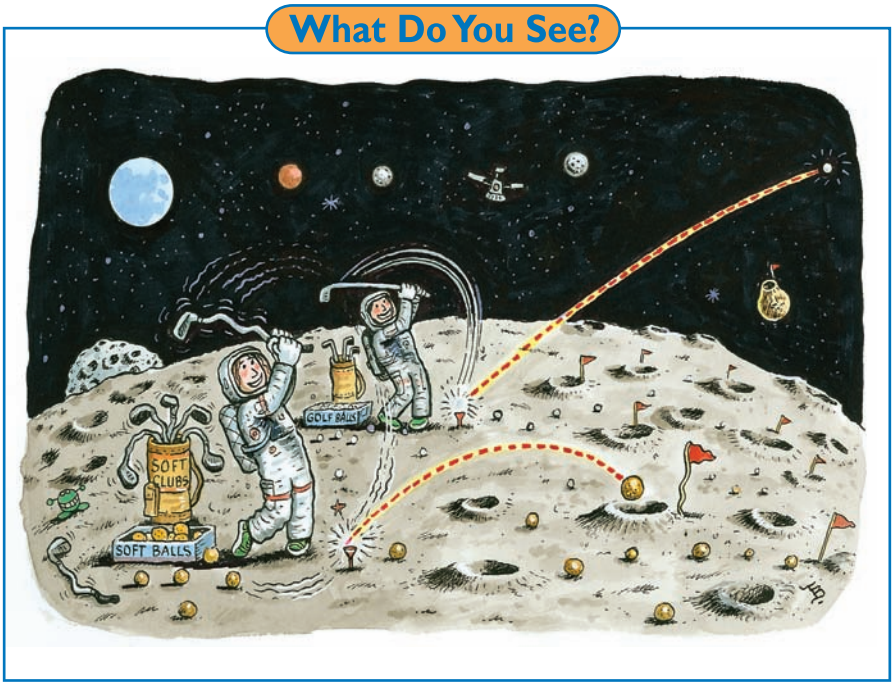
Section 6 Momentum and Gravity: Golf on the Moon

Learning Outcomes

In this section, you will

- **Compare** the bouncing qualities of balls made from a variety of materials.
- **Relate** bounce height to velocity immediately after impact.
- **Analyze** the required characteristics of a replacement for a standard golf ball that would limit the range of a ball hit on the Moon to the typical range of a golf ball hit on Earth.
- **Analyze** how a golf club would need to be modified to limit the range of standard golf balls hit on the Moon to the typical range of a golf ball hit on Earth.
- **Discover** collision and rebound difference when masses of the objects are not the same.

What Do You See?



What Do You Think?

Astronaut Alan Shepard accomplished two firsts. He was the first American to ride a rocket into space (May 1961) and he was the first person to hit a golf ball on the Moon (February 1970).

- **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?**

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

For this *Investigate*, you will first explore how balls of different construction respond when dropped on the floor and bounce. You will apply this information to the physics of golf to see how the game could be changed to make it playable on the Moon. Finally, you examine the physics of the interaction between a golf club and a golf ball to see if altering the ball, the club, or both would make golf an enjoyable sport for the Moon.

1. From your previous analysis, one would expect that the golf ball would travel six times as far on the Moon as on Earth. That may be much too far for players to walk.

a) List three ways in which you could limit the distance that the ball would travel.

2. You will explore one strategy to limit the distance — a golf ball that does not bounce well off the ground and/or off a golf club. A "dead" golf ball might reduce the flight distance on the Moon. Obtain a standard golf ball and several other balls of similar size, such as, a super ball and table-tennis ball that might be used for "Moon golf." Identify each ball in some way.

a) Make a descriptive list of the golf balls in your *Active Physics* log.

b) Decide whether or not you agree with the physicists who made the following statements:

i) When different kinds of balls are dropped from equal heights, all of them hit the floor with the same speed if air resistance is small.

ii) Each ball rebounds with its own particular speed relative to the floor.

iii) The speed of each ball after impact would be the same if the balls remained still and the floor moved upward at impact speed and hit each ball from below.

c) Rank these in order of "ease of understanding."

3. Position a 2-m stick (or two ordinary meter sticks clamped end to end) vertically with the zero-end resting on the floor. Secure the 2-m stick to a wall or the edge of a table so that it will not move. Allow enough room to observe a falling ball with the stick in the near background.

4. Drop each ball from a height of 2 m so that it falls in front of the stick. One member of the group should be prepared to read the maximum height reached by the bottom edge of the ball when it bounces back up from the floor. Practice a few times before recording data. Decide how many trials for each ball you will perform and average the bounce heights.

