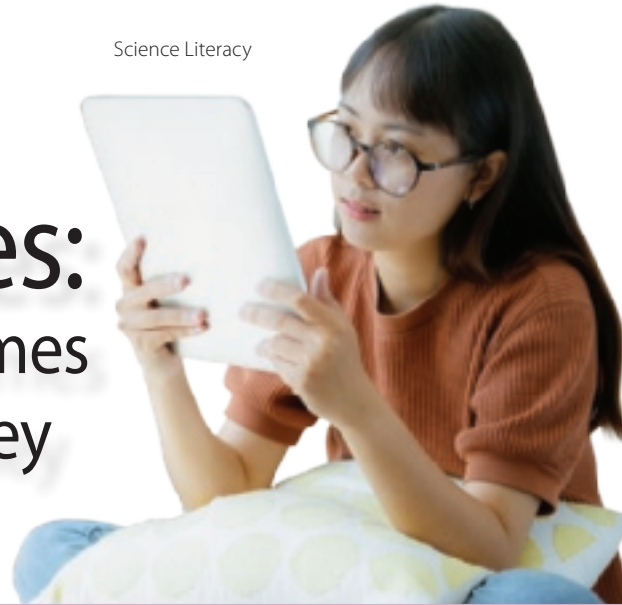
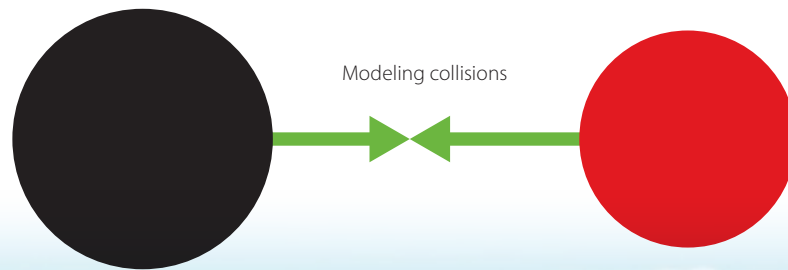


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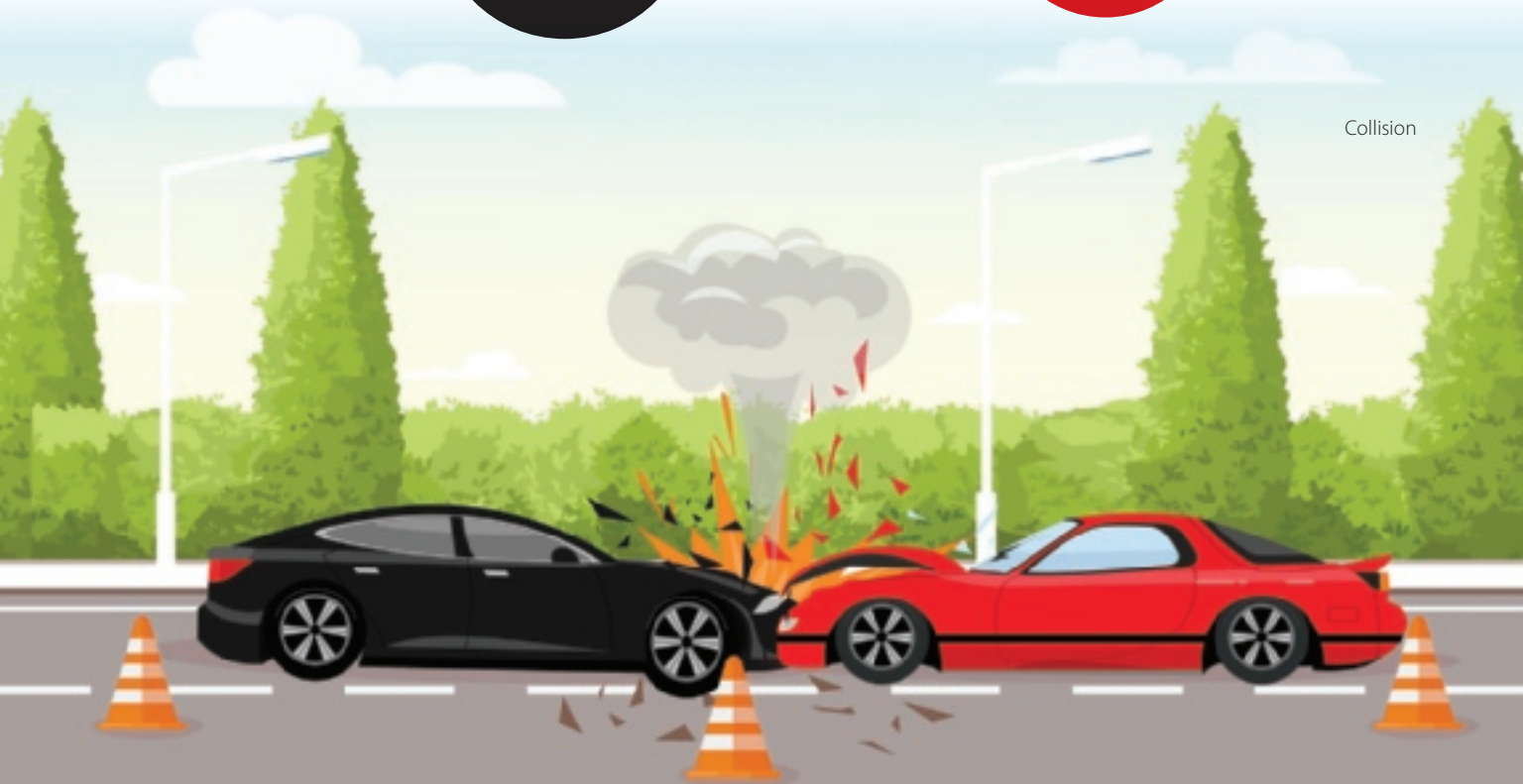
Why do things sometimes get damaged when they hit each other?



Science Literacy Student Reader



Collision



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Contact Forces

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Contact Forces

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Put Yourself in This Scene

A group of friends heads to the nearby state park on a hot summer day. The lake there has a swimming area with a lifeguard. It's the perfect place to cool off. The swimming area has a floating platform with diving boards, too. The deck of the platform is about three feet above the surface of the water. The low diving board is about five feet above the water.

"Come on, let's bounce off the diving board. I'm so hot. I can't wait," says Julian.

"I think I'm just going to jump off the deck," says Arya, who tends to be more cautious than Julian. "I don't want to slap the water that hard."

"What difference does it make?" replies Julian. "The water's plenty deep. You're lighter than I am, anyhow, so you won't hit the water hard even if you aren't the most graceful diver."

The two friends debate the different factors at play in

how hard they would hit the water. They know that the energy with which they hit the water has something to do with mass and the way gravity makes things increasingly gain speed as they fall toward Earth. But how a body hits the water seems to be important, too, at least in terms of whether or not it hurts. Will Arya, at 100 pounds, really hit the water with less energy than Julian at 120?





They're still talking it over when a third voice chimes in, from atop the high dive. "You guys are ridiculous. I'm going to jump from up here!"

Reggie is perched atop the high dive, a good twelve feet above the surface of the water.

"It's not a problem," he proclaims. "At any of these heights, there's no real difference in how hard any of us will hit the water. Just jump in however you want. You'll be fine."

Reggie always needs to be the one that takes things just a bit higher, faster, and farther than everyone else. He makes his jump—and an impressive splash when his 85-pound cannonball smacks the water.

Who's right? What factors really are in play here? Is it about distance? Mass? Or does a painless jump have more to do with the shape the diver takes as the body enters the water?

That's what this book is about—scientific literacy, which means knowing how to

think about science topics that you read or hear about. Our world has 24–7 news, social media, and too many websites to count. The amount of information we must sort through is overwhelming, and all the information is not reliable. In the internet age, sources of information are often obscure or not trustworthy. It is good to process information with a healthy degree of skepticism.

We will make our way back to the topic of diving by the end of the book. Along the way, the series of reading selections and the writing exercises that go with them will help you flex your mental muscles and sharpen your science literacy skills. The ability to read about science, understand the information, and tell truth from fallacy or misrepresentation is important. Science literacy helps you as an individual and as a consumer, and it shapes the ways you affect the community in which you live.

Designing for Collisions

This modern yellow car with the crumpled hood was designed to collapse in the front end of the vehicle. That increased the chances that the passenger compartment remained intact.

The older car did not have a crumple zone built into its design. It suffered damage to all of its parts, and the accident was fatal for the driver. The crumple zone is now a standard part of automobile design. How does a crumple zone work?



Let's think first about what determines how powerful a **collision** will be. A moving object experiences a change in velocity when it collides with something else (either moving or stationary). The change in velocity is a product of two things—on the **force** acting on the object and on the length of time over which the force acts. So, if the impact can be spread out across a longer span of time, the force of the impact will be reduced. Crumple zones can cause the interior part of an automobile to slow down—adding a tiny amount of time to the impact—just enough to avoid catastrophic damage.

The expendable front end is designed to collapse first. By the time the force of a collision has reached the part of a car frame surrounding the passengers, the velocity of the car has been reduced. The crumple zone's broken, bent, snapped, and folded materials have absorbed some of the energy of movement from the car's collision.

Passengers behind the crumple zone are also protected by airbags. Airbags inflate when sensors in the car detect an impact above a certain speed, usually around 8 to 14 miles per hour. A chemical reaction is triggered, producing a gas that very quickly inflates the bags. The airbags cushion the passengers as their forward motion carries them toward the steering wheel and dashboard. Side-impact airbags can provide the same



Seat belts restrain passengers from crashing into the steering wheel or being hurled through the windshield, but they do not restrain the head and neck. Airbags inflate very quickly, slowing the head that snaps forward.

cushioning effect against the insides of the doors. Like the crumple zone, the airbag exerts a force on the bodies that results in their velocity changing from a high value to zero. But by having this occur over a longer period of time, the force experienced by the bodies is reduced.

Vocabulary

collision, n. a physical meeting of objects as a result of motion

force, n. a push or pull on a mass that causes the mass's velocity to change

kinetic energy, n. the form of energy that an object has by reason of its motion

Words to Know

- *Velocity* is the speed of an object's motion in a given direction.
- *Acceleration* is a change in velocity.
- The formula "force = mass $\times$ acceleration" ($F = ma$) is known as *Newton's second law of motion*.
- *Contact forces* require physical contact between objects.

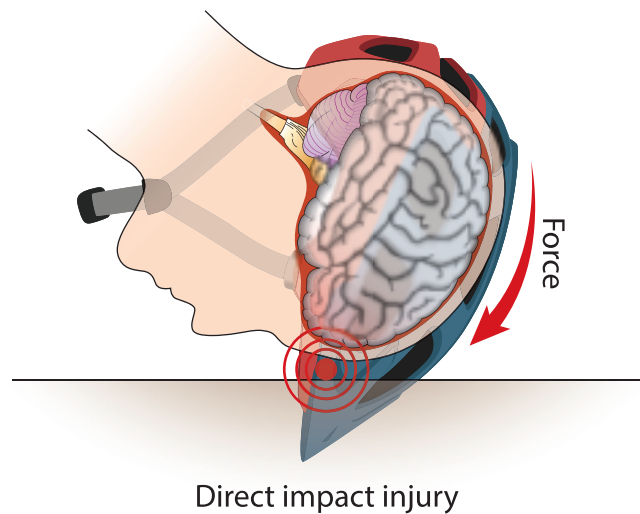
Bike helmet design takes a similar approach, but instead of having crumple zones, bike helmets have parts that are designed to shatter on impact. Like with a crumple zone, this transmits some of the **kinetic energy** (the energy of motion) of the objects in the system—biker's head, asphalt road, automobile—into the materials of the outer shell, which are relatively fragile. Beneath the shell, which shatters easily, is a dense layer of foam material. This material absorbs some of the remaining energy, somewhat like the airbag in a car.



The hard shell of a bike helmet takes some of the force of impact. The dense foam underneath the shell absorbs and distributes kinetic energy, preventing some of it from reaching the rider's skull.

Helmets for baseball, softball, lacrosse, hockey, and football all feature hard shells that receive an initial impact and dense foam that absorbs and redistributes some of the remaining force before it reaches the head. Impact can still injure a person, despite use of a well-designed helmet. Why? Some impacts have so much force that the helmet does not provide enough protection. If a rider's helmet comes in contact with the ground, the ground exerts a force on the helmet. But also, inside the skull, the brain is still moving forward and can be damaged by collision with the skull. The collision of the brain with the inside of the skull can result in a concussion, producing symptoms such as a headache, dizziness, or confusion.

Concussion



Describing Collisions

Which object do you think is responsible for the collision that took place here, the car or the building? Knowing little about the situation, you'll conclude that the car struck the building. After all, cars have wheels and are designed to move. Buildings usually stay in place. Which object hits another one depends on the frame of reference, the point of view from which we are describing or measuring motion within the context of a system of objects.

It was the car's motion that resulted in the collision, though in physical terms, both objects collided. Technically, the house



was moving as well, thanks to Earth's rotation around its axis and revolution about the sun. But in the system involving the two objects as shown in the photo, describing their motions relative to the space they occupy, the car must have been moving toward the house.

