will be more difficult on the Moon, since the same mass needs to be accelerated as on Earth, but the frictional force available to do the acceleration is much less.

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9-7b Blackline Master

Physics Talk

Students read how friction acts on the feet when they are walking by recalling observations in the *Investigate*. It is important to point out that static friction is the reaction force between the shoe and the ground that pushes you forward. Traction between the feet and the floor determines the amount of static friction. If you see an object sliding on a surface, it means that the force of friction is changing from static friction to kinetic friction. The reaction force of friction is now called kinetic friction and is less than static friction.

For students to understand how an object moves at constant speed, ask them to recall how they were able to determine in the *Investigate* that the box was being pulled across the table at constant speed. Emphasize that the reaction force of friction resisting the forward pull is equal in magnitude to the amount of force applied horizontally. The vector diagram in the student text illustrates that the net force on the box is zero when it is moving at a constant speed. Consider reviewing the definition for acceleration at this point and ask students when a weight would accelerate across a surface. If students have studied Newton's laws of motion in a previous chapter, remind them of the condition necessary for constant velocity.

Physics Talk

FRICTIONAL FORCE

When you observed your walk during the first part of the *Investigate*, you noticed how you push your feet back in order to move forward. The static friction between your shoe and ground is the force that pushes you forward. If there was no friction, you could not get the traction to push your feet back and you would slip in place.

A force called **friction** also arises when an attempt is made to slide an object on a surface. The amount of the force of friction between the object and the surface is equal in magnitude to the amount of horizontal force required to make the object move at constant speed. When the object moves at constant speed, the frictional force resisting the motion is equal in amount but opposite in direction to the applied force causing the motion. This is often shown in a force vector diagram.

The red vector represents the applied force. The blue vector represents the frictional force. Since the two force vectors are equal, the object would have a net force of 0. Newton's second law ($F = ma$) informs you that if there is no net force, there is no acceleration. Therefore, the object moves at a constant speed.

If the amount of the applied force is less than the maximum frictional force for that weight, the object does not slide at all on the surface; if the amount of the applied force is greater than the force of friction, the object accelerates as it slides across the surface. This occurs on ice where the friction is very small.

In the *Investigate*, you found that the force of friction increases if the weight of the pulled object increases. Since weight on the Moon is $\frac{1}{6}$ the weight on Earth, you can therefore assume that friction on the Moon will be $\frac{1}{6}$ the friction on Earth. That means everybody will be slipping and sliding on the Moon. In basketball, where you have to make a quick shift so you can go left instead of right, the decreased friction may cause you to slip and fall. When you slide into second base in baseball, you may slide right into the outfield.

Frictional forces also depend on surfaces. The lunar (Moon) surface is different than some Earth surfaces. You may be able to vary the surface of the playing field or the traction of the shoes to help players get more friction when they are engaged in a sport on the Moon.

Physics Words

friction: a force that acts to resist the relative motion or attempted motion of objects whose surfaces are in contact with each other.

Checking Up

1. When an object is moving at constant speed, how do the applied force and the frictional force compare in both magnitude and direction?
2. If you try to pull an object with a force less than the frictional force, what will happen?
3. What could be done to increase the friction of playing surfaces of a sport on the Moon?

Discuss how the force of friction increases when the weight of an object increases. Determine if students understand why this force of friction is reduced on the Moon even though the two surfaces interacting are the same as on Earth. Ask how a sport like basketball would be affected when played indoors on the Moon and how traction can be increased to increase the static friction to make it easier for the players to engage in a sport.

Checking Up

1.

When an object is moving at constant speed, the applied force and the force of friction must be equal in magnitude but opposite in direction. The object is in equilibrium. Following Newton's first law, since there is no net force, the object will continue in a straight line with constant speed.

2.

If you try to pull an object with a force less than the frictional force, the object will slow down if it is moving. If the object was at rest, it will remain at rest, since the frictional force is the maximum force applied by friction (but not the minimum).