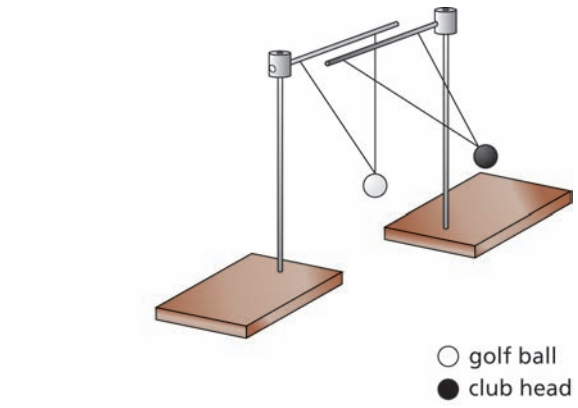
a) Record the bounce height in your log next to the description of each ball.

b) Divide each bounce height by the bounce height of the standard golf ball. Record the answers in your log book.

c) One strategy for limiting the ball's traveling distance would be to alter the bounciness of the ball. Would a ball that bounces only $\frac{1}{6}$ as high as a golf ball "fly" only $\frac{1}{6}$ as far when hit by a golf club?

d) Do any of the balls bounce only $\frac{1}{6}$, or 0.167, as high as a golf ball? Which, if any of the balls, comes closest to bouncing $\frac{1}{6}$ as high?

5. Golfers on the Moon will want to swing their clubs at normal speed. Altering a traditional golf ball or using another type of ball could cause big problems. A second strategy is to change the mass of the head of the golf club as a way of reducing the range of a golf ball hit on the Moon. Use the apparatus shown in the diagram to simulate hitting a golf ball with the head of a golf club.



One ball, representing the head of a golf club, is pulled back and released to collide with a stationary ball representing a golf ball.

Practice the collision a few times so that you can repeat it with precision.

6. On Earth, the launch speed of a golf ball is typically 1.5 times the speed of the club at impact. Perhaps the head of the golf club could be changed, so that the a golf ball's launch speed would be reduced to about 0.6 the speed of the golf club. Reducing the speed of the golf ball from 1.5 times to 0.6 times the speed of the golf club keeps the range of the golf ball about equal to a comparable *range* on Earth.

Try various combinations of masses representing the golf ball and the head of the golf club. Find a combination for which, as shown in the sketch, the ball moves away just after the collision at about 0.6 times the speed of the head of the golf club just before the collision. Judging the speed of the "ball" after the collision to be 0.6 times the speed of "head of the golf club" is not easy. If the "ball" rises to about $\frac{1}{3}$ the height the "head of the golf club" was dropped from, then the speed should be about right. (The *Physics Talk* discusses the energy transformations that show why this will work.)

a) What combination of masses for the golf ball and the head of the golf club most closely meet the above condition? For this case, which "representative ball" was more massive, "the one representing the golf ball" or the "one representing the head of the golf club"? What is the ratio of the masses, (mass of "golf ball")/(mass of "head of the golf club")? Write your answers in your log.

b) Describe how the "head of the golf club" moves after it hits the "golf ball." Do you think golfers would be able to accept that situation? What problems are apparent with this method of reducing the range of a golf ball on the Moon?

7. Discuss within your group whether it seems possible to use some combination of altering both the golf ball and the golf club to make the game of golf a viable sport on the Moon if the size of the golf course on the Moon is the same as that on Earth. Write the reactions of your group and your personal opinions concerning the following questions in your log:

a) Does playing golf on the Moon seem feasible? Explain.

b) Would golfers on the Moon be likely to have complaints? Explain.

c) How else might you try to solve the problems with Moon golf?

8. Golf may not be your game. Lots of other sports involve hitting a ball with a bat, a foot, a hand, or a racquet. For each of these sports on the Moon, you may be bothered by how far the ball travels and you may want to "tame" the sport by altering the ball or the object that hits the ball. Choose two sports in which a ball gets hit and describe how you might alter the ball or the object that hits the ball to decrease the distance the ball travels.

   a) Record your descriptions in your log.