Can you determine how this collision occurred?

In this case, both objects involved in the collision were capable of movement. The visual evidence suggests that the blue car struck the silver one. But did the silver car cut in front of the blue car? Was the silver car in motion when the collision occurred? It's hard to tell from just the photo. The two drivers might have conflicting stories about who's to blame!





In this photo, two crash-test cars are colliding in a laboratory owned by the car maker.

From the point of view of the camera, both vehicles were in motion toward each other,

and they collided head-on. Notice how the rear ends of both cars are raised during the collision. The momentum of each car caused its rear end to lift upward when the front end's motion was stopped.

On Earth, gravity and our own perception of weight determine what we label up and down. Our position on Earth's surface establishes a frame of reference. When a basketball is shot toward a hoop, we call that "up" because the ground is our frame of reference. There are three dimensions, though, to the ball's motion. You can measure the changes in the ball's position forward from the shooter, upward from the ground, and side-to-side in the vertical plane shared by the shooter and the hoop. How we describe or measure the ball's motion relies on agreement among the people identifying the frames of reference.



The basket is "up" relative to the players. When a player goes "left," people usually mean relative to that player's own right and left, not relative to the court or anyone else.

Modeling Collision Systems

A collision is a system involving mass (objects or materials) and velocity (motion, speed, and direction). To describe the system, ask: What masses are involved in the collision? What masses aren't? What are the velocities of the involved masses? Are there any other forces affecting the outcome?

Words to Know

Speed is how fast something is moving. *Velocity* describes both how fast and in what direction an object is moving.

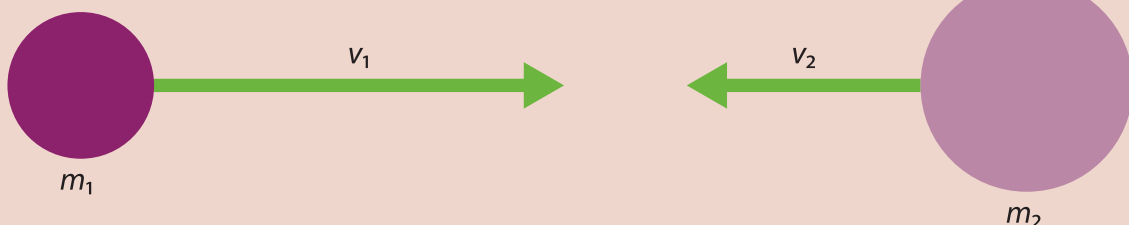
Consider a simple collision system in which two objects are in motion in the same plane and on the same line. For example, two balls rolling on a flat table are traveling on the same plane. To make things even simpler, the objects traveling the same line can only go directly toward or away from each other. There's no way for them to strike glancing blows against each other. Their motions on the line can only result in

- a head-on collision if they are moving toward each other,

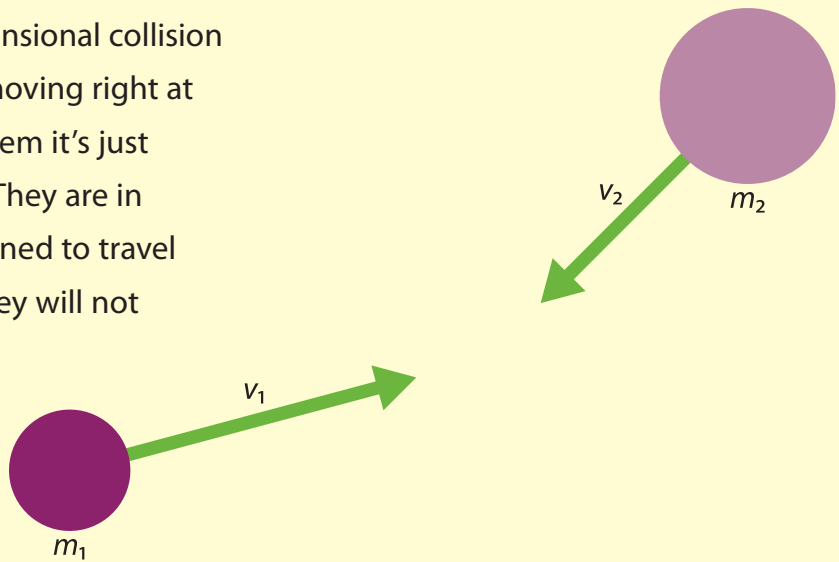
- a rear-ending collision if they are moving in the same direction but the one in the rear is moving faster,
- or no collision at all if the objects move in opposite directions or if they move in the same direction at the same speed.

The objects' masses are represented by purple circles labeled " m ," and velocities are represented by green arrows labeled " v ."

In this model, there's no gravity pulling the objects in any direction. There's no friction between the objects and anything else around them. It's just the two objects and their relative motions.



In a more complex two-dimensional collision system, the masses are not moving right at each other. Again, in this system it's just the two objects interacting. They are in the same plane but not confined to travel along the same line. Since they will not collide head-on, the result of the collision will be different from the result of a direct hit.



Knowing how masses and their velocities would result in a collision enables collisions to be prevented. Aircraft, for example, should not collide. Aircraft operate in a three-dimensional system, so

pilots must control forward, up-and-down, and side-to-side motion. (A pilot also must manage the orientation of an aircraft, adjusting pitch, roll, and yaw to control the plane's alignment relative to the ground.)



Beyond Cars and Crashes

On Earth, many collisions are driven by gravity. All forms of precipitation—snow, sleet, rain, hail—are collisions between different forms of falling water and Earth’s surface. As snow falls, it collides with particles in the air and is prevented from accelerating very much. The eventual collision of a snowflake with Earth’s surface doesn’t involve a lot of mass or velocity, so there’s not much kinetic energy involved. A drop of rain, on the other hand, most likely has more mass and more speed, and therefore, it collides with Earth’s surface more powerfully. This is why we can hear raindrops on a roof but not snow. Hailstones can be comparable to golf balls in size and mass, producing collisions that result in serious damage.



Liquid water collides with solid objects on coastlines, especially where winds whip up large surface waves. Where waves break, the kinetic energy in moving water transforms into other forms, including sound. The mechanical energy of moving water against rock weathers the rock into sediments such as gravel and sand. When the waves break against the shoreline, they produce a loud roar and cause extensive weathering.





Some collisions occur when animals engage in different behaviors, from predator-prey interactions to fighting over mates. Male bighorn sheep butt heads at 20 miles per hour, in a competition for female mates. These competitions can last many hours. The horns and skulls of these sheep are thick enough to endure the repeated collisions.

The fish called long tom, also known as needlefish, has long, narrow jaws that form a swordlike point. The long tom can propel like a dart through the air and strike prey that are several meters away. Occasionally, bad luck causes a leaping long tom to collide with a passing canoeist or swimmer, causing serious injury or death to both human and fish.



It's far more common for cars to crash into animals than the other way around. On roads around the world, collisions between automobiles and wildlife result in injury and death, usually for the wildlife but sometimes for passengers in the automobiles, too.

Collisions between automobiles and large animals such as the moose can result in injury and death, as well as extensive damage to automobiles.



Collisions between ships and marine wildlife can also cause damage, injury, and death. The North Atlantic right whale numbers fewer than 400 individuals as a species, with many deaths due to ship strikes.

The right whale, like all marine mammals, must swim at the surface to breathe. Many

right whales have suffered fatal injuries from collisions with large, fast-moving boats. The species also collides with anchored ropes in fishing gear and can become entangled. Both threats are incidental collisions in terms of human industry, but they are major threats to this endangered species.

Materials That Stretch and Bend



Vocabulary

deform, v. to change shape

A thrill-seeking bungee jumper places a lot of faith in a bungee cord. The bungee cord is elastic.

Elastic materials stretch, bend, or otherwise deform, and then they return to their original shape. Elastic materials often consist of elastomers. An elastomer is made of long chain- or coil-like molecules that can be stretched without breaking. After stretching, elastomers return to their

coil-like shapes, like a stretched spring that snaps back into place.

What's the difference between *elastic* and *flexible*? If you stretch an elastic rubber band, the material deforms, but it returns to its original shape when you release it. If you bend a flexible paper clip, the material reshapes without breaking, but it doesn't return to its original shape on its own.

The original elastomer used to make stretchy things is latex, a gooey liquid harvested from rubber trees. The liquid is tapped from trees without doing permanent damage. Though synthetic elastic materials have been developed, many mattresses, gloves, balloons, and other products are still made of natural latex.



Vulcanized rubber is rubber that has been treated with sulfur and heat. This treatment hardens the material and makes it less likely to melt in summer or freeze and break in winter. While it is still flexible, it can be molded into complex shapes that resist abrasion. The automobile industry was revolutionized once tires were made of vulcanized rubber.

Silicone is an elastomer made of silicon, carbon, hydrogen, and oxygen. People use it for nonstick bakeware, home-repair materials, food storage containers, mouthguards, and many other products. The silicon helps this rubbery material resist heat and electricity.

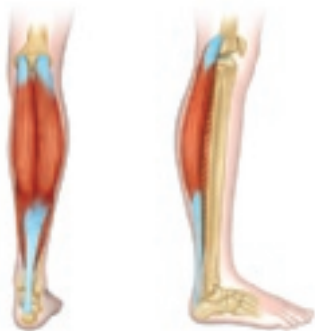




Wooden bows have been used for centuries. Natural bowstring materials include sinew, which is made of tendons harvested from animals, as well as hemp, silk, linen, and animal skin. The bowstring is somewhat elastic, but most of the springy power of the bow comes from the elasticity of the wood. The

natural shape of the wood is straight. The bowstring bends the wood into a C shape when the archer pulls back on the bowstring. When the string is released, the elastic bow rapidly attempts to return to its original position, which pulls the bowstring, propelling the arrow forward.

Phosphor bronze is an alloy, a mixture of multiple metals. It was engineered to make flexible, corrosion-resistant products such as springs, bolts, and guitar strings.



Tendons are a type of tissue that connects muscle to bone. Elasticity of tendons is especially important for athletes who execute big movements. Tendons can tear if they lose elasticity or are overworked. The Achilles tendon, which connects the calf muscle to the heel, can tear when an athlete does not warm up properly.

Bottles and Baseballs

People used to send messages in glass bottles. A thick glass bottle seems like a strong, waterproof vessel. A glass bottle is strong . . . until it isn't. Once the material cracks and breaks, the container fails. Plastic bottles would have been a better choice because they can deform when colliding with another mass.

A glass bottle is almost totally rigid, inflexible. When the **breaking point** of glass is reached, it fractures. There is no in-between phase in its deformation, and once it shatters, the bottle can't regain its original shape. Glass, rocks, salt crystals, and other solids that shatter are described as brittle.

In contrast, a plastic bottle is, well, plastic. The noun *plastic* comes from the adjective *plastic*, which means “easily molded and shaped.” A plastic bottle can take a hit and be squeezed without fracturing.

Some solids that seem hard and inflexible are not brittle but are instead, upon closer examination, surprisingly elastic. For example, a baseball deforms quite a bit in its brief instant of contact with a bat moving at high speed. Then it elastically springs back to its original shape.

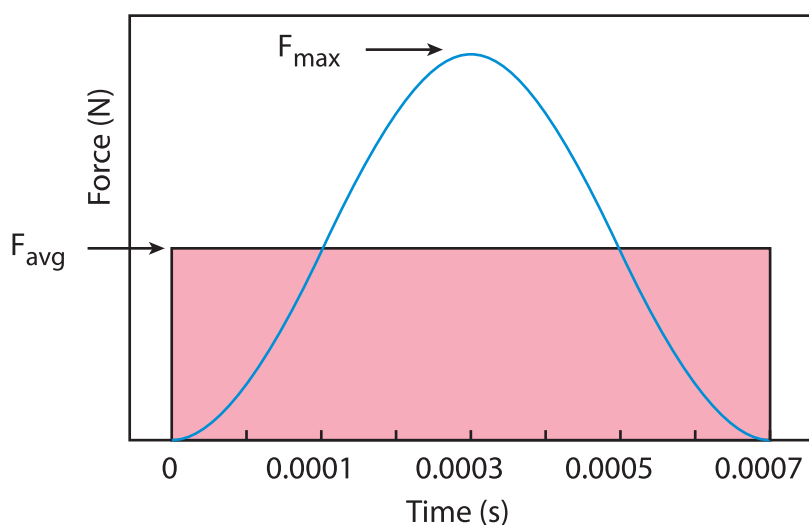


Even flexible materials have their own limits beyond which they cannot retain or bounce back to their original shapes. When a solid object reaches its **elastic limit** during a collision, the object is no longer able to “un-deform” and return elastically to its original shape. Think about dents put into a car in a fender bender. Metal springs and elastic bands have their own elastic limits. They will stretch until a certain point, and then beyond that point they’ll break if more force is applied.

