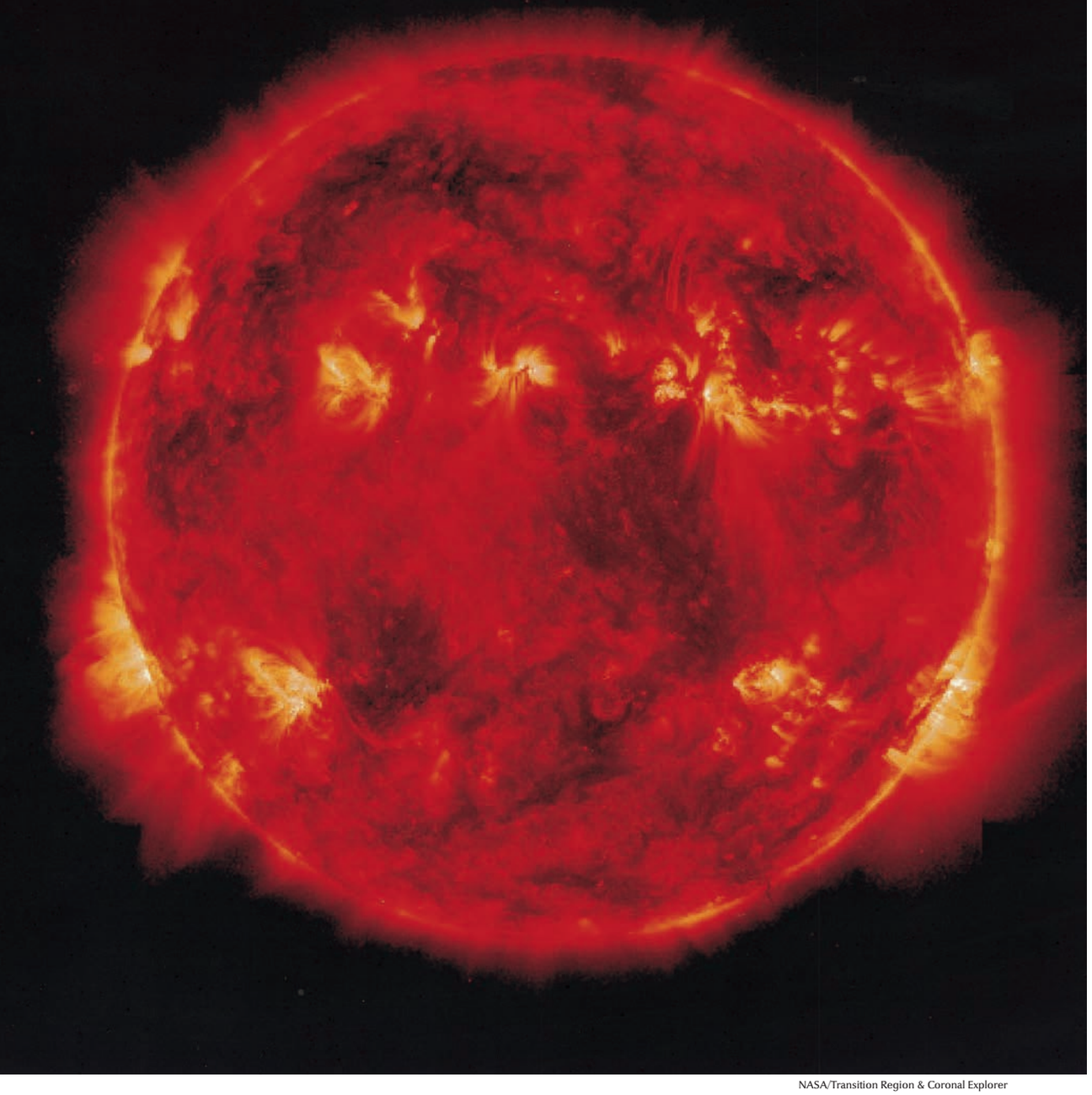


NASA/Transition Region & Coronal Explorer

The sun blazes with energy. On its surface, magnetic forces create loops and streams of gas that extend tens of thousands of miles or kilometers into space. This image was made by photographing ultraviolet radiation given off by atoms of iron gas that are hotter than 9 million °F (5 million °C).

Sun

Sun is a huge, glowing ball at the center of our solar system. The sun provides light, heat, and other energy to Earth. The sun is made up entirely of gas. Most of it is a type of gas that is sensitive to magnetism. This sensitivity makes this type of gas so unique that scientists sometimes give it a special name: *plasma.* The solar system's planets and their moons, millions of asteroids, and trillions of comets revolve around the sun. The sun and all these objects are in the solar system. Earth travels around the sun at an average distance of about 92,960,000 miles (149,600,000 kilometers) from it.

The sun is one of hundreds of billions of stars in the Milky Way Galaxy. It is about 25,000 *light-years* from the center of the galaxy, and it revolves around the galactic center once about every 240 million years. One light-year, the distance that light travels in a vacuum in a year, equals about 5.88 trillion miles (9.46 trillion kilometers).