3.

The force of friction depends upon the force holding the surfaces together and the types of surfaces in contact. To increase the frictional force on the Moon, one could increase the mass of the players (by maybe wearing lead-coated sneakers), and thus the weight holding the players to the surface. Alternatively, the surfaces might be adjusted to provide a greater frictional force by making them like sandpaper, or perhaps "sticky."

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CHAPTER 9

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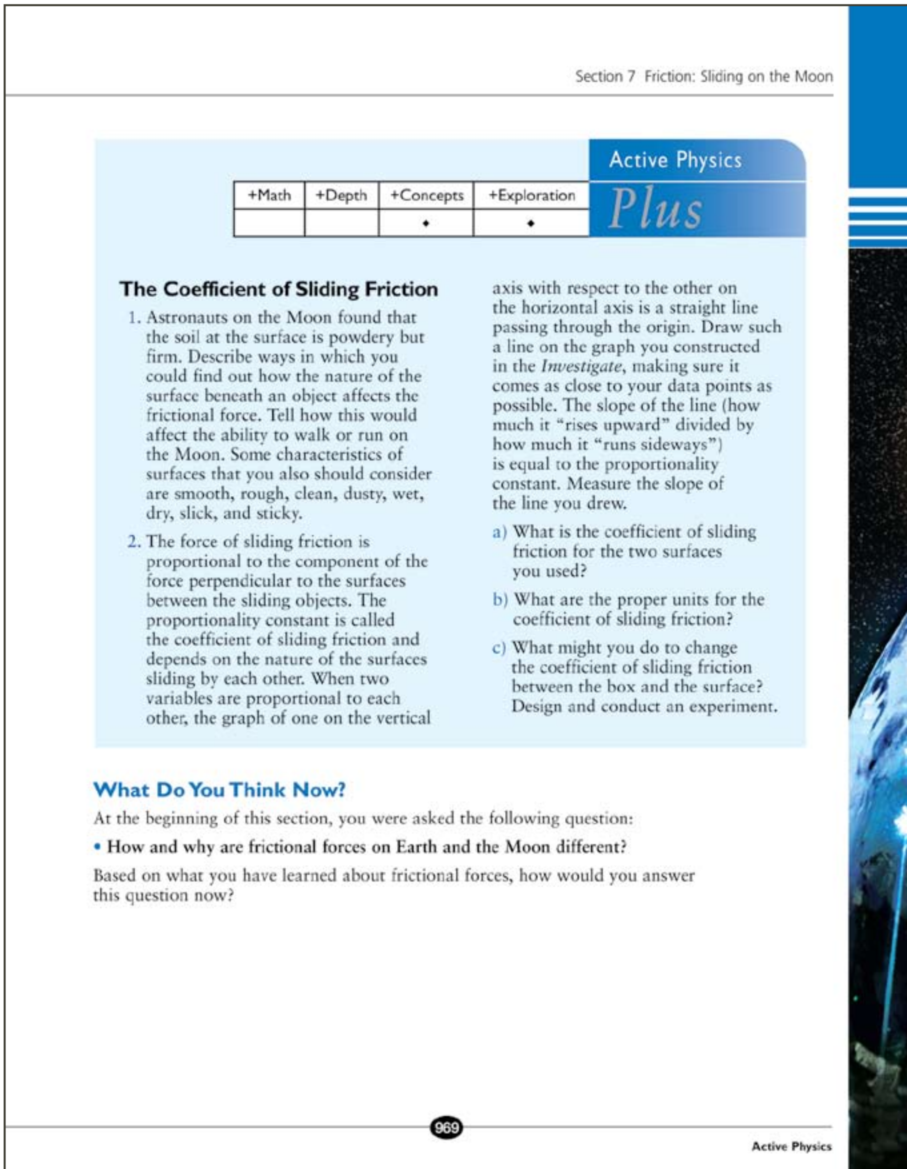
Active Physics Plus

Students further explore the effects of friction on the Moon. They are asked to speculate on how the powdery surface material of the Moon would affect running or walking, and how this can be generalized to other surfaces. Students then calculate the slope of the graph they constructed in the *Investigate* and relate the slope to the coefficient of friction for the surfaces. They discover that the coefficient of friction is a dimensionless quantity. Finally, they explore methods to see if they are able to increase the coefficient of friction between surfaces.