The maximum combined force of colliding objects is called the **peak force**. If we can slow down a collision, we can determine that the peak force does not occur at all times during the contact between objects. Consider a collision event in which a moving bat strikes a moving ball. The total duration



of contact between the bat and the ball is just 0.7 milliseconds, or less than one thousandth of second. Within that sliver of time, the forces between bat and ball increase until the halfway point of their collision. At this point, the ball is as deformed as it’s going to get. The force peaks (F_{max}) and then declines as the ball regains its shape and moves off the bat at high speed. The average force (F_{avg}) of the entire collision is halfway between zero and the peak force.



Vocabulary

breaking point, n. the degree of stress under a force at which something breaks

elastic limit, n. the maximum stress a material can withstand without permanent deformation

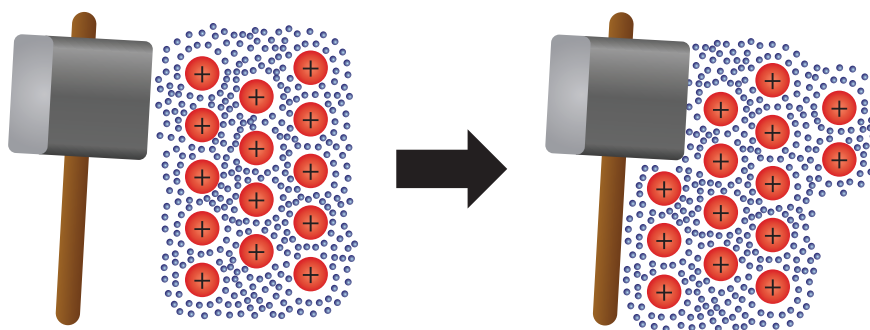
peak force, n. during a collision, the measure of force at the instant in which the force is greatest

Collisions Up Close

When solids collide, the energy transferred in the collision can reshape the colliding solids or break them apart. Whether something is deformed or broken in a collision depends on the chemical bonds holding the material's molecules together.

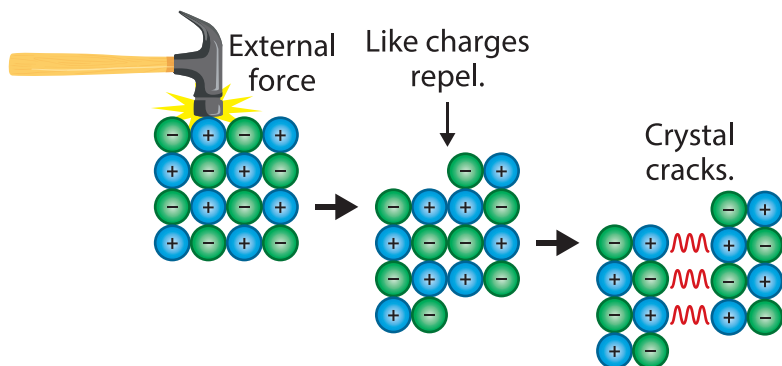
In metals—solids held together by metallic bonds—the atoms share electrons, and

the distribution of electrons can change if the whole object is stressed. If a chunk of iron is hammered, for example, the atoms can slide around thanks to the shared electrons flowing. This property of solid metals is known as malleability. Jewelers take advantage of this quality of metals by shaping gold or silver to make highly ornate items.



In contrast, an ionic solid such as table salt is held together by ionic bonds. These bonds are based on the attraction of opposing electrical charges. If enough force strikes a chunk of solid salt, the neat alignment of charges can be easily disrupted. This results

in ions repelling each other at the micro level, the level of the material's ions. At the macro level, the “bigger picture,” the solid breaks, fracturing along the plane where the ions repelled each other. Ionic solids are brittle for this reason.



Word to Know

A *malleable* substance can be reshaped without shattering or fracturing.

Sharp and Pointy

Why does a fishhook need to be sharp? Why is filleting a fish so hard when the knife's edge is dull? We don't think about *cutting*, *piercing*, *hooking*, and *spear*ing as words describing collisions, but in a physical sense that is what they describe. A fishhook works by colliding with the jaw of a fish, with all the force behind the point of the hook focused on a very small area.

Let's say you're trolling for blue marlin off the big island of Hawaii. The lure has a stainless-steel hook with a very sharp point. The lure is connected by a fishing line to a fishing pole on the boat. The boat applies a force to the lure to pull it through the open water. Let's say the total force pulling on the lure as the boat travels at nine knots is 10 **newtons**. Now, 10 newtons won't feel like

all that much force if it's spread out across a large surface. A two-pound weight held in your hand, for example, is pulled down by gravity with about 10 newtons of force. No problem, right? It just feels like some **pressure** against your hand. But if all that force were concentrated in a single, small point, it would probably pierce the skin of your hand. That's the idea behind the point of a fishhook. A fish bites on a lure that has some force applied to it—and the fish adds its own force in the form of the bite—and as a result the hook sinks in and the fish is caught.

Early fishhooks, knife edges, and spear tips were made of whatever materials could be shaped to cut, slice, and pierce. Wood was a common choice if it was strong enough



Vocabulary

pressure, n. the perpendicular force per unit area, or the stress at a point within a confined fluid; $P = F/A$

to be shaped into sharp edges and points without breaking. Warriors in the South Pacific added shark teeth to the edges of wooden weapons. Early islanders also fashioned animals' teeth and bones into needles, knives, swords, and other pointy objects. Stone could also be shaped into points or sharp edges.

The breakthrough in manufacturing sharp, strong points and edges came with the invention of steel. While steel consists of natural elements, humans needed to figure out how to put them together to make what is essentially a more useful form of iron. Steel is mostly iron, but the key ingredient is carbon. A thousand years ago, smiths determined that by heating iron-rich sand in a furnace fired by carbon-rich charcoal, the resulting mass of iron would be stronger than pure iron.

Pure iron is malleable, a trait it shares with other metals. Its atoms can slide alongside each other if stressed by, for example, a smith's hammer. Carbon atoms that get randomly distributed among the iron atoms act like locks, preventing iron atoms from

being dislodged. In this way, the carbon impurity of the metal makes it stronger and more useful.

Steel permits edges and points to be very thin yet strong enough to do their jobs more than once. This allows fishhooks, knives, and other steel tools to be useful for a long time. When steel points and edges get dull, they can be sharpened.

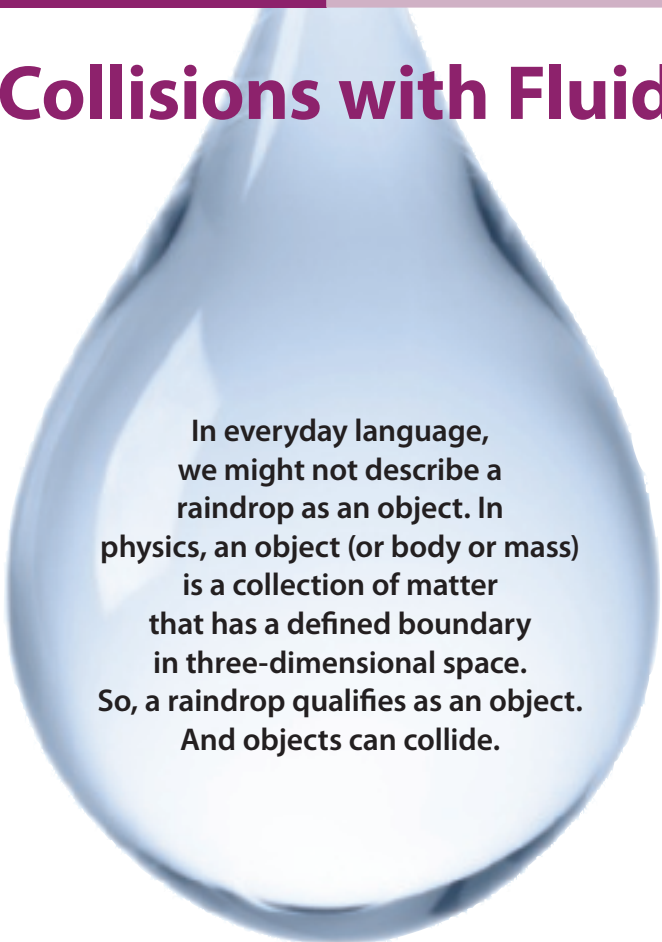


Vocabulary

newton, n. the unit for measuring force; one newton equals the force required, in one second, to accelerate a mass of one kilogram by one meter per second ($1 \text{ kg} \cdot \text{m/s}^2$)

Heating iron in a carbon-rich fire yields steel, which is considerably stronger than pure iron because the carbon atoms are distributed among the iron atoms.

Collisions with Fluids



In everyday language, we might not describe a raindrop as an object. In physics, an object (or body or mass) is a collection of matter that has a defined boundary in three-dimensional space. So, a raindrop qualifies as an object. And objects can collide.

Gases can also be described as masses if they can be contained or their boundaries can be defined in some way. For example, scientists who study weather and climate investigate the interactions of air masses. An air mass is a volume of air defined by its temperature, pressure, and water vapor content. The collision between two air masses can produce severe weather. Large rain clouds can quickly form where cold and warm air masses collide. Although all interactions occur at the microscopic level, the entire air mass can be considered as an object and can be studied as such.

Air can also collide with solids and liquids. Ocean surface waves are produced by the force of moving air tugging or pushing the liquid water. Molecules of air moving in one general direction generate surface waves that also move in that direction. This process is called fetch.

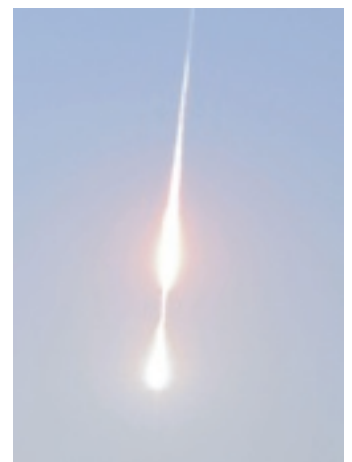


Above the surface, moving air collides with the sails of a sailboat. The force of one molecule of air against a sail doesn't add up to very much. But collectively, the force of billions of molecules fills the sails with air, pushing them downwind. In turn, the rigging that connects the sails to the boat's

mast transfers the force to the hull—the wind pushes the sail, the sail pulls the mast, and the mast pulls the boat. Air can also nudge a sailless boat across a body of water, as anyone who has tried to paddle a kayak against the wind can confirm!



Solids collide with air all the time, but usually the forces between them do not produce noticeable changes or events. Meteors are an exception. The mass and speed of a meteor colliding with air in Earth's atmosphere produces so much friction that the meteor burns up in a white fireball. Larger meteors can explode into fragments. In 2013, the explosion of a meteor over Chelyabinsk, Russia, produced a cannon-like boom that broke windows and even some brick walls on the ground below.



Through Thick and Thin

What do a mako shark and a jet plane have in common? Notice the similar shapes. The mako shark is adapted to move through water with efficiency and speed. Jet planes

have been engineered to move through air with efficiency and speed. Where there's less matter to collide with, motion is easier. So how do the mako shark and jet plane compare?



Mako Shark

- moves through water, a material with a density of 1.0 gm/cm^3
- experiences **friction** in the form of water, which resists shapes moving through it
- water density = 1.0 gm/cm^3
- moves through water, which is 830 times denser than air
- swims near the water's surface, where water has less density
- swims at all times unless it wants to rest on the sea floor

Jet Plane

- moves through air, a material with a density of 0.001225 gm/cm^3
- experiences friction in the form of **air resistance**, also known as drag
- air density = 0.001225 gm/cm^3
- moves through air, which is 830 times less dense than water
- reduces drag by flying higher, where the air is thinner

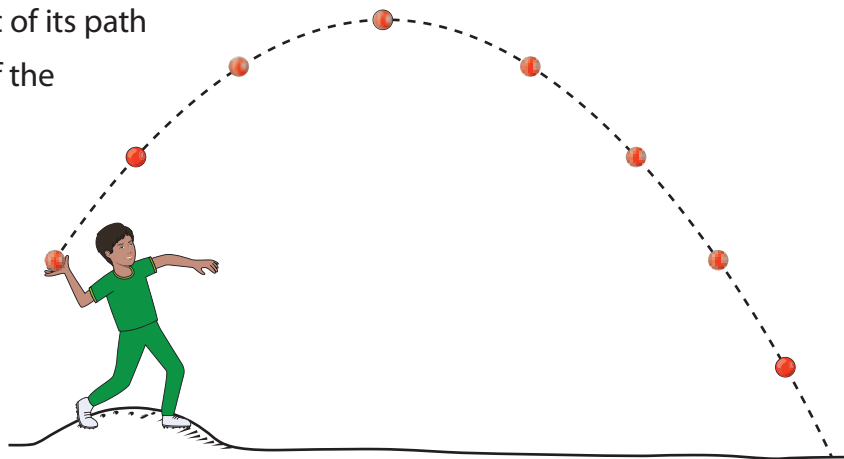
Vocabulary

friction, n. the resistance of motion between objects or materials that are in contact

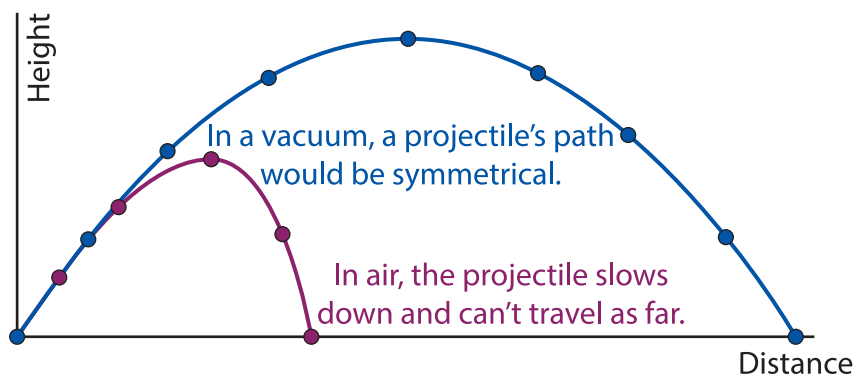
air resistance, n. the friction that air exerts on an object moving through it; drag

What's Wrong with This Picture?

