There are only so many modifications you can make to a tennis ball or a baseball, but golf balls are constantly changing. Since Americans spend $650 million per year on golf balls, there is much financial incentive for manufacturers to try to find a ball that will go just a little farther and straighter. Today, there are well over 90 different types of golf balls available to the public! Once you hit the ball, the laws of physics govern what happens to it. But the composition of the golf ball itself is due to amazing advances in materials science that are firmly rooted in chemistry.

Golf balls have come a long way since the first wooden ones were made in the 15th century on the east coast of Scotland. These inefficient wooden balls were used until the mid-seventeenth century, when the “featherie” was introduced. The featherie was made from a spherical leather pouch that was soaked in a solution of alum. It was then filled with “a top hat full” of wet goose feathers that were softened by boiling. The feathers expanded as they dried while the leather shrunk. The result was a very hard ball. It was painted white to make it more visible. At best, these balls could travel from 150–175 yards, which was twice the distance that the wooden balls could travel. But the high price of these first golf balls made the sport inaccessible to the common man. A single golf ball could be more expensive than a club!
In 1848, the gutta-percha golf ball was introduced. Gutta-percha is the dried rubber-like sap of the sapodilla tree from Malaysia. When this sap is heated to the temperature of boiling water, it develops the consistency of putty, allowing it to be fashioned into a solid ball. When cooled, it becomes a very hard sphere. These balls could be inexpensively produced. They could easily be reheated and reshaped if they became deformed. As a result of these affordable balls, golf became increasingly popular. As these balls became nicked up from use, they traveled much farther. Eventually, these “guttie” balls were intentionally made with rough surfaces, becoming the forerunner of today’s dimpled golf ball.

In 1898, a Cleveland, OH golfer named Coburn Haskell produced a one-piece golf ball with a rubber core that is considered the forerunner of the modern golf ball. The solid rubber core was wrapped in rubber thread that was then enclosed within a gutta-percha pouch. These balls could be mass-produced, further lowering their cost. The Goodrich Company came out with a pneumatic ball in 1906, which had a compressed air core. Since gases expand when heated, these balls would sometimes explode! Other manufacturers experimented with cores of metal, mercury, or cork.

In 1932, the United States Golf Association standardized the mass and size of all golf balls, which has remained constant up to the present day. The weight cannot be greater than 45.93 grams (1.620 ounces) and the diameter cannot be less than 42.67 mm (1.680 inches). Golf balls pretty much look the same now as they did in the 1930s. But what goes on inside the ball is another story.

The key to a good golf ball is its ability to be both soft and elastic. Older golf balls accomplished this by having a hard elastic core surrounded by a layer of rubber windings that looked like rubber bands. The elastic core is the most important component. Elasticity is very important, since the ability of the ball to spring back quickly is crucial to achieving maximum distance. The elasticity of any substance is measured by something called the coefficient of restitution (CoR). The CoR is simply a measure of how bouncy a ball is. If a ball is dropped from a height of 1 meter, and it bounces back 60 cm, then its coefficient of restitution is 0.6. If it bounced back 70 cm, its CoR would be 0.7 at this particular velocity. If a ball were perfectly elastic, when dropped it would bounce back to its original height. An object like a Superball has a coefficient of restitution that is close to 1. When dropped on a hard surface, it nearly bounces back to its original height. A piece of clay on the other

### Dimples and Spin—The Physics of Golf Ball Flight

Probably the most unique aspect of a golf ball is its dimpled surface. A typical golf ball usually will have anywhere from 300 to 500 dimples, with shallow dimples often alternating with deeper dimples. Dimples may be of various shapes, from circular to hexagonal to triangular. Dimples were officially introduced in 1908 by the Spalding Company, but it was well-known for many years that a roughed up golf ball went farther.

How does it work? As the ball travels, it pushes the air out of the way, leaving a region of reduced air pressure behind the ball, known as a turbulent wake. Think of a boat traveling through the water. As the boat pushes water aside, a wake is created behind the boat. The same thing happens as a golf ball travels through the air. Because the wake is essentially a region where air has been pushed away, there is a partial vacuum behind the ball. Air will rush in to fill this partial vacuum. As a result of air rushing in to fill this partial vacuum behind the ball, drag increases on the ball and the ball slows down.

However, with a dimpled ball, the tiny dimples on the surface of the ball create turbulence in the boundary layer—the thin layer of air surrounding the ball. This turbulence is in the form of little vortices or eddy currents all along the dimpled surface of the ball. Air becomes trapped along the surface of the ball, causing air to flow farther down around the ball before it separates to form the wake. Because less air is displaced, more air can flow directly around the ball, decreasing air resistance. The size of the wake behind the ball is greatly decreased. With a smaller wake, there is less drag and the ball travels farther.