1.

The nature of the surfaces sliding past each other is very important in determining the force of friction. A powdery surface can allow for significant friction if it is packed together well and does not move during sliding. But more frequently, the powder on the very top surface will move as the object slides by, reducing



Active Physics *Plus*

+Math	+Depth	+Concepts	+Exploration
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The Coefficient of Sliding Friction

1. Astronauts on the Moon found that the soil at the surface is powdery but firm. Describe ways in which you could find out how the nature of the surface beneath an object affects the frictional force. Tell how this would affect the ability to walk or run on the Moon. Some characteristics of surfaces that you also should consider are smooth, rough, clean, dusty, wet, dry, slick, and sticky.
2. The force of sliding friction is proportional to the component of the force perpendicular to the surfaces between the sliding objects. The proportionality constant is called the coefficient of sliding friction and depends on the nature of the surfaces sliding by each other. When two variables are proportional to each other, the graph of one on the vertical axis with respect to the other on the horizontal axis is a straight line passing through the origin. Draw such a line on the graph you constructed in the *Investigate*, making sure it comes as close to your data points as possible. The slope of the line (how much it "rises upward" divided by how much it "runs sideways") is equal to the proportionality constant. Measure the slope of the line you drew.
   a) What is the coefficient of sliding friction for the two surfaces you used?
   b) What are the proper units for the coefficient of sliding friction?
   c) What might you do to change the coefficient of sliding friction between the box and the surface? Design and conduct an experiment.

What Do You Think Now?

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

- How and why are frictional forces on Earth and the Moon different?

Based on what you have learned about frictional forces, how would you answer this question now?

the force of friction considerably. An experiment similar to the one performed in *Investigate* would be a suitable one to find out how much friction is produced by a powdery but firm surface. Instead of sliding the object along a hard surface, simply measure the force necessary to slide it along the surface of a powder that has been packed firmly.

2.a)

Students should obtain a slope less than 1.

2.b)

Since the slope is calculated by dividing the applied force by the weight (another force), the slope has no units (so the coefficient of sliding friction has no units).

2.c)

Changing the nature of one or both of the surfaces is the only way to change the coefficient of sliding friction.