If you throw a ball, does the arc of its path on the way up match the arc of the ball's path on the way down? It depends on where you are. If the person in this picture, for example, were in a space suit and throwing the ball on the moon with no atmosphere, then the path of the ball's motion could be depicted as symmetrical.



In air, though, resistance puts on the brakes. A projectile loses kinetic energy to collisions with air particles and slows down. Drag reduces how high and how far the projectile goes. The slowing effect makes the projectile's path asymmetrical.



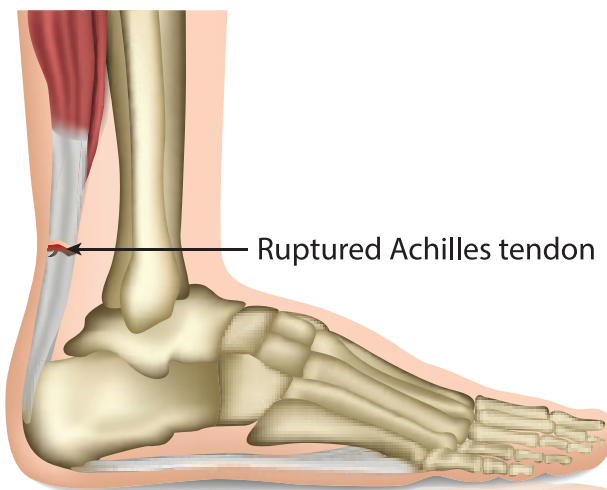
The kinetic energy doesn't just disappear, though. Some of the kinetic energy of the moving projectile gets transferred to the air through all the collisions with air molecules, all the friction that occurs. Whatever kinetic energy is left when the object lands gets transferred to the ground.

Human Tissues and Elastic Limits



If you do an internet search for “Achilles tendon rupture,” names of well-known professional athletes will come up in the search results. Many sports stars have torn (ruptured) an Achilles tendon, which connects the heel to the calf muscle of the lower leg. This tendon is also known to rupture during collisions when the foot and ground come into forceful contact.

Athletes reduce the effect of collisions by having flexible tendons. As a unit, the calf muscles and the Achilles tendon flex the ankle and cause the foot to straighten, which helps propel the body off the ground when walking, running, and leaping.



Though it is a flexible tissue and the largest tendon in the human body, an Achilles tendon can rupture or break completely.

The overall elasticity of the muscles and the thick tendon in this system affects how “springy” a person is—and how safe from injury they are. Someone with an inelastic Achilles tendon and tight calf is more vulnerable to tearing the tendon or the muscle. Someone with a long, elastic Achilles tendon is more likely to have explosive leaping ability and be less likely to injure the tendon.

So, why do athletes end up straining and rupturing this tendon? Every material has its elastic limit, including human tendons, ligaments, and bones. A basketball player who plants his foot and stretches his calf muscle and tendon during a collision with

the ground might reach the elastic limit, causing the tendon to snap like a broken rubber band. Can such a collision be serious? It takes about a year for a surgically repaired Achilles tendon to heal and recover.

Other human tissues have elasticity and elastic limits. We think of bones as rigid, but they do bend and give, to a point. Working your bones by exercising, especially doing weight-bearing exercises, helps them maintain and build strength. But at a certain point, a collision can break a bone. Some larger athletes can suffer stress fractures in the small bones of their feet just by running and jumping.



The Danger Zone

Automobile Collisions

Every year, over a million people are killed when automobiles collide with other objects.

A collision is “big” enough to be dangerous when the forces transferred to the body exceed what the tissues can sustain.

Newton’s second law of motion states that net force equals mass times acceleration.

$$\mathbf{F} = m \times a$$

Here, F means the sum of all the forces acting on an object. The formula gives us the means to measure values that quantify a force—and declare how strong it is.

Acceleration is the rate of change in velocity over time. In a collision, if an object is moving very fast and the collision causes it to come to a complete stop—picture a car crashing into a large tree—the change in velocity is very sudden, and the acceleration will be large. That translates to the force of the collision also being relatively large.

If the same car instead rear-ends another car that is going in the same direction at a slightly slower velocity, the cars won’t come to a full stop as a result of the collision. The car that rear-ends the other car will decelerate but at a slower rate than if the front car was stationary.

In the context of a car collision, less force means less damaging and less dangerous. In real-world terms, car collisions are safer when they occur at slower velocities.

A speed limit is a way of compelling drivers to operate vehicles at speeds that are less likely to result in loss of control or in dangerously strong collision forces. For example, the speed limit on a highway offramp that has a tight curve might be 20 miles per hour because a vehicle traveling faster may leave the road and have a collision. On the mostly straight highway, the speed limit might be 65 to 75 miles per hour. Those speeds do yield large, destructive forces if collisions occur. But on roadways that are designed for it, “highway speed” can be maintained with lower risk of the driver losing control of the vehicle.



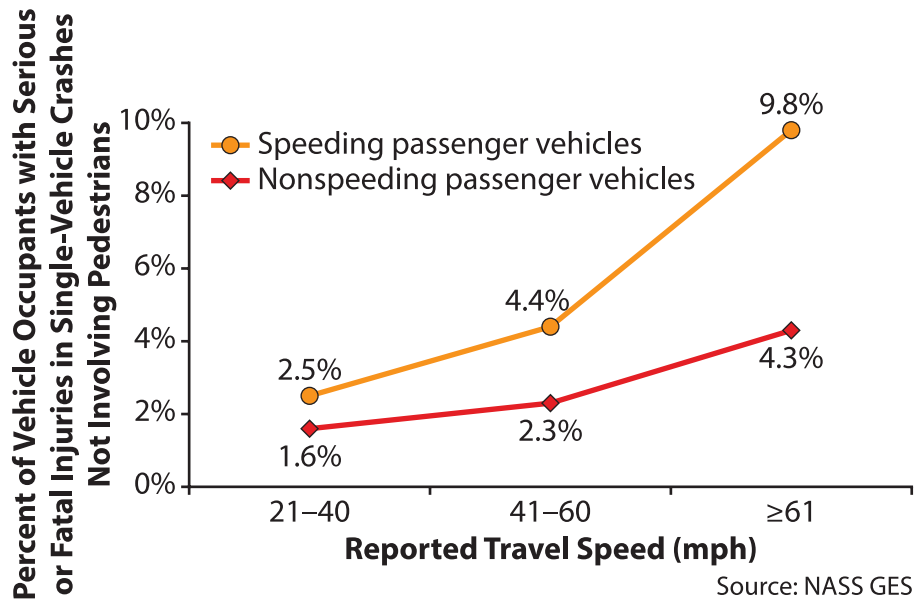
This highway is designed to separate the northbound traffic from the southbound traffic so that head-on collisions won’t occur. Off-ramps are curved, with lower speed limits to prevent accidents. On-ramps are long, to allow for safe acceleration.

Automobile safety experts have been studying the connection between velocity and vehicle accidents for almost as long as there have been cars. When an accident occurs, investigators piece together what happened by examining evidence, such as skid marks that indicate sudden braking, the damage to vehicles, and the recollections of people involved in the accident. It's not always possible to know exactly how fast a vehicle was traveling or in what exact direction, but solid estimates are made. Data gathered from accidents paint a picture of how velocity is associated with the severity of accidents. In one study from 2014, among single-vehicle crashes not involving pedestrians, the data showed two things:

1. Traveling at higher speeds is more dangerous. Even if a vehicle occupant is in a car that was not speeding (traveling

above the speed limit or too fast for the road conditions) prior to the accident, they are more likely to sustain a serious or fatal injury if the vehicle was traveling at high speed. For example, in cars that were going over 60 miles per hour at the time of an accident, 9.8% of occupants were hurt or killed, versus 2.5% of those in cars going 21 to 40 miles per hour.

2. Speeding increases the odds of sustaining a serious or fatal injury. For example, 4.4% of occupants of speeding vehicles that were traveling between 41 and 60 miles per hour prior to getting into an accident were injured or killed, versus 2.3% for those who were traveling in that range of speed but not speeding. In the above-60-miles-per-hour group, the number was 9.8% versus 4.3%.



Consider the Source

The source of the graph is a study by the National Highway Traffic Safety Administration, a government agency whose mission is "to save lives, prevent injuries, and reduce economic costs due to road traffic crashes, through education, research, safety standards, and enforcement."

Collisions in Sports

Beyond collisions involving vehicles such as cars and bicycles, collisions in sports and other recreational activities are also a source of injuries, some of them quite severe. Naturally, these collisions are more common in contact sports, such as football, hockey, and lacrosse. Most players wear helmets and pads to make these sports less dangerous. However, collisions can also occur in basketball, soccer, and other sports in which bodily contact is not necessarily considered part of the game. In soccer, for example, two players that are attempting to head the same ball in the air might collide with each other, head to head. But even an intentional header, involving just one player and the ball, can result in an injury depending on how the ball

and the player's head collide. Such headers have resulted in many concussions, which in turn has led to rules that ban headers for players under certain ages.

Heading the ball among older players, such as high schoolers, collegiate athletes, and professionals, is less likely to be banned because it is a major component of the game of soccer, especially at advanced levels. But in a way, headers are even more dangerous at that level because the ball is traveling at higher speeds thanks to stronger players kicking the ball at higher speeds. Collisions between older, larger, faster players are also more likely to result in serious injury because more mass and/or more acceleration means more force.



Word to Know

A *concussion* is brain injury that occurs when the head is struck by or strikes another object or surface or when the head shakes in a fast or violent manner causing the brain to strike the inside of the skull. It is a type of traumatic brain injury.

Spot the BS

Heads up! There's some **bad science** on the opposite page. Can you spot the misunderstanding of Newton's second law of motion?



Randy Walker

Look. I care about kids' health as much as anyone. I am, after all, a parent to three great kids. But I think soccer won't be soccer unless players can head the ball. The game has a vertical component. Not as much as basketball, but leaping and twisting in the air is a key skill and part of what makes soccer "the beautiful game." I also don't think we know enough about the actual concussion risk of header-related collisions to decide now. We need more data!



Sidra Vithiananthan

More data are needed, but I think the precautionary principle is warranted here. We could hit "pause" on headers in youth soccer but allow it in high school and above.



Grant Childs

I think it's much ado about nothing. People have been playing soccer and using their heads for ages. A concussion is just a bad headache. Kids are young, and they will grow and heal. We need to stop pretending we can protect them from every little thing! Let them play! Little kids' heads are so small and light, they don't get concussions as bad as adults anyway. Not much mass, so the force can't get very high.



Sidra Vithiananthan

OMG, no! A concussion is a traumatic brain injury, and it can lead to lasting or permanent impairment. Children's brains are indeed developing, and that is exactly why it is important to exercise caution and protect them, not throw caution to the wind. Also, while it's true that a small child might not contribute as much to a collision force as a more massive adult, the force of the ball against the child's head could be just as hard, depending on the speed OF THE BALL. And I am concerned that the child's head is more vulnerable to concussion because it is smaller, the skull may be thinner, etc.

Impossible Superhero Physics

Where would our comic books and movies be without the superhero? Superheroes can leap over tall buildings, fly faster than missiles, produce various forms of energy from their hands or eyes, transform into animals, stay underwater for hours at a time without scuba gear, or stop a moving train

in its tracks. To enjoy a good superhero story requires the suspension of disbelief. We must turn off our critical thinking and not worry much about how impossible the things the superhero is doing actually are in the real world governed by the laws of physics.



There's a lot going on in this scene. A massive moving object is being stopped by a superkid who appears to be much less massive and simply standing in place. To put things in perspective, the boy would have a mass of 50 kilograms. A six-car subway train during a full morning commute would have a mass of around 300,000 kilograms. Imagine what would happen if 6,000 of your friends all pushed you back at the same time.

With little mass times no acceleration ($m \times a$), how is this kid matching the force of the train? If the boy were to stop the train, all of the force from the boy would be from his back legs pushing into the ground with the same force as the moving train.