Physics Talk

THE PHYSICS OF TAMING THE GOLF BALL

The conservation of energy informs you that the total energy of an object must remain constant unless it does work or work is done on it. A bouncing ball has gravitational potential energy *GPE*, then it gains kinetic energy *KE* as it falls, which then leads to a gain once again of *GPE* as it travels up followed by *KE* followed by *GPE*, and so on. It is as if the energy is "bouncing" between *GPE* and *KE* as the ball is bouncing up and down. Since each successive bounce is not as high as the previous bounce, there is a loss of energy. In this section, you measured the change in height of a golf ball and could calculate the loss in energy of each successive bounce. Where does the energy go? Since energy is conserved and you noted a loss in the gravitational potential energy after each bounce, you must look or listen for where this energy went. Some of the energy went into sound (each bounce made some sound) and into heat (the temperature of the ball probably increased a tiny bit, and into vibration of the floor (yes, the floor vibrates — if it were a bowling ball, you would notice it). If you were able to measure all these energies with precision, their sum would equal the energy loss in the height of each bounce.

By introducing a different ball, you can have a poorer bounce and a greater loss of energy during each bounce. This could limit the **range** of the golf ball so that the game of golf on the Moon does not send the ball so far away.

Physicists like to view the same phenomenon from different perspectives in order to better understand all that is happening. When a ball bounces, one perspective is that the ball and floor collided. The very massive floor appears to remain at rest after the collision, but could be moving a bit, and it would take some ingenuity to measure the vibration of the floor. By changing the floor, you could change the bounce. The floor's bounce properties could change with padding or by using a different floor material. It is difficult to change the mass of the floor.

A golf club and a golf ball also undergo a collision. You can change the mass of the golf club in order to change this collision with the golf ball. You investigated this change and the affect on the golf ball in this *Investigate*.

Physics Words

range: the total horizontal distance that a projectile travels.

It is true that a ball that bounces only ⅙ as high as a golf ball when dropped from the same height would have ⅙ of the range of a golf ball when hit by a golf club. Two equations help to show this.

The first equation is found by equating the kinetic energy of the bouncing ball at the instant it leaves the floor to the gravitational potential energy the ball has at the peak of its bounce:

$$\frac{1}{2}mv^2 = mgh$$

For a specific ball, the mass remains constant as does the acceleration due to gravity. If the height decreases by a factor of 6 (on the right side of the equation), then the v^2 must also decrease by a factor of 6 (on the left side of the equation).

This means that if the "take-off" speed squared of an object doubles, then the height it reaches doubles. Or if the "take-off" speed squared of an object decreases to half its value, then the height the object reaches decreases to half its value.

A second equation provides the range or total horizontal distance that a ball travels.

$$R = \frac{v^2}{g},$$

where R is the maximum range (horizontal travel distance) of a projectile that is launched with speed v at a 45° angle of elevation. (This equation is explained in *Active Physics Plus*, if you wish to see how it is derived.) Notice that this equation shows that the maximum range of a ball is related to the ball's launch speed squared v^2 in the same way the maximum height an object reaches is related to the ball's "take-off" speed squared.

Both the bounce height of a dropped ball and the range of a ball depend on the ball's speed squared in a similar way. Therefore, a ball that bounces ⅙ as high as a golf ball also would have ⅙ of the maximum range of a golf ball.

The data you have gathered about the bounce heights of balls can be used to infer how the speeds of various kinds of balls, when hit, compare to the speed of a golf ball after it gets hit. This will help you decide if any of the balls you have tested would be feasible substitutes for playing golf on the Moon with a traditional Earth golf ball.

Checking Up

1. A bouncing golf ball loses energy with each successive bounce. Where does this lost energy go?
2. How is energy conserved if a ball loses height with each successive bounce?
3. How does the range of a projectile depend upon its launch velocity?
4. If the height of a golf ball's bounce decreases by a factor of 6, how will the range of the golf ball change?

Active Physics *Plus*

+Math	+Depth	+Concepts	+Exploration
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Horizontal and Vertical Projectile Motion

You can analyze the motion of any projectile launched over level ground. To make the analysis general, you must consider a projectile launched at any speed and at any angle. Let v_0 be the speed at launch and let θ be the launch angle. First, draw the horizontal (v_x) and vertical (v_y) components of v_0 by constructing the right triangle with sides v_x and v_y and hypotenuse v_0. From this triangle, you can see that

$$\cos\theta = \frac{v_{0x}}{v_0} \text{ and } \sin\theta = \frac{v_{0y}}{v_0}$$

Using algebra, then

$$v_{0x} = v_0 \cos\theta \text{ and } v_{0y} = v_0 \sin\theta$$

These two relationships will be useful later.

In analyzing this projectile motion, the horizontal and vertical motion are independent of each other.