If a golf ball is hit properly, it will spin as it moves through the air. The spin should be such that the top of the ball is moving toward you (away from the direction the ball is going) and the bottom of the ball spinning away from you. This is known as backspin and is imparted to the ball by the grooves on the head of the club when hit squarely. When a ball has backspin, the air that is moving over the top of the ball is moving in the same direction as the air that flows over the top of the ball, causing the air along the top to move faster than the air underneath the ball. According to Bernoulli’s principle, the faster the air moves, the less pressure it exerts. Because the air is moving faster over the top surface of the ball, there is less pressure on the top and more pressure underneath. This increased pressure under the ball produces lift, keeping the ball in the air longer and allowing it to travel farther.

Dimples help to produce lift because they increase airflow around the ball, maximizing lift. End result—a dimpled golf ball will go twice as far as a nondimpled golf ball.
hand, has a CoR close to zero, since it does not bounce back at all.

The greater the CoR of a golf ball, the farther it will go when struck. A large CoR represents a ball that is traveling very fast when it leaves the tee. A typical golf ball will have a CoR of approximately 0.8 when struck at 20 mph and a CoR of around 0.6 when struck at 100 mph. This does not mean that balls struck at 20 mph will go farther, but rather that less energy is lost at lower speeds than at higher speeds. If the collision between ball and club was perfectly elastic, then 500-yard drives would be the norm! Watch out, Tiger Woods!

Interestingly, it was the development of the Superball that led to many advances in the golf ball. Superballs are made with polybutadiene, a synthetic rubber with a very large CoR. However, by itself polybutadiene is too soft to be used in golf balls. The key is that the rubber must be vulcanized, which means that the polymer strands must be partially cross-linked by a substance, which can add to the double bonds in the polymer. Using vulcanized rubber, the CoR of golf balls could be made even greater.

Elasticity is only one aspect of a golf ball, however. The golf ball must also deform significantly during the millisecond of contact between ball and club. This deformation is too brief to witness with the naked eye but can be witnessed using high-speed photography. At the moment of contact, the ball flattens considerably, losing as much as one-third of its original diameter. This deformation is only possible because the bonds between molecules within a golf ball act like tiny springs that can be stretched and then snap back into place.

This flattening of the golf ball greatly increases the amount of time the club is in contact with the ball. If the club is in contact with the ball for a longer period of time, you have delivered a greater impulse to the ball. A greater impulse means that more of the momentum of the club will be transferred to the ball. That is why it is so important to follow through with your swing. In order to maximize the time of impact between a golf ball and club, the ball must deform when hit. The greater the time of impact between the club and ball, the farther the ball will go.

One material by itself cannot give both optimal deformation and elasticity. Older three-piece golf balls met this challenge by being composed of a hard elastic core that would bounce back quickly. A hard elastic core, however, does not deform very much during impact with the club. That is why there was a second layer of rubber windings around the core. It was this middle layer that deformed during contact, while the core provided the elasticity. This middle layer looked like little rubber bands. The ball would then be covered with balata, a nonelastic natural rubber obtained from the latex of South American rubber trees. These “rubber band” balls are no longer manufactured today.

Try this with a golf ball:

1. Determine the density of a golf ball. Use the formula \( D = \frac{M}{V} \). Find the mass using a balance. To find the volume, use water displacement, or use the formula \( V = \frac{4}{3} \pi r^3 \). Because you probably know what happens if you hit a golf ball into a body of water, the density you arrive at should be greater than that of water, which is 1 g/ml. You can buy floating golf balls at a novelty shop. These are made with a hollow core. If you can find one, determine its density using the same method.

2. Determine the coefficient of restitution of various golf balls as well as other types of balls (like the Superballs on page 4). Drop each from a height of 1 meter and measure the distance it rebounds. If the ball rebounds 50 cm, its coefficient of restitution is 0.5 at that velocity.

The more modern 2-piece golf balls are composed only of a large core and a thin cover. If the core were made of only one material, it would be impossible to be both soft and elastic. Therefore, the core of the ball is made up of progressively softer layers, with the harder layers on the inside. The two-piece balls can then effectively mimic the 3-piece balls in terms of both temporary deformation when struck and elasticity.

All golf balls today essentially have a core surrounded by either one or two layers. The core is always composed of some combination of rubber compounds. Some lower-end balls also have a fluid-filled sphere at the center of the core. Today, nearly all golf balls are covered with a synthetic outer layer, replacing the natural balata covers. Higher-end balls are typically covered with a synthetic rubber such as urethane or a combination of rubber compounds. Lower-end balls typically use Surlyn, which is a synthetic thermoplastic polymer. Thermoplastics soften upon heating.

The next time you go golfing (or watch it on TV), think of all the wonderful chemistry that has gone into the humble little golf ball. A big reason that records are continually being broken in golf, as well as many other sports, is because of improved technology. Understanding a little about the science of golf will obviously not make you into the next Tiger Woods, but it can’t hurt your golf game.

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