The contributors of this article are Jay M. Pasachoff and Leon Golub. Pasachoff is Field Memorial Professor of Astronomy and Director of the Hopkins Observatory at Williams College. Golub is an astrophysicist at the Harvard-Smithsonian Center for Astrophysics.

The sun's *radius* (distance from its center to its surface) is about 432,000 miles (695,500 kilometers), approximately 109 times Earth's radius. The following example may help you picture the relative sizes of the sun and Earth and the distance between them: Suppose Earth were the size of a man. The sun would be roughly the size of a 60-story building, and the sun would be about 13 miles (21 kilometers) from Earth.

The part of the sun that we see has a temperature of about 5500 °C (10,000 °F). Astronomers measure star temperatures in a metric unit called the *kelvin* (abbreviated K). One kelvin equals exactly 1 Celsius degree (1.8 Fahrenheit degrees), but the Kelvin and Celsius scales begin at different points. The Kelvin scale starts at absolute zero, which is −273.15 °C (−459.67 °F). Thus, the temperature of the solar surface is about 5800 K. Temperatures in the sun's core reach over 15 million K.

The energy of the sun comes from *nuclear fusion reactions* that occur deep inside the sun's core. In a fusion reaction, two atomic nuclei join together, creating a new nucleus. Fusion produces energy by converting nuclear matter into energy.

The sun, like Earth, is magnetic. Scientists describe the magnetism of an object in terms of a *magnetic field.* This field is a region that includes all the space occupied by the object and much of the surrounding space. Physicists define a magnetic field as the region in which a magnetic force can be detected—as with a compass. Physicists describe how magnetic an object is in terms of *field strength.* Field strength is a measure of the force that the field would exert on a magnetic object, such as a compass needle. The typical strength of the sun's field is only about twice that of Earth's field.

But the sun's magnetic field becomes highly concentrated in small regions, with strengths up to 3,000 times as great as the typical strength. These regions shape solar matter to create a variety of features on the sun's surface and in its *atmosphere,* the part that we can see. These features range from relatively cool, dark structures known as *sunspots* to spectacular eruptions called *flares* and *coronal mass ejections.*

Flares are the most violent eruptions in the solar system. Coronal mass ejections, though less violent than flares, involve a tremendous *mass* (amount of matter). A single ejection can spew approximately 20 billion tons (18 billion metric tons) of matter into space. A cube of lead $\frac{3}{4}$ mile (1.2 kilometers) on a side would have about the same mass.

The sun was born about 4.6 billion years ago. It has enough nuclear fuel to remain much as it is for another 5 billion years. Then it will grow to become a type of star called a *red giant.* Later in the sun's life, it will cast off its outer layers. The remaining core will collapse to become an object called a *white dwarf* and will slowly fade. The sun will enter its final phase as a faint, cool object sometimes called a *black dwarf.*

The sun at a glance

Distance from Earth: *Shortest,* about 91,400,000 miles (147,100,000 kilometers); *longest,* about 94,500,000 miles (152,100,000 kilometers); *average,* about 92,960,000 miles (149,600,000 kilometers). Sunlight takes about 8 minutes to reach Earth, traveling at 186,282 miles (299,792 kilometers) per second.
Radius, distance from the sun's center to its surface: About 432,000 miles (695,500 kilometers), approximately 109 times the radius of Earth.
Volume: About 33×10^{16} cubic miles. This number would be written out as 33 followed by 16 zeroes. It is equivalent to 14×10^{17} cubic kilometers and is 1,300,000 times the volume of Earth.
Mass, amount of matter: About 2×10^{27} tons or metric tons. The sun's mass makes up 99.8 percent of the mass of the solar system and is about 333,000 times as great as the mass of Earth.
Density: *Average,* about 90 pounds per cubic foot (1.4 grams per cubic centimeter), roughly 1.4 times the density of water; *core,* about 100 times the density of water; *radiative zone,* about equal to the density of water; *convection zone,* about $\frac{1}{10}$ the density of water.
Temperature: *Surface,* about 5800 kelvins (5500 °C or 10,000 °F); *core,* more than 15 million kelvins (15 million °C, or 27 million °F).
Age: About 4,600,000,000 years.
Chemical makeup: By mass, hydrogen, about 72 percent; helium, approximately 26 percent; other elements, roughly 2 percent. By number of atoms, hydrogen, about 94 percent; helium, about 6 percent; other elements, about 0.1 percent.
Luminosity, the rate at which the sun sends out energy: About 4×10^{26} watts.
Solar constant, the amount of energy from the sun that arrives at the top of Earth's atmosphere: About 1,370 watts per square meter.
Rotation period: About 25 days at the equator; about 28 days at higher latitudes.
Revolution period (in the Milky Way Galaxy): About 250 million years.

Characteristics of the sun

Mass and density. The sun has 99.8 percent of the mass in the solar system. The sun's mass is roughly 2×10^{27} tons. This number would be written out as a 2 followed by 27 zeros. The sun is 333,000 times as massive as Earth. The sun's average density is about 90 pounds per cubic foot (1.4 grams per cubic centimeter). This density is about 1.4 times that of water and less than one-third of Earth's average density.