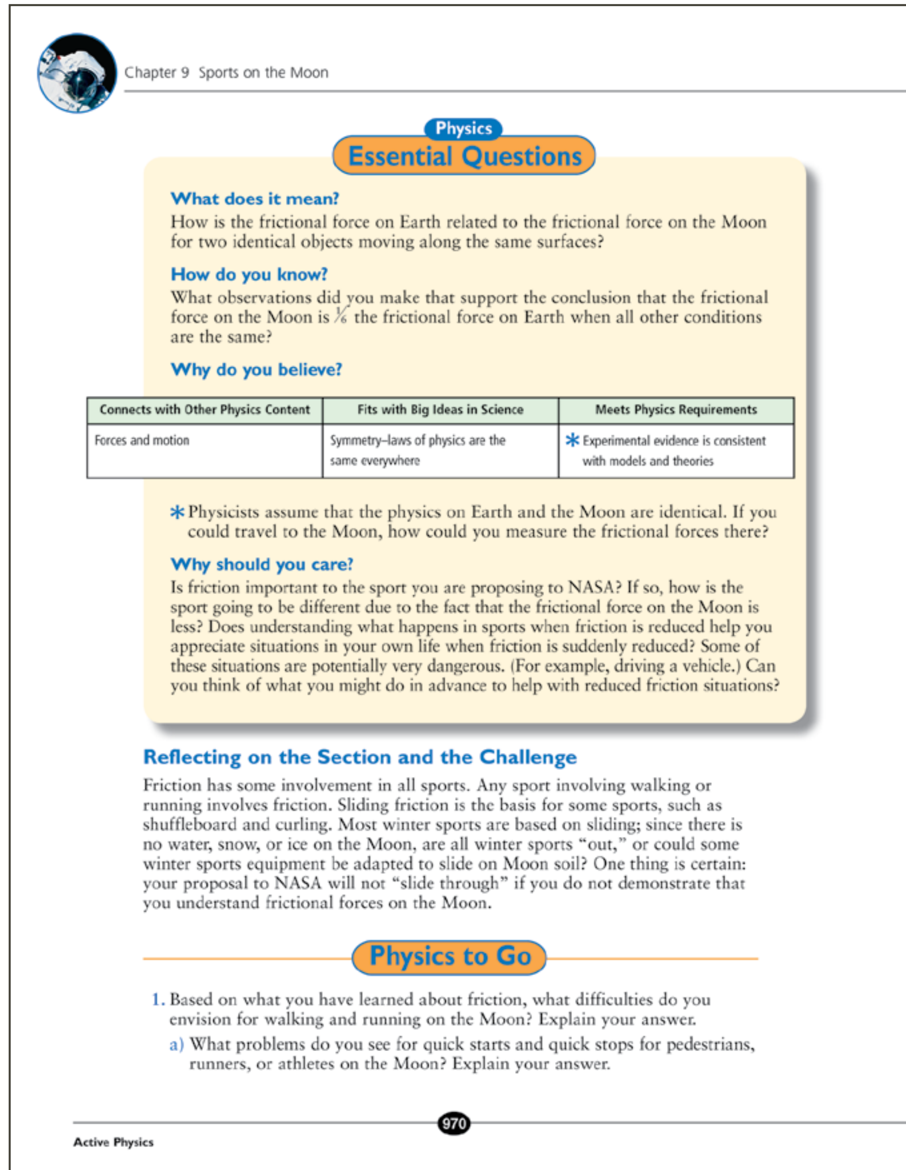
What Do You Think Now?

Students should now update and revise their answers to the *What Do You Think?* question. Consider sharing *A Physicist's Response* to initiate a discussion. Students should now be able to present an answer that is accurate, based on what they have learned about friction. Emphasize that they must include examples to support their argument and show why friction depends upon the force holding surfaces together. Encourage students to discuss their responses with their classmates. This is a good time to review the difference between gravity on Earth and gravity on the Moon. Suggest to students that they should revisit the *What Do You See?* illustration to gain a deeper appreciation of how the artist has tried to render aspects of the *What Do You Think?* through an interplay of interesting images.

CHAPTER 9

Reflecting on the Section and the Challenge

Read or have a student read this section aloud from the student text. Ask why sliding friction is the basis for some sports, while static friction is the basis for others. If students are interested in including a winter sport in their NASA proposal, ask them why that sport may be difficult to play on the Moon. Reiterate that this is the time for them to review what they have learned and apply it to their *Chapter Challenge*. Students should reflect on the connection between friction and sports so that any sport they design takes into account the challenges posed by reduced friction on the surface of the Moon. Encourage students to reflect on the *Investigate* and *Physics Talk* to generate ideas on how what they have learned can be used to make their proposal to NASA more convincing.



Chapter 9 Sports on the Moon

Physics

Essential Questions

What does it mean?

How is the frictional force on Earth related to the frictional force on the Moon for two identical objects moving along the same surfaces?

How do you know?

What observations did you make that support the conclusion that the frictional force on the Moon is $\frac{1}{6}$ the frictional force on Earth when all other conditions are the same?

Why do you believe?

Connects with Other Physics Content	Fits with Big Ideas in Science	Meets Physics Requirements
Forces and motion	Symmetry–laws of physics are the same everywhere	* Experimental evidence is consistent with models and theories

* Physicists assume that the physics on Earth and the Moon are identical. If you could travel to the Moon, how could you measure the frictional forces there?