In 2014, some college students in England decided to suspend their suspension of disbelief and dig into the superpowers of the super-est of superheroes: Superman. According to numerous editions of the DC Comics *Superman* and many other versions of the story, including several Hollywood films, Superman absorbs energy from the sun and is then able to use that energy to perform various super-feats of strength and speed. The students just accepted that explanation but then asked, *Okay, but if he's getting all of his energy from the sun, does it*

make sense that he can fly at supersonic speed and do all of these other things with that stored energy as his only source?

They fancifully proposed Superman as a solar cell, which is a technology that converts sunlight into electricity. Based on Superman's body size, they calculated that the most sunlight he could possibly absorb is 1,096 joules per second. That's not much. It's about how much energy you use to lift an apple one meter. Then they calculated that Superman, as a projectile of human size flying at high altitude for, say, eight hours, would burn through 207 *billion* joules of his stored solar energy to convert to the kinetic energy of that motion. From there, it doesn't take a math whiz to see that Superman uses *waaaay* more energy than he could possibly absorb and store if the sun were his only energy source. Somehow Superman can create energy in a closed system, a complete violation of the law of conservation of energy!

How many superheroes can endure forces that would destroy normal human body structures? A lot of them. And how many can produce a force that is clearly greater than their mass times their acceleration? I guess superheroes don't have to obey Newton's laws either!

Corked Baseball Bats

Baseball and softball are related sports in which the opposing teams try to beat each other by doing a better job handling (and avoiding) collisions. The player that is up to bat tries to hit the ball so that it flies over the outfield fence or eludes the fielders. The pitcher throws to force the ball into contact with the catcher's mitt—without allowing the batter to make good contact. Batted balls collide with fielders' gloves, and fielders throw to each other. Base runners must contact bases with at least one foot while attempting to get to home plate untagged. Sometimes a base runner collides with a fielder, especially the catcher. Talled up, there are hundreds of collisions between bats, balls, gloves, players, and bases in a single game.

Analysts study piles of data generated in baseball games. They analyze the launch angles of batted balls, their “exit velocities,” and the “breaks” of pitches—how much balls thrown by pitchers seem to leave their initial trajectory. Analysts even count the rotations per minute of pitched balls, their spin rate, as more spin can mean a bigger break or a “heavier” ball that breaks bats and results in weak ground balls. Hitters know that a

heavier bat will place more force against the ball, but a heavier bat is harder to swing at high speed, so it's a trade-off.



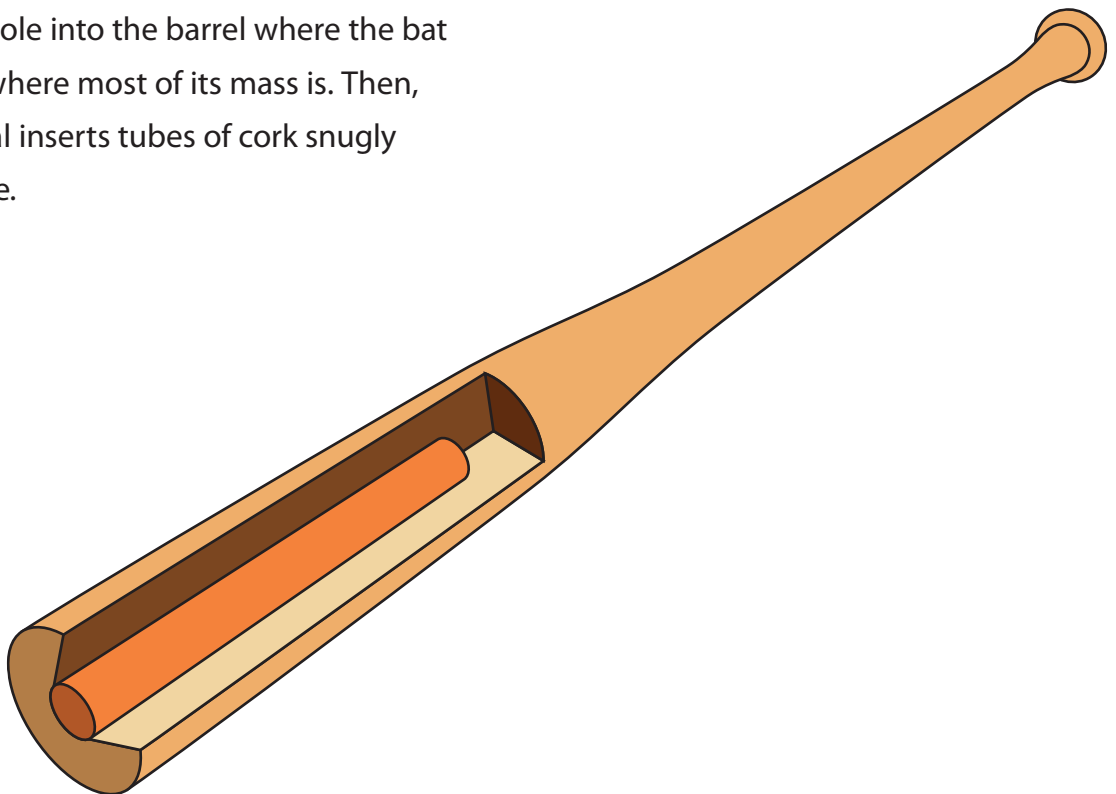
Power hitter Aaron Judge of the New York Yankees once hit a home run that traveled 496 feet. He used a legal bat, not one that was corked.

Some ballplayers are naturals, or they work hard at their craft so they can play professionally. Others take shortcuts. And sometimes even the “naturals” or all-stars end up taking shortcuts, too. Because physical strength improves bat speed, some ballplayers have used anabolic steroids and human growth hormone to build strength. Greater strength and improved bat speed mean forceful collisions that send pitches over the outfield fence for home runs.

Another approach is to alter the bat itself so the collision between bat and ball causes the ball to travel farther. This is why the corked bat became popular and was banned in professional baseball. What’s a corked bat?

The first step in corking a bat is drilling a cylindrical hole into the barrel where the bat is thickest, where most of its mass is. Then, an individual inserts tubes of cork snugly into the hole.

Years ago, batters believed that the somewhat elastic nature of the cork provided a trampoline effect when bat and ball collided, causing the ball to carry farther. Experiments with corked bats show slight increases in exit velocity—how fast the struck ball travels off the bat—but the main advantage seems to be the bat’s reduced mass, which allows batters to swing faster, thus trading mass for acceleration. However, using a corked bat is risky. Hollowing out the bat head reduces its strength and makes it less able to absorb the shock of high-speed collisions with a baseball without breaking. Many corked bats have been discovered because they splintered into pieces during a game, revealing the cork inside the bat—direct evidence that the batter cheated.



Criteria and Constraints

Have you ever used interlocking building blocks to construct a model of something, such as a house or castle? If so, without even thinking much about it, you have engaged in an important part of the engineering and design process—identifying **criteria** and **constraints**. What you set out to build, even if based on a vague idea, served as the criteria: *something that looks like a house, with walls, a roof, and a doorway*. As you started building, you might have come up with another criterion: *now that I see this thing taking shape, I want to add a chimney to it*.

The blocks themselves—and your own skills as a builder—were the constraints in the house-building scenario. Building requires resources. Early human builders needed to gather, grow, harvest, mine, and hunt to secure the materials they needed. People traded resources and fought over them as well. Before trade took to the seas and then to the air, allowing goods from one

part of Earth to be taken to another, people relied only on the resources available near them. The lack of mobility was a constraint for those design problems, and so was the absence of some resources.

Advances in trade over the last two centuries allowed resources to be shipped more easily around the world. In 1920, for example, a person in India could purchase ice harvested from frozen ponds in Massachusetts thanks to advances in insulation and shipping. Today, countless resources are shipped all over the



Before materials were traded internationally, human ingenuity was constrained by the resource limitations in their environments. The Inuit people of the Arctic circle could craft lightweight, maneuverable kayaks from driftwood and animal skins. The people of Fiji had no such skins available, so they built dugout canoes.

Vocabulary

criteria, n. needs that are to be met by a product or process

constraint, n. a limitation or restriction on a process or product

globe by boats and planes. Nevertheless, access to resources is still limited, and the number-one limitation, or constraint, is money. Those who have lots of money have greater access to resources, while those who lack money have less access.

Criteria often come from the people that want to build something for their customers. Such a person is called a stakeholder. This term dates to the early 1700s and refers to someone who has a stake in something, such as a bet. There are often two groups of stakeholders: one group that is developing something to be sold and one group of would-be buyers. For example, if a company is designing a new baseball bat, the company is a stakeholder, and so are the baseball players who might be interested in the bat. In other cases, the number of stakeholders might be much greater because the thing that is being developed will affect people other than those who sell or buy a product. Transportation safety is also a public issue, as so many people are affected by it. An improvement to automobile safety affects car builders, sellers, and buyers, as well as other drivers on the road who encounter improved car designs on the roadways.

The criteria and constraints for a given product can be determined by the market—

Word to Know

A *stakeholder* is a person with an interest or concern in something, especially a business.



Anyone who passes through this intersection is a stakeholder in the development of the technologies at use here, from cars to stoplights to the engineering of the road.

the people who are buying and selling—but they can also be determined by a government. For example, the automobile industry is a heavily regulated. In the United States, some laws establish criteria for automobile manufacturers. For example, new cars must have airbags. A related constraint designers face in the design of airbag systems is the available space in which they must be installed. Many automotive manufacturing rules are focused on safety. Others are designed to reduce negative impacts on the environment, such as air pollution.



Prior to 1975, gasoline used in automobiles usually contained lead. This toxic metal was dispersed into the environment in the emissions from auto engines. Since 1996, new vehicles in the United States have not been allowed to run on leaded gasoline unless they are aircraft, marine vessels, race cars, or farming vehicles.

The following are examples of products that have criteria mandated by a government or authority.

Airbags are a safety feature that has been mandated by the U.S. government for use in new automobiles since 1999. Criteria for airbag use include the following:

- They must deploy when an automobile's front end collides with a solid, fixed object at a speed of eight miles per hour or higher. Sensors detect the force of the collision and trigger a chemical reaction that inflates the airbag in about one-twentieth of a second.
- Once an airbag has been deployed, it needs to be replaced by a qualified technician. It cannot be packed back in and reused.
- They are designed to be used in conjunction with seat belts, which keep passengers from being too close to the steering wheel and dashboard airbag deployment locations. Being too close to the airbags upon inflation can cause severe injury.
- Side airbags deploy from doors, protecting passengers from side impacts through the windows. These are not yet mandated but may become standard features in the future.



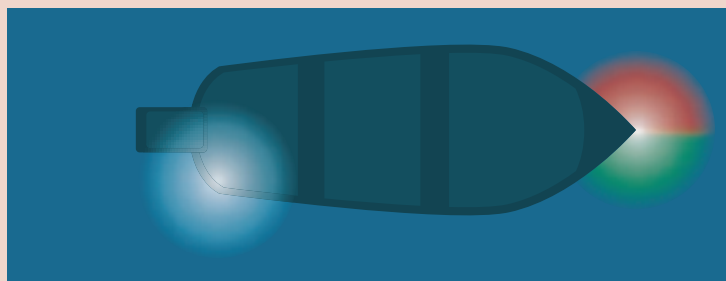
Seat belts preceded airbags as a mandated safety feature in automobiles. New automobiles must have three-point belts installed for all seats. A three-point belt has one belt that runs across the hips and another that runs from one hip across the torso to behind the shoulder. Both belts help prevent a body from moving forward during a collision or being ejected from an automobile during a rollover. Seat belts save thousands of lives every year, and thousands more would be saved if seat belts were used at all times. Many states have laws mandating the use of seat belts.

Lacrosse is a sport that involves a dense rubber ball with a solid core that can be thrown at speeds exceeding 100 miles per hour. Players can also “check” each other with their bodies or the sticks they carry, especially in men’s lacrosse. This contact can lead to injuries, including a rare condition called commotio cordis.



This condition is basically the heart stopping when a person is struck in the chest at a particular instant in their heart rhythm, and it can prove fatal. Starting in 2022, all field players in boys’ lacrosse will need to wear a chest protector that is certified by the National Operating Committee on Standards for Athletic Equipment.