Composition. The sun, like most other stars, is made up mostly of atoms of the chemical element hydrogen. The second most plentiful element in the sun is helium, and almost all the remaining matter consists of atoms of seven other elements. For every 1 million atoms of hydrogen in the entire sun, there are 98,000 atoms of helium, 850 of oxygen, 360 of carbon, 120 of neon, 110 of nitrogen, 40 of magnesium, 35 of iron, and 35 of silicon. So about 94 percent of the atoms are hydrogen, and 0.1 percent are elements other than hydrogen and helium.

But hydrogen is the lightest of all elements, and so it accounts for only about 72 percent of the mass. Helium makes up around 26 percent.

The inside of the sun and most of its atmosphere consist of plasma. Plasma is basically a gas whose temperature has been raised to such a high level that it becomes sensitive to magnetism. Scientists sometimes emphasize the difference in behavior between plasma and other gas. They say that plasma is a fourth state of matter, alongside solid, liquid, and gas. But in general, scientists make the distinction between plasma and gas only when technically necessary.

The essential difference between plasma and other gas is an effect of the temperature increase: This in-

Some breeds of dogs have unusual characteristics. A Chinese shar-pei puppy, *left,* has a wrinkled coat that looks too large for its body. A black tongue is the distinguishing feature of the chow chow, *center.* The puli, *right,* has a coat that becomes tangled into long, ropelike cords.

WORLD BOOK photo by Brent Jones

WORLD BOOK photo

WORLD BOOK photo by Dave G. Wacker

Dogs provide companionship for people of all ages. These children's affectionate friend is a *mongrel* (mixed-breed dog). In general, mongrels display the dominant traits of each of their parents and make excellent pets.

WORLD BOOK photo

Specially trained dogs perform many tasks. This German shepherd uses its keen sense of smell to detect drugs being smuggled into the United States.

WORLD BOOK photo

Dog

Dog is an animal that has lived with people as a pet for more than 10,000 years, longer than any other animal. During that time, breeders have developed about 400 dog breeds to perform various tasks, provide companionship, and please the human eye.

Most scientists believe that prehistoric human beings first valued dogs as watchdogs. Later, people realized that dogs could also be used for herding and hunting other animals. Over thousands of years, such breeds as collies, komondors, and pulis were developed to herd sheep, goats, and cattle. Hounds, pointers, retrievers, setters, spaniels, and terriers were bred for various kinds of hunting.

The intelligence, loyalty, and tracking ability that make dogs useful to herders and hunters serve people in other roles as well. For example, the police use dogs to track criminals and to sniff out illegal drugs and hidden explosives.

Dogs of all breeds provide company for human beings, and many breeds were developed for this purpose. These breeds include most of the small breeds called *toy dogs,* such as Japanese chins and Pomeranians. The companionship of a dog can contribute to a person's general well-being. Scientific studies have shown that petting a dog slows the heart rate and lowers the blood pressure of the person who is doing the petting.

Dogs assist disabled people in many ways. For example, they guide the blind and serve as "ears" for the deaf. In addition, dogs lift the spirits of patients in hospitals and nursing homes.

Dogs have also entertained people for centuries. In earlier times, audiences enjoyed betting on fights between dogs and between dogs and other animals, such as bears, bulls, and lions. Many countries now ban such fights. Today, such contests as dog racing, field trials, and obedience trials draw large crowds. Dogs also perform in circuses, on stage, in motion pictures, and on television.

Some dog breeds have an unusual appearance. For example, the Mexican hairless has no fur on its body except for a few tufts on the top of the head. The loose skin of the Chinese shar-pei folds into wrinkles. These wrinkles are so deep that they may cover the animal's eyes. The chow chow has a blue-black tongue. The basenji is the only dog that cannot bark, though it can make a singing sound.

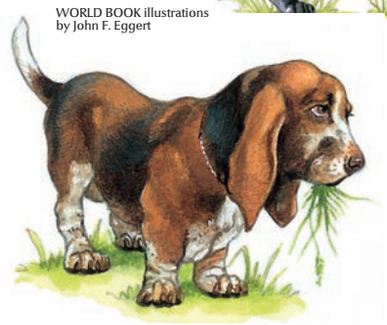
Terri McGinnis, the contributor of this article, is a veterinarian and the author of The Well Dog Book.

Why dogs do the things they do

Tail chasing is a normal form of play for puppies. A puppy instinctively chases the tip of the tail, possibly because it resembles moving prey. Adult dogs are more likely to chase their tails because of inadequate exercise or inadequate attention from their owners. They also may have fleas or some other medical problem.

Digging is an instinctive activity that dogs retain from their wild ancestors. The ancestors of dogs often buried part of the food they caught on hunts to protect it from other animals. Dogs frequently bury bones or food, or simply dig holes.

WORLD BOOK illustrations by John F. Eggert



Eating grass. Most dogs seem to enjoy the flavor of grass. Dogs also eat grass when they have digestive disorders. The grass causes vomiting, which can help make the dog feel better.