Why should you care?

Is friction important to the sport you are proposing to NASA? If so, how is the sport going to be different due to the fact that the frictional force on the Moon is less? Does understanding what happens in sports when friction is reduced help you appreciate situations in your own life when friction is suddenly reduced? Some of these situations are potentially very dangerous. (For example, driving a vehicle.) Can you think of what you might do in advance to help with reduced friction situations?

Reflecting on the Section and the Challenge

Friction has some involvement in all sports. Any sport involving walking or running involves friction. Sliding friction is the basis for some sports, such as shuffleboard and curling. Most winter sports are based on sliding; since there is no water, snow, or ice on the Moon, are all winter sports "out," or could some winter sports equipment be adapted to slide on Moon soil? One thing is certain: your proposal to NASA will not "slide through" if you do not demonstrate that you understand frictional forces on the Moon.

Physics to Go

1. Based on what you have learned about friction, what difficulties do you envision for walking and running on the Moon? Explain your answer.
   a) What problems do you see for quick starts and quick stops for pedestrians, runners, or athletes on the Moon? Explain your answer.

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Active Physics

Physics Essential Questions

What does it mean?

An object on the Moon weighs one-sixth of its weight on Earth. The frictional force on the Moon will also be one-sixth that of Earth.

How do you know?

The relation between the force of friction and the object's weight was measured on Earth and was a direct proportion. That means that the heavier an object, the greater the frictional force. Because objects on the Moon weigh one-sixth of their weight on Earth, it can be surmised that the friction is six times less on the Moon.

Why do you believe?

On the Moon, the experiment would be identical as to that on Earth. The pulling force would be measured for different weights. A graph would be completed to show the relationship between the weight of the object and the frictional force on the Moon.

Why should you care?

People will be slipping and sliding during sporting events on the Moon due to the decreased friction. Friction can be increased by changing the surface on the shoes of Moon participants. Another approach would be to add sticky fabric to the bottom of shoes and on the field of play.

Physics to Go

1.a)

Reduced friction combined with loose soil on the Moon could present problems for the ability of people to walk or run on the Moon—for you at this stage. Be aware that the pendulum action of the human leg during walking, introduced in the next section, is another problem that affects the ability of people to walk on the Moon. Without the advantage of a strong frictional force, quick starts, stops and changes in direction would be quite difficult. Pedestrians and runners would have to plan these parts of their exercises more carefully to avoid falls, and athletes who require quick changes in direction would require special footwear.

NOTES

NOTES

2.

Weight on Earth =
Desired weight on the Moon =
$mg = 70\text{ kg} \times 10\text{ m/s}^2 = 700\text{ N}$

Person's weight on the Moon =
$70\text{ kg} \times 1.6\text{ m/s}^2 = 112\text{ N}$

Additional weight needed on the Moon $= 700\text{ N} - 112\text{ N} = 588\text{ N}$

Weight of bag of potatoes on the Moon $= 4.5\text{ kg} \times 1.6\text{ m/s}^2 = 7.2\text{ N}$

Number of bags needed to carry on the Moon =
$588\text{ N} \div 7.2\text{ N/bag} = 82\text{ bags}$

3.

Carrying extra weight on the Moon equal to five times the person's body weight on Earth would provide the normal amount of "Earth" frictional force for walking on the Moon. For example, a person who weighs 100 lb on Earth carrying 500 lb (500 Earth points, that is) would feel normal weight and frictional force on the Moon. This would make starting and stopping more difficult however, since the inertia associated with increasing the mass by a factor of six would mean a great deal of muscle.

4.

Reduced friction on the Moon would increase the tendency to "spin out" on curves, causing the cars or bikes to leave the track. This could be compensated for by banking the track to provide the necessary centripetal force that would normally be provided by friction.

5.