Navigation lights on boats are key safety features that help boat operators avoid collisions. The United States Coast Guard created constraints that mandate a variety of rules around these



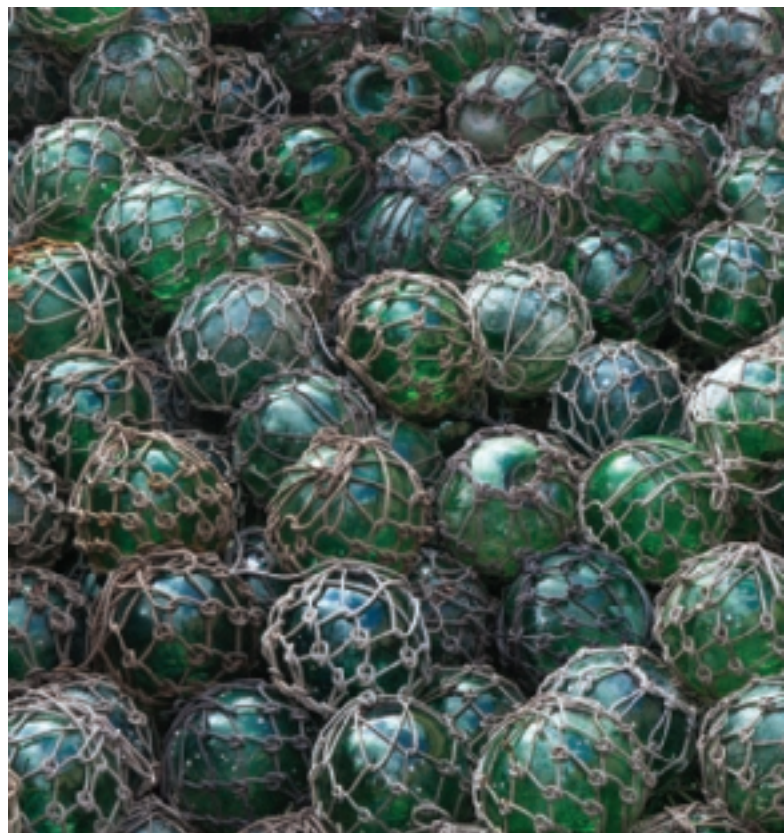
lights. For powered vessels less than twelve meters in length, a white light must be mounted on the stern (rear) and visible across 90 degrees. The other 270 degrees must be covered by a second white light that is mounted higher up. To indicate a boat’s orientation, a red light is on the left, or port, side while a green light is on the right, or starboard, side. This allows two vessels to know whether they are facing each other at night. Similar red-and-green light schemes are used to mark channels along the coast. “Red right return” is a phrase boaters learn. It means the red light of a channel marker or buoy should be to your right if you are returning to shore. Green lights should be to the left from the perspective of a boat’s pilot.

Plastics

Look around your classroom, home, supermarket, ballpark, or virtually anywhere that has things made by humans. Plastics are everywhere. They are relatively inexpensive to produce, they can be molded into any shape, and they do an excellent job at containing things despite being lightweight. They are relatively durable and waterproof, too. In other words, they can be made to meet many criteria. And in some ways the only constraint on plastic manufacturing is the availability of the raw materials, most of which are developed from petroleum, coal, and natural gas. The petrochemical industry continues eagerly to make plastic because it's a way to squeeze more value out of fossil fuels.

Being able to make useful objects out of plastic instead of other materials has transformed many industries. The commercial fishing industry, for example, relied for centuries on floats, also known as buoys, that were glass spheres surrounded by carefully woven strands of rope. The hollow glass provided flotation, while the rope shell around it offered some protection from collisions and provided an attachment point for rope that hung nets or lines down into the depths to catch fish. In the age

of plastic, glass floats have largely been replaced by plastic ones. Some plastic floats are soft, allowing them to be bumped by boats without damage to the float. Others are thick, hard plastic that also withstands collisions. There are so many different plastic polymers that can be made and molded into different shapes, it's understandable why plastic has overtaken glass, wood, metal, and other more natural materials.



These glass floats were used to dangle fishing nets and lines in the sea. Such floats are still in use in some locations, but most of the world has moved on to plastic floats.

So, what's not to like about plastic? Well, plastics are everywhere. And they have a habit of staying everywhere for a long, long time. What about recycling? Can't all this stuff just be smashed up, melted, and reused? Unfortunately, the plastic recycling industry is not what many of us think. While many plastic products are stamped with a symbol that implies that they can be recycled, this does not mean that they are recycled. In many locations, there simply aren't adequate sorting facilities to process the many tons of plastic that are put into recycling bins but that must be sorted to remove plastic that is contaminated by food or other material.

In some cases, it is too costly to ship the plastic to a place where it can be recycled. In general, it is less expensive to simply produce more plastic products than recycle used ones.

Some plastic products get lost, too. Consider plastic fishing floats. Fishing gear can get wrecked by storms or simply get lost at sea. It might continue to fish for a while—think of a lost net suspended by floats, catching tuna and swordfish and sharks without any of those fish being harvested by fishers—but a lot of it washes up on shores. Islands of the central and south Pacific Ocean have become magnets for lost fishing gear and other plastic debris.



Confessions of an Online Retailer

A Small Business Blog by Sandy Lin, Founder and CEO of Grand Rapids Goodies

The COVID-19 pandemic has been terrible for just about everyone. I have friends who have lost loved ones to the disease. My children have been stuck at home for months, with school going to remote-only learning and sports and other activities shut down. But I have to admit that my own business is booming.

After years of doing just okay with my cookie-and-brownie business, things really took off when the pandemic hit and people started buying almost everything online. Our sales in general went up 300%, and our online sales went from being about 18% of our business to about 90%. I wish the circumstances were different, but in terms of my business this is the best year we've ever had.

But I feel terrible about one thing: packaging. To mail our cookies and brownies, which we ship either frozen or fresh, we go through a lot of cardboard boxes as well as plastic bubble wrap. I would like to think that our customers are finding ways to reuse or at least recycle this material, but the statistics suggest otherwise. Could we use a different packing material to keep

our products from breaking into crumbs during shipping? Possibly. There's an alternative material made from cornstarch that provides cushioning and insulation. I ordered some of it for shipping frozen cookies and brownies, but it's more expensive than plastic or polystyrene. Also, the company that makes it here in Michigan had labor shortages because of the pandemic. The low availability and relatively high price of the eco-friendly alternative pushed that choice outside the constraints for my operation.

In an ideal world, all the material from open packages could get delivered to packaging supply hubs that would then supply used packaging to be reused. Only things that lose their ability to do the job—such as bubble wrap whose bubbles have been popped—would be taken out of circulation, like dollar bills that are too torn up.

I watched a TV show the other night about how much plastic waste ends up in Indonesia and other places, now that China has cut back on the amount of recyclables it takes in from the United States. It's heartbreaking, and yet . . . what can we do? Businesspeople like me need to sell our wares, and plastic is just too useful to avoid.



Protective Produce Packaging



Janae Cobos

I don't know how to feel about this. I'm in the produce section at the grocery this morning, and they've just put out this display of fresh new apples. I get why egg cartons have to give every egg its own little protective compartment, but apples?



Most Recent Comments ▾



Paige Van Cleve

Yeah, that seems a little overprotective for something that literally grows on trees. What a waste of money!



Janae Cobos

I struck up a conversation with the worker in the produce department who saw me taking this picture and posting it. I asked, "Don't you think all this packaging is overkill for apples?" His reply seemed pretty open-minded. He said, "I guess I'd have to give some thought to how much benefit comes from the packaging in exchange for the costs, and for whom." He went on, "I can testify that the truck driver who delivered the apples has a pretty easy time moving the pallets containing these neatly stackable boxes. For me, right here, it makes the apples much easier to move and display without damaging them. And it saves the store money by reducing loss from apples that get so bruised we have to throw them away. The price of buying the apples packaged this way doesn't seem to make them too expensive for people to buy. Then I guess you are also thinking about environmental costs." (I was.) "Less food waste is certainly a plus for the environment, right?" he continued. "And we have separate recycling dumpsters out back for the cardboard boxes and the plastic. So, after some thought, I feel like this apple packaging is A-okay."

Arches and Domes

Thousands of years ago, builders developed an understanding of the strength and value of the arch. The word *arch* comes from the Latin *arcus*, which means “bow” (as in the curved thing that shoots arrows). An arch is a curved structure that can support a lot of weight despite the space below the arch being empty. The forces on the top of the arch get distributed out to the side supports, which are anchored or held in place against the ground. Arches have been used for thousands of years in the construction of bridges, castles, aqueducts, homes, and other structures.



These aqueducts were designed by Romans two thousand years ago to carry water from a countryside source to the homes, fountains, and baths of a Roman colony. The many arches of the aqueduct provided adequate strength to bear the load of water, but the arches meant much less building material was required. Also, areas then would not be divided by a solid wall.



Word to Know

The *distribution of force* describes how much force is spread out over a certain area.

Stress is force per unit area in a material that is experiencing an external force. It can occur in the form of compression, twisting, shearing, or being pulled apart.

Arches made of material with some elasticity can provide cushioning as well as strength. You possess such arches—in your feet. The arches are strong enough to support your body weight and withstand high-impact forces of running and jumping, while the flexibility allows for agile movements and helps distribute stress throughout the foot bones.



This suspension bridge is hanging from the strong arch bearing its load. Suspension cables drop down from the arch and support the deck, the load-bearing portion of the bridge.



A three-dimensional version of an arch is a dome. The overall physical principles of a dome are the same as those of an arch. If the peak of the dome is solid, strong, and firmly in place, it distributes the stress forces out from the center in all directions and then downward to the rim of an upside-down bowl. In construction, domes are often made of concrete with reinforcing steel bars hidden inside. Some are steel structures sheathed with glass that lets in light.

An arcade is built using many arches supporting a dome.



Snap! That's a Great Idea After All

You've probably had fun popping bubble wrap. You apply quite a bit of force with your fingertips to pop one or two bubbles at a time. When bubble wrap is doing its job, the bubbles don't pop, though. Instead, they act like little flexible domes that distribute the force applied by your hand. Each bubble receives the initial contact force.

The stress is distributed, and the gas inside is slightly squeezed. Energy is absorbed and force is reduced in the slowed-down collision. If you have hundreds of these bubbles around a fragile thing that needs to be protected—say, a glass bottle in a shipping box—then force on the glass is greatly reduced.

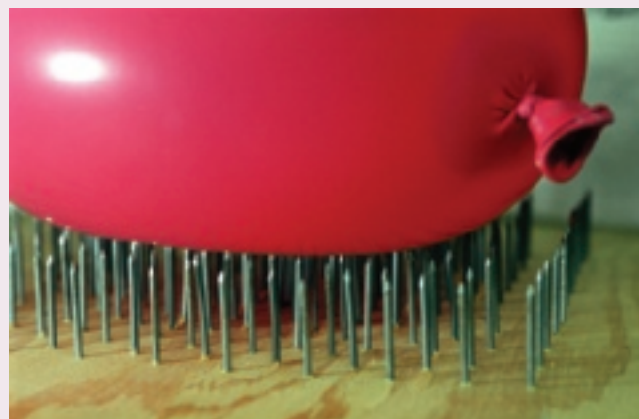
Bubble wrap was invented accidentally. The original product was meant to be a textured wallpaper to serve as insulation. It wasn't a successful product for that purpose, but people realized it worked great as cushioning material for packaging.

A variety of such packaging material is widely used today, ranging from single, large air pillows that can be packed around an object to sheets of very tiny bubbles. Most of this wrap is made of plastic, which is elastic and, therefore, a good material for the absorption of impact of contact forces.

Getting to the Point(s)

Many devices, technologies, and tools rely on distributing a contact force across a larger area—more points of contact. Other solutions succeed by reducing points of contact or disrupting the transfer of forces through them.

Pressed against just one nail, this balloon would pop sooner than it will being pressed against a whole bed of nails. Why? Because the contact force is distributed across many nails, not just a few. That's why, if you've ever seen a human perform the trick of lying on a bed of nails, the practice involves lying down (slowly) and not standing on the nails. Standing would cause injury because all of the weight of the person's body would be concentrated on fewer nails, and thus there would be more pressure on each point of contact.



A turntable is another term for a record player. A vinyl disc containing small grooves spins under a delicate needle. Tiny indentations in the grooves cause the needle to rise and fall. The rising and falling creates electrical impulses. These are transmitted to an amplifier and speakers. To prevent the needle from skipping across the grooves or sliding across the record's surface, external motions and vibrations need to be minimized. Telling people to not jump near a turntable helps, but it also helps if the turntable sits on padded or springy feet that minimize the contact between the turntable and the surface it sits on.



A helmet designed for biking, skiing, or playing a contact sport has several functions. The outer shell uses some of the force from an impact to shatter the material of the shell. This deliberate breakage reduces the energy passing to the next layer. The next layer is usually a dense foam padding or a honeycomb-like lattice of connected pockets. This layer is designed to distribute the impact force more evenly so it contacts the skull across a wider area but less powerfully. For example, if the actual area of contact between a helmet and a colliding surface is 5 square inches, the helmet can spread the force across about 50 square inches of area.



Is this tool an axe or a sledgehammer? Yes! It has the same mass and velocity whether an individual user strikes a blow with the axe side or the hammer side. But which side of the tool is best at smashing a brick? Which is best at chopping firewood? It's all about how the force in the tool's head is distributed across the surface that strikes objects. The sledgehammer head has an area around the size of a soup can top. A sharp axe head has a surface area on its sharp edge that is perhaps one one-hundredth that of the sledgehammer side. The axe's force is concentrated in that narrow line of steel, whereas the hammer's is distributed across a much wider area. This makes the axe great at moving through objects such as logs, while the hammer is designed to transfer force more broadly into hard objects to shatter them into pieces.



Sneaker Mania

Sneakers are big business. Each year, shoe manufacturers collectively haul in nearly eighty billion dollars. They pay tens of millions of dollars a year to high-profile athletes who endorse their products by wearing them in games and advertisements. Some athletes make more money from hawking sneakers than they do from their actual jobs playing sports. With all the money at stake, manufacturers spent a lot of time and money researching what materials and designs make athletes perform better. The choices have a lot to do with managing contact forces.