Now consider only the vertical motion. The projectile starts out with a vertical velocity of v_{0y} and it has a vertical velocity of zero when it reaches it highest point (because at that point it is not moving up or down). Then it undergoes free fall, starting with a vertical velocity of zero and ending with a vertical velocity of $-v_{0y}$ when it strikes the ground. The vertical motion on the way down is the same as the vertical motion on the way up, only in the reverse direction. This means that it takes the same time for both parts of the motion. You can find the time for half the trip by remembering the definition of acceleration and the fact that for one half of the trip, the velocity was zero.

$$a = \frac{\Delta v}{\Delta t}$$

$$\Delta t = \frac{\Delta v}{g}$$

This is the time for one-half the trip and can be signified as:

$$t_{1/2} = \frac{v_{0y}}{g}$$

The time for the entire trip would be twice this value:

$$t = 2t_{1/2} = \frac{2v_{0y}}{g}$$

The horizontal motion is simply motion at a constant speed. Therefore, the range R of the projectile is given by

$$R = v_{0x}t = v_{0x}\left(\frac{2v_{0y}}{g}\right) = \frac{2v_{0x}v_{0y}}{g}$$

If you now substitute in your earlier expressions for v_{0x} and v_{0y}, you arrive at the general result:

$$R = \frac{2(v_0 \cos\theta)(v_0 \sin\theta)}{g}$$

$$= \frac{2v_0^2 \sin\theta \cos\theta}{g}$$

1. To find the launch angle that gives the maximum range, first note that v_0 and g do not depend on the launch angle and therefore do not vary. The maximum range results when the function $2\sin\theta\cos\theta$ has its maximum value. Graph the function $2\sin\theta\cos\theta$ for various values of θ to determine at what θ it is a maximum.

   You should have found that the R is a maximum when $\theta = 45°$. At this value of θ,

   $$\sin\theta = \cos\theta = \frac{1}{\sqrt{2}} = 0.707.$$

   This means that $2\sin\theta\cos\theta = 1$ and that

   $$R = \frac{v_0^2}{g} \text{ when } \theta = 45°.$$

2. From your plot of $2\sin\theta\cos\theta$ vs. θ, compare the range when $\theta = 40°$ and when $\theta = 50°$. What about when $\theta = 30°$ and $\theta = 60°$? Can you make a general statement about the range for angles less than 45° as compared to angles greater than 45°?

3. Another way of finding that the maximum range occurs at 45° is by using the trigonometric equation $2\sin\theta\cos\theta = \sin 2\theta$. If you maximize $\sin 2\theta$, then you will maximize the range. The $\sin 2\theta$ function is maximum when $2\theta = 90°$. Therefore, $\theta = 45°$ will produce the maximum range as shown by your graphical analysis.

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.

What you learned in this section would apply in similar ways to other sports in which a bat, racquet, paddle, club, or other hitting device is used to launch an object into a state of projectile motion. In your actions to "tame down" the motion of a golf ball, you learned that you can expect similar problems and use similar solutions in other sports.

Physics to Go

1. Describe briefly why you would have to change the racquet or ball in a game of tennis.
2. On Earth, golfers sometimes hit "divots," chunks of grass sod, when the club hits the ground in the process of hitting the ball. On the Moon, a divot would be a cloud of sand and dust from the lunar soil. With weak gravity and no wind due to the lack of air, would "Moon divots" present a problem for golfers on the Moon? What would a "dust divot" look like on the Moon?
3. Many golfers enjoy the social part of golf as much as the game. It's a good chance to talk or to conduct business with golfing partners. Would golfers be able to talk and conduct business as usual on the Moon? Also, golfers holler "Fore" to warn people in the fairway who might be in the way of a hit golf ball. Would that method of warning work on the Moon? Explain your answers.
4. Make a list of three reasons for
   a) being in favor of proposing golf to NASA as a sport for the Moon
   b) being against proposing golf to NASA as a sport for the Moon
5. Name three sports that use bats, clubs, or racquets. Describe the changes that you would make in the ball or hitting device to ensure that the sport is fun on the Moon.
6. ***Preparing for the Chapter Challenge***

   Not all Earth sports could be played on the Moon, even if modified. Other than golf, suggest a sport that you think would not be suitable for the Moon and give your reasons why.

Inquiring Further

Coefficient of restitution

It has been suggested that one way to play golf on the Moon would be to use a ball that bounces one-sixth as high as a standard golf ball. For a physicist, this would be discussed in terms of a golf ball's "coefficient of restitution." Find out how the coefficient of restitution is determined for a golf ball, and if professional golf associations set any limits on the size of the coefficient for officially sanctioned golf balls.