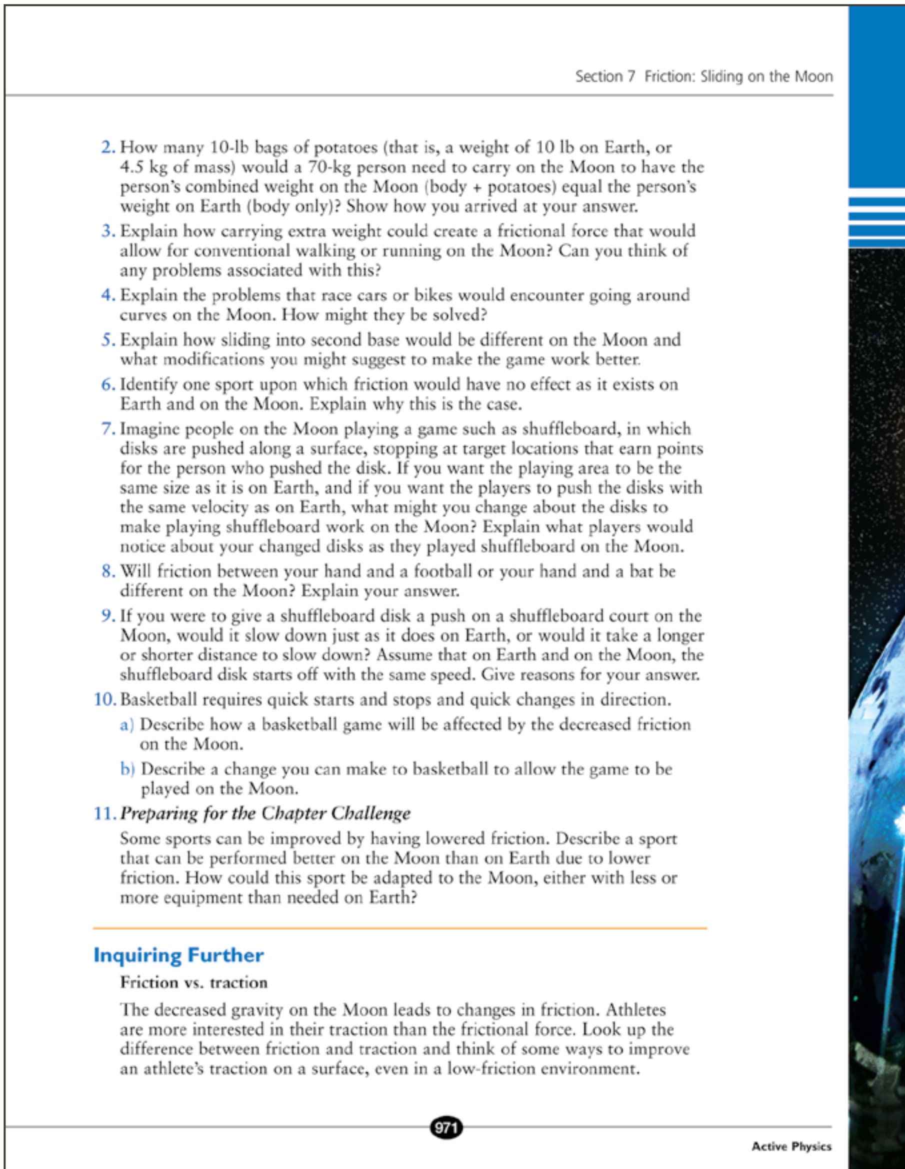
A person would slide much more because of the decreased friction. The person may slide right past the base. To help prevent this problem, one solution might be handholds attached to the bag to allow the slider to grab on when sliding into the base.

6.

If air resistance is included as a frictional force, it is difficult to think of a sport that would not be affected by differences in frictional effects between Earth and the Moon—perhaps the sport of curling, which is played on ice and deals with very low friction in the first place.

7.