Years ago, people referred to athletic shoes as sneakers or “tennis shoes” even if they were not made exclusively for tennis. Now, shoes are custom-designed for each sport, from basketball to wrestling to golf to indoor soccer. A lot of what makes a shoe good for one sport but not for another is about what’s between the wearer’s feet and the ground, masses involved in collisions.

The part of the shoe’s sole that comes into direct contact with the ground will be spikes or cleats if the playing surface is grass. The toothlike cleats dig in and allow the foot to pull against the surface and avoid slipping. Between the outer sole and the foamy insole, which

typically can be removed or replaced, is the midsole. In the midsole, athletic shoes vary a lot.

A short-distance sprinter needs sprinting spikes with a thin, rigid midsole. A sprinter’s shoes are called spikes because the shoe is just a means of connecting the toothlike spikes, or cleats, to the sprinter’s feet. The more force the sprinter can direct into the track, the faster the sprinter will go. Cushioning is not a priority. Grip is. By cutting down on cushioning in the midsole, the large forces that a sprinter needs to direct into the ground are not dampened or disrupted. The foot is less likely to slip or slide within the shoe. This results in more pounding on the sprinter’s legs and joints, so a runner must have strong legs and healthy joints to be a competitive sprinter.





The thick foam midsole of this shoe is designed to cushion the runner and reduce the cumulative forces on their feet and legs.

Distance runners need more cushioning, as their feet are hitting a track surface or a paved roadway many thousands of times, which adds up to a lot of force and strain on bones, joints, and muscles. Other athletes who perform for extended periods on hard surfaces, including basketball players, benefit from cushiony midsoles.

Manufacturers have used plastic pockets of air, small metal springs, bubbles of gel, and a wide variety of foams to make midsoles cushiony. However, these shoes must still allow the athlete's coordinated effort to produce chosen movements. It does a basketball player very

little good to plant a foot to jump if the shoe is so soft and cushiony that their power is reduced or their foot slips. Many athletic shoes have cushiony material in the heel area of the midsole, so there's cushioning when the player's heels come down but less cushioning in the forefoot area where the player directs the most force into the floor while running and jumping.

Word to Know

In physics, *power* is the transfer of energy over time. The power of a sprinter, or a car, can be measured.

Pluma Zuuma Only \$209!

The new Zuuma from Pluma features 200 grams of highest-quality goose down, making this shoe the most luxuriantly cushiony distance running shoe on the market. The shoe feels so soft that it's like walking on your favorite down jacket atop the softest bed you've ever slept on, on the softest sand beach you've ever imagined. In fact, the insoles are full of synthetic goose down. Fluffy AND

lightweight! You'll swear you are running in the clouds.

Find yours at your favorite footwear store, starting at \$209!

Get \$25 off one pair of Zuuma running shoes by Pluma.

Not valid with any other discount. Limited offer, while supplies last.



Spot the BS

There is some **bad sensemaking** in here that doesn't quite add up for the claims made in the ad. Would the features this product advertises really work to make a good running shoe?

Sports Op-Ed

The Collision Safety Conundrum . . . or Illusion?

By Cameron Wallace, MD

As a quarterback in high school and at State, I had the advantage of getting hit hard relatively infrequently. These years later, knowing what I know as a physician, I find myself wincing occasionally just watching the game.

It was only in the last two decades that medical scientists found a connection between traumatic brain injuries such as concussions and long-term declines in brain health, including conditions such as dementia and chronic traumatic

encephalopathy (CTE).

This problem appears to be especially prevalent among retired professional football players. The league responded by supporting the development of better protective helmets and by adjusting some of the rules of the game to reduce the incidence of high-speed, head-on collisions.

The challenge in making a better helmet or a better set of shoulder pads is to improve safety without wrapping athletes in so much protective

gear that they can't move and perform the same way. For example, a football helmet can be made safer if the foam padding is thicker and the helmet itself is larger. This results in more kinetic energy being absorbed by the helmet and not the skull and brain. But a helmet that is too large or heavy can be cumbersome and difficult to play in.

Likewise, too many layers of protective gear would make it hard to move and would be hot. Maintaining the action in

Words to Know

A *practical limit* is a constraint based on what is practical or realistic, such as how much money is available for a building project or how large a piece of luggage can be before it is impractical to carry.

Op-ed refers to the page in a newspaper that appears opposite the editorial page. Often this page features opinion essays and commentary written by guest contributors who do not regularly write for the newspaper. The term *op-ed* is now commonly used in short for "opinion editorial," guest-written pieces that appear in both newspapers and magazines.

sports themselves—athletes moving this way and that and sometimes colliding with each other, with the ball, or with playing surfaces—is a constraint on how protective gear can be designed and on how much of it can be worn.

Money is another practical limit. While a professional football player or perhaps a well-funded college team might be able to afford \$1750 custom-made helmets that mold perfectly to a player's head and offer the greatest absorption or redirection of kinetic energy, the average player cannot.

Furthermore, some scientists insist that there is no such thing as a helmet that can prevent traumatic brain injuries. Collisions between the helmet and other objects are part of the problem, but it is the movement of the brain within the skull that tends to do a lot of damage. A person can suffer a brain injury simply by thrashing their head up and down or side to side while enjoying music. Unless a

helmet can prevent a person's head from accelerating very suddenly, athletes will continue to suffer concussions and other traumatic brain injuries. Some scientists think that human brains and skulls just aren't cut out for the kinds of high-speed activities and technologies that we have invented.

I remember taking this hit. Being tackled at the torso, my head didn't take the direct impact, but based on our velocities on impact, both of our brains were colliding with the interiors of our skulls. We may have caused ourselves injuries that went undetected on

that day. Would I do it all over again? I can't say definitely not, but the idea gives me pause.

Athletes and parents of athletes need to be mindful of the risks. Some risk can be reduced, and there is value in developing better helmets, better pads, and better rules. But there is no such thing as a helmet that prevents all brain injuries, and none is coming down the pike either. Physics is what it is.

Cameron Wallace, MD, has his own family medicine practice in Cooperville. In his youth, he played high school and college football. His kids play soccer.



Egg Drop Competition

By Will Brewer and Stephania Jackson

Mrs. Nguyen's Grade 8 Science Class, Eerie J.H.S.

Introduction

Our class was given an assignment: In groups of two, design, build, and test a homemade device to hold an uncooked egg and protect it from breaking during a 15-foot fall from the roof of the school to the sidewalk. Another criterion was the use of extra-large eggs randomly selected from several cartons kept in a refrigerator until just five minutes before the competition. Constraints included a ban of any plastic materials other than a maximum of six inches of tape. All materials used in the devices needed to be biodegradable. Also, our devices could not have fixed wings, propellers, or parachutes to slow the descent to the ground.

Materials

Our device was made with the following:

- $6 \times 6 \times 6$ -inch cardboard box
- cellulose insulation
- rubber cement
- adhesive tape, 6 inches
- paper steamer material, 96 inches

Our Methods

We relied on the cardboard box to provide structure for the device. We used soft, loose, cellulose insulation to serve as a nest for the egg inside the box. We used rubber cement mixed with insulation to form a base layer on all sides of the box interior, including the flaps. We hypothesized that the rubber cement could help absorb some of the energy of the collision. Loose insulation was packed into the box until it was half full. The rest was added once the egg was tucked into the first layer. We put the egg into the material with its large, rounded end

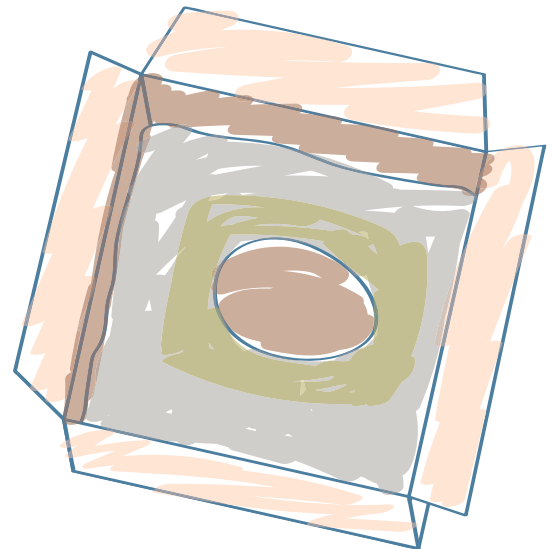
oriented down because the archlike shape would be less likely to crack. Four 24-inch streamers were cut, and the end of each was pressed into the sticky cement-and-insulation mixture under a flap edge. We hypothesized that these would add some drag as the box fell, perhaps reducing its acceleration. When we received our egg at the start of the competition, we placed it into the box, buried it under a packed layer of insulation, and then sealed it under the flaps. We taped the flaps shut with two three-inch lengths of adhesive tape. Instructions about how to drop the box were part of our design. The teacher, who dropped all devices, was instructed to drop the box with the bottom side down.

Results

Our device succeeded. It was difficult to determine if the streamers slowed the box's fall, but the streamers moved, so they might have provided some drag. The streamers may have also helped keep the box upright, as it fell almost flat on its bottom side before bouncing and rolling onto a side. Upon opening the box, we saw that the cellulose insulation was still pretty well packed, and the egg appeared to be upright, with no signs of damage.

Discussion

We think our design worked because of the orientation of the egg, the use of streamers to add some stability and drag, and the shock-absorbing properties of the cellulose insulation. It is likely that the egg was slowed down enough to survive the collision thanks to the insulation below it. The insulation material contains spaces full of air, so it acted in a similar manner to an airbag in a car. It's unclear if the layer of rubber cement served a purpose besides holding the insulation in place. We could test it by setting up a nearly identical device and leaving out the rubber cement. The ability of the cellulose to cushion the egg, along with its known usefulness as an insulator, suggests that cellulose would be an excellent material for packing and shipping cooled eggs.



Debate Transcript

Banning Import of Plastic Bottles

Note: Niue is a real self-governing island in the South Pacific. However, the debate transcript that follows is fictitious.

First Proposition: We are here today to debate whether Niue should ban the import of plastic bottles, which would effectively mandate that Niue live without a variety of useful or vital products that are packaged in plastic. This matter will be voted on by the parliament soon. I have been asked to represent members who are opposed to this ban. While we recognize that plastic pollution is a serious issue facing the Pacific islands, we do not want Niue's economy to abruptly ban a wide variety of products that are important to the Niuean people, including our health. Soda bottles get most of the attention, and I would concede that Niue does not need soda, but other products such as soaps, disinfectants, and medicines are mostly packaged in plastic bottles. Manufacturers are not going to make special batches of glass- or paper-packaged



products just for our island of 1,500 people. Our tourism industry, which is small but nonetheless vital, would also be disrupted by this proposed ban.

First Opposition: Thank you to my colleague for his opening remarks. I would like to begin simply by opening this potato sack and revealing what I collected on the road on my walk to work this very morning. I collected six one-liter bottles, two two-liter bottles, and this wide variety of small containers. This is from a half-kilometer walk, and these are items that were all within arm's reach of the actual road. None of these items carried medicine, soap, disinfectant, or anything that

Words to Know

A mandate is an official order to do something. It can be in the form of a law or in a less-formal rule.
Context is the setting, circumstances, or time in which something is occurring.

I would consider necessities. They're all for sugary drinks that ruin our kids' teeth and are contributing to the epidemic of obesity and diabetes on our small island. We do not need these products, and we cannot afford to keep importing them when we cannot export them for recycling. Burning these bottles is bad for our health, and we have no space for landfills. I would also note that the proposed ban would not affect tourism, as tourists would be allowed to bring in plastic-packaged items, such as a bottle of shampoo, for personal use.

Second Proposition: My point about tourism was not about personal items or the context of imports. Tourists come to Niue to enjoy its serene beauty, fish for wahoo and tuna, snorkel with the banded sea snakes, and see the whales breaching just off shore. But the latest report from the Visitors Bureau shows that 75 percent of tourists that come to Niue want access to comforts from home, including beverages, ground coffee, and the occasional package of painkiller in case they get a headache from scuba diving. These things are packaged in plastic. Also, the same report shows that tourists would pay an added tax that could be used to fund a semiannual export of all plastic waste. The waste would be shipped to New Zealand and recycled, at no cost to our government. We would simply need to do some cleanup.

Second Opposition: I noted with interest that the Visitors Bureau's report did not ask tourists if they wanted to see less plastic rubbish on Niue's beaches and roads or whether they would actually refuse to visit Niue if they couldn't buy a plastic bottle of soda. It is of course not a surprise that most tourists *want* comforts of home while abroad, so I find the question flawed and the responses unconvincing. My office, the Ministry of Environmental Affairs, regularly receives emails and even drop-in visits from tourists who express their dismay that there is so much plastic rubbish everywhere. Many do not make the connection between their own purchases of plastic containers here on Niue and the eventual pollution because they assume the empty containers that they place in bins in their hotel rooms are recycled. They are wrong. The only solution to this problem is to stop bringing in so much plastic. The tourists could keep coming, and I suspect many more would come if we cleaned up this island. By the way, to "simply do some cleanup" would be a massive undertaking. It's already clear that we either are uninterested in such work or cannot keep pace with the rate of pollution.

Proposition: Final Words: Niue must indeed find solutions to the problems of plastic waste and pollution. I would also concede



that some products that happen to be packaged in plastic are indeed unnecessary and are connected to some other problems we have here, such as obesity and diabetes. However, there is no denying that we do need some products that are packaged in plastic—medicines, for example—so a ban of all imports packaged in plastic would have a net-negative effect on our people's health. A better approach to our pollution problem would be to fine adult polluters and involve the school system so that children are discouraged from polluting and are actively involved in the cleanup of our environment.

As I have noted, we can vote down this proposed ban of important imports and instead pursue a tax on tourism that could fund the export of our plastic rubbish twice a year. This combination of behavioral change and a simple tax would solve the problem without depriving our people of things we need and, frankly, things that we should be able to enjoy even if they are not vital necessities. I would like to close by sharing an image of my granddaughter, Fiana. She came down with dengue fever last year, and the thing that saved her was a simple fever-reducing medicine that happened to be packaged in a plastic container. I do not know if she would be here today if the proposed ban of plastic bottles had been mandated a year ago, and I hope we do not vote in favor of such a ban anytime soon. Thank you.

Opposition: Final Words: We are all grateful that my colleague's beautiful granddaughter is still with us, of course. And we are all grateful for some of the products that we import that improve our health or even save lives. But it is a false choice between having those things and having them come to us in plastic packaging that then pollutes our island. There are alternative packaging options for things such as medicines. We simply need to import those alternatives—perhaps at some added cost to us—instead of importing the cheapest ones that come

in plastic. Meanwhile, the vast majority of plastic that comes to Niue is in the form of completely unnecessary products such as soda and snacks. Our people survived on this island for over a thousand years without plastic, but part of that was due to the recyclable nature of things on this island. The coconut tree falls, decays, and provides soil and nutrients for the next generation of trees. A plastic bottle goes nowhere unless we burn it or toss it into the sea—which are just ways of kicking the problem to another island, a different ecosystem, or the atmosphere. Our only responsible option would be to export this rubbish to a country that has the facilities to recycle this material, but we know that is not realistic. I encourage all my colleagues to vote in favor of the ban. And I too would like to leave you with a visual. It's of one of the most beautiful and most visited spots on our island. We must preserve our island's beauty, or nobody would come here and we won't have any money to buy these products! Without some basic standards that will improve our lives and improve the tourism industry, we are finished! Thank you.

Word to Know

Standards are goals or requirements that must be met.



Connection

In formal debate, one side supports or makes a proposition within a set amount of time, and the other represents the opposition, also within a time limit. The formal structure of a legitimate debate prohibits interruption and removes the noise of informal argument or bickering. This makes it easier for the audience to follow as arguments and evidence are presented.

Controlling Collision Factors

Recall that the equation for force involves just two factors: mass and acceleration. The F here is the net of all forces involved.

$$F = m \times a$$

To reduce how much force a collision involves, we can try to reduce mass or reduce acceleration. In real-world terms, we can make things lighter, or we can make things slower.

Consider the brakes on a car or bike. Brakes slow down and stop a vehicle, giving the operator time to avoid colliding with other things. Braking is smoothest when it's not done too abruptly. If a driver "slams" on the brakes, the vehicle slows down in a very short amount of time and over a short distance. It decelerates rapidly. Abrupt braking causes some of the tires to rub off

as a skid marks. The abrupt slowdown is also experienced by the passenger or rider, sometimes to the point of injury. A cyclist might tumble over the handlebars if she brakes too abruptly, as her momentum causes her to keep moving even if the bike has stopped. In a car, a passenger wearing a seat belt might be jerked against it as his momentum carries him forward despite the car slowing down and stopping. Ideally, a bicycle or automobile slows gently, over more time, so that the kinetic energy does not get transformed or transferred so suddenly. Coasting to a stop allows a gradual change from a velocity of 60 miles an hour to zero. Braking systems work best when the braking occurs under normal conditions and without too rapid a loss of speed.



Skid marks and collisions are outcomes that reflect the velocities of cars during acceleration and sliding. Sudden braking can prevent a disastrous collision, but an accident and damage are still possibilities. In this case, a car spun as it attempted to brake, and it rear-ended the guardrail.



Tanker ships like these have so much mass, and they are traveling through a fluid that does not provide a lot of friction, so slowing them down can require one or two miles of distance.

To counteract the effect of its large mass, a huge vehicle will require stronger brakes or more distance to slow down. If a ship does not have a way to “brake,” such as throwing the engine into reverse, then the pilot must give it plenty of coasting time and space to slow down more passively. Because container ships, oil tankers, military ships, large fishing boats, and other heavy craft have so much mass that the potential force of a collision is enormous, operators of very large vessels

must be highly trained and licensed in most parts of the world.

In contrast, small vehicles take much less time and space to slow down. A rowboat can be slowed down simply by paddling the other direction. A sailboat can turn to the left or right out of the wind, and it will slow down quickly. The more massive boats hauling cargo and oil take much longer to stop even though their engines can be reversed to help slow down forward momentum.

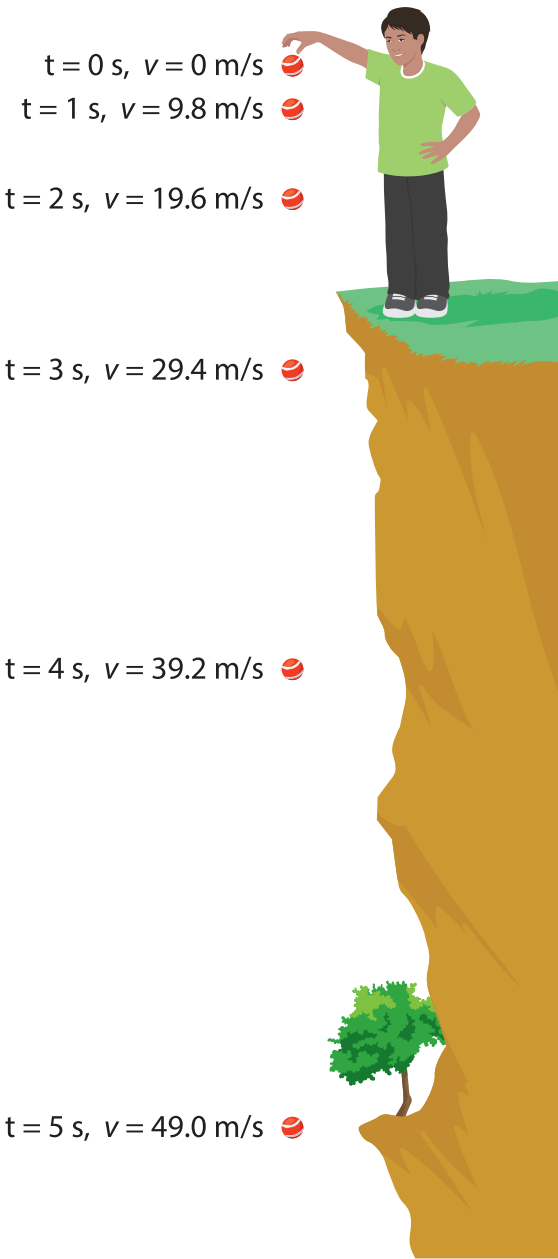
Type of boat	Mass (kg)	Stopping time (minutes)	Stopping distance
Rowboat with two people	200	1	20 meters
Sailboat with two people	4,000	5	100 meters
Fully filled common supertanker	73,000,000–109,000,000	15–20	3 km
Fully loaded cruise liner	200,000,000	15–20	3 km
Fully loaded cargo ship	200,000,000	15–20	3 km

Acceleration of Falling Objects

Gravity, a noncontact force, provides the pull that accelerates falling objects toward the ground. Contact forces come into the picture when a falling object hits the ground. Like all collisions, the force involved in a falling object striking the ground depends on the object’s mass and acceleration. When a falling object hits the ground, the stop is going to be abrupt, to say the least. What’s more, a free-falling object’s velocity increases the longer the object falls, especially with no air resistance.

For every second that an object is falling, another 9.8 meters per second get added to its velocity. The acceleration due to gravity in this table ignores air resistance. In real-world terms, falling objects do not keep accelerating indefinitely; they reach a terminal velocity, which is a top speed that the object cannot pass because of the effect of air resistance on the object.

Time, t (s)	Object’s velocity downward, v (m/s)
0	0
1	9.8
2	19.6
3	29.4
4	39.2
5	49.0



A person who jumps feet first into a pool from a one-meter diving board will probably not feel a sting on her feet. A higher diving board forces a diver to plan more carefully how to hit the water. In this scenario, air resistance doesn't provide braking in a way that matters to a diver. Greater height means larger speed at impact so the diver experiences a larger negative acceleration. Concentrating the force of a collision with water onto a small area of the body that is less delicate, such as the palms of the hands or soles of the feet, can be the difference between fun and fractured bones. This is why cliff divers dive into the water as arrowlike shapes instead of wider, less-graceful shapes. Just as the small area of an arrow more easily pierces armor, an arrow-like diver pierces the water and allows the rest of the body a less violent entry into the water. Then friction with the water, spread across the swimmer's body surface, continues to more gracefully slow the body down.

The opposite of a graceful entry is a belly flop, and from much height that is not only painful but dangerous.

Words to Know

The *efficacy* of a technology or behavior is a measure of how well it produces a desired result. An object's *terminal velocity* is the maximum speed it can achieve when in free fall, due to the resistance of the fluid through which it is falling.



There isn't much this diver can do to slow her descent into the water below.

Glossary

acceleration, n. a change in velocity

air resistance, n. the friction that air exerts on an object moving through it; drag

breaking point, n. the degree of stress under a force at which something breaks

brittle, adj. easily broken or shattered

collision, n. a physical meeting of objects as a result of motion

concussion, n. a brain injury that occurs when the head is struck by, or strikes, another object or surface, causing the brain to strike the inside of the skull

constraint, n. a limitation or restriction on a process or product

contact force, n. any force that requires physical contact between objects

context, n. all the words and ideas that surround an individual word, passage, event, or situation and can shed light on its meaning

criteria, n. needs that are to be met by a product or process

deform, v. to change shape

deformation, n. a change in shape or form

design, v. to plan and/or make something for a specific purpose or use

distribution of force, n. the amount of force that is spread out over a certain area

efficacy, n. a measure of how well a technology or behavior produces a desired result

elastic, adj. capable of recovering size and shape after being deformed

elastic limit, n. the maximum stress a material can withstand without permanent deformation

elastomer, n. any substance with properties similar to rubber

energy, n. the capacity to do work

flexible, adj. capable of being flexed

fluid, n. matter that does not hold a fixed shape and is able to flow; gases and liquids

force, n. a push or pull on a mass that causes the mass's velocity to change

frame of reference, n. the point of view from which we are describing or measuring motion within the context of a system of objects

friction, n. the resistance of motion between objects or materials that are in contact

gravity, n. the force that tends to cause physical objects to move toward each other based on mass

kinetic energy, n. the form of energy that an object has by reason of its motion

law of conservation of energy, n. the law that states that energy can neither be created nor destroyed

load, n. a mass or weight supported by something

malleable, adj. able to be reshaped without shattering or fracturing

mandate, n. a command or official order to do something

mass, n. a measure of the amount of matter in an object; a measure of the amount of inertia in an object

model, n. a representation of a real thing

newton, n. the unit of force

Newton's second law of motion, n. the formula "net force = mass $\times$ acceleration" ($F_{net} = m \times a$)

op-ed, n. commonly used to describe an "opinion editorial," a page in a newspaper that appears opposite the editorial page

peak force, n. during a collision, the measure of force at the instant in which the force is greatest

polymer, n. a chemical compound or mixture of compounds that forms repeating structural units

power, n. the transfer of energy over time

practical limit, n. a constraint based on what is practical or realistic

pressure, n. the perpendicular force per unit area, or the stress at a point within a confined fluid; $P = F/A$

projectile, n. a body thrown forward by external thrust that also continues forward motion by its own inertia

resistance, n. a force that acts in opposition to another force

rigid, adj. stiff or lacking in flexibility

scientific literacy, n. the ability to read, hear, and comprehend information about scientific topics and demonstrate understanding in discussion and through writing

speed, n. rate of motion

stakeholder, n. a person with an interest or concern in something, especially a business

standards, n. goals or requirements that must be met

stress, n. a force per unit area in a material that is experiencing an external force

symmetrical, adj. having similar or identical correspondence in size, shape, or relative position on opposite sides of a dividing line, center, or axis

terminal velocity, n. the maximum speed an object can achieve when in free fall, due to the resistance of the fluid through which it is falling

velocity, n. the speed of an object's motion in a given direction

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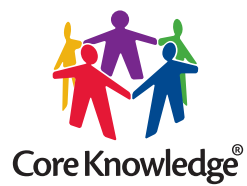
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