The mass of the shuffleboard disks could be increased in order to produce the same frictional force as on Earth. This would make the disks slow down similarly to a game played on Earth. But the much larger mass would mean that the player would notice they must apply a much larger force to the disk in order to get it moving at the same speed. Perhaps a better way to go would be to change the nature of the playing surface and/or disk surface so that the frictional force is six times larger for a given weight. This would produce the same slowing-down behavior as on Earth but would not change the force necessary to accelerate the disks to the same speed.



2. How many 10-lb bags of potatoes (that is, a weight of 10 lb on Earth, or 4.5 kg of mass) would a 70-kg person need to carry on the Moon to have the person's combined weight on the Moon (body + potatoes) equal the person's weight on Earth (body only)? Show how you arrived at your answer.
3. Explain how carrying extra weight could create a frictional force that would allow for conventional walking or running on the Moon? Can you think of any problems associated with this?
4. Explain the problems that race cars or bikes would encounter going around curves on the Moon. How might they be solved?
5. Explain how sliding into second base would be different on the Moon and what modifications you might suggest to make the game work better.
6. Identify one sport upon which friction would have no effect as it exists on Earth and on the Moon. Explain why this is the case.
7. Imagine people on the Moon playing a game such as shuffleboard, in which disks are pushed along a surface, stopping at target locations that earn points for the person who pushed the disk. If you want the playing area to be the same size as it is on Earth, and if you want the players to push the disks with the same velocity as on Earth, what might you change about the disks to make playing shuffleboard work on the Moon? Explain what players would notice about your changed disks as they played shuffleboard on the Moon.
8. Will friction between your hand and a football or your hand and a bat be different on the Moon? Explain your answer.
9. If you were to give a shuffleboard disk a push on a shuffleboard court on the Moon, would it slow down just as it does on Earth, or would it take a longer or shorter distance to slow down? Assume that on Earth and on the Moon, the shuffleboard disk starts off with the same speed. Give reasons for your answer.
10. Basketball requires quick starts and stops and quick changes in direction.
    a) Describe how a basketball game will be affected by the decreased friction on the Moon.
    b) Describe a change you can make to basketball to allow the game to be played on the Moon.
11. *Preparing for the Chapter Challenge*

    Some sports can be improved by having lowered friction. Describe a sport that can be performed better on the Moon than on Earth due to lower friction. How could this sport be adapted to the Moon, either with less or more equipment than needed on Earth?

Inquiring Further

Friction vs. traction

The decreased gravity on the Moon leads to changes in friction. Athletes are more interested in their traction than the frictional force. Look up the difference between friction and traction and think of some ways to improve an athlete's traction on a surface, even in a low-friction environment.

8.

The frictional forces in these two cases would be the same. Here, friction is not dependent on gravity, but on the pressure of your fingers on the ball or on the bat.

9.

The shuffleboard disk would require a much larger distance to slow down on the Moon as compared to Earth. Since the disk has a weight of one-sixth its Earth weight on the Moon, the normal force it exerts on surface will also be one-sixth as large, and thus the friction force slowing it. One-sixth the force implies one-sixth the acceleration. Using $v^2 = 2ad$, shows that with the same initial speed, but an acceleration one-sixth as large, the distance traveled during the negative acceleration will be six times further.

10.

Basketball players rely on the force of friction between their shoes and the court to apply the force needed for the quick starts, stops and changes in direction they use in the game. With a friction force one-sixth the size on the Moon, these changes will be impossible without them slipping a great deal. One possible solution to this difficulty could be to change the surface and the shoes the players wear to increase the coefficient of friction between them by a factor of six.

11.

Preparing for the Chapter Challenge

Ice skating relies on the low friction between the skates and the ice to allow the athletes to glide along the surface. With an even lower force of friction on the Moon, the skaters could perform many more maneuvers without having to push off on the ice to increase their speed again, possibly leading to multiple jumps and other moves in rapid succession.

Inquiring Further

Traction is the physical process in which tangential force is transferred through friction. In sports, athletes think of traction as a means to "grip" the surface in order to push off with force for a quick change of direction. Students may suggest cleats, spikes, or even a sneaker with some kind of adhesive on the sole to improve traction.

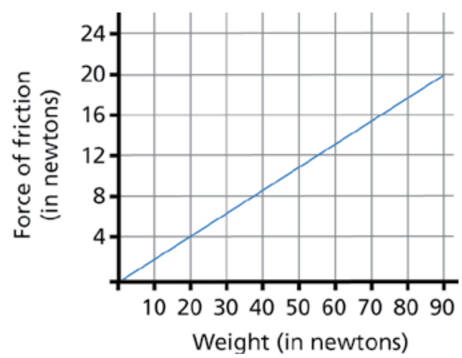
CHAPTER 9

SECTION 7 QUIZ

9-7c **Blackline Master**

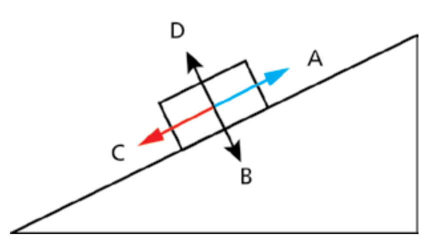
For the purpose of answering the following questions, the acceleration due to gravity on the Moon is 1.6 m/s² and on Earth is 10 m/s².

1. The graph below shows how the force of friction increases between two surfaces as the force holding the surfaces together increases. According to the graph, what is the force of friction when an object weighs 60 N?



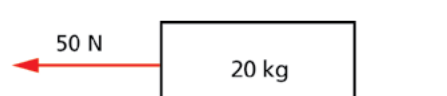
a) 60 N
b) 24 N
c) 16 N
d) 13 N

2. The diagram below shows a box sliding down an inclined plane. The force of friction on the box is in direction



a) A.
b) B.
c) C.
d) D.

3. The diagram below shows a box of mass 20 kg and weight 200 N being pulled across a level floor with constant speed by a force of 50 N. The force of friction between the box and the floor is closest to



a) 4 N.
b) 20 N.
c) 50 N.
d) 200 N.

4. Which statement below best explains why the force of friction for someone running on the Moon is lower than for the same person running on Earth?

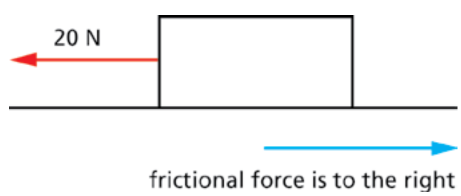
   a) The Moon has a weaker gravitational field than Earth.

   b) People on the Moon weigh less than people on Earth.

   c) The force holding someone down on the Moon is less than on Earth

   d) All of the above are reasons.

5. The diagram below shows a force of 20 N applied to a box at rest on a level surface. If the maximum frictional force between the box and the surface is 30 N, which statement below describes the motion of the box?



   a) The box will move with constant velocity to the left.

   b) The box will have a negative acceleration while moving to the left.

   c) The box will accelerate to the right.

   d) The box will remain at rest.

SECTION 7 QUIZ ANSWERS

1. d) By direct reading from the graph, find 60 N on the weight axis, read up to the line, then over to the friction force axis, and you will see it is 13 N.

2. a) The force of friction always opposes the motion of a moving object. If the box is sliding toward point C, friction is toward point A.

3. c) Newton's first law states that an object travelling with constant velocity has no net force acting on it, so the force opposing the applied force (the force of friction) must also equal 50 N.

4. d) The force of friction depends upon the surface and the force holding the surfaces together. The force holding a runner to the surface of the planet is the runner's weight, and the runner's weight depends upon the strength of the planet's gravitational field. Thus, answers a)–c) all apply, and d) is the most correct.

5. d) The force of friction is a reaction force that varies with the applied force up to the maximum friction force. If an applied force is less than the maximum, the force of friction equals the applied force, and the box that is at rest remains at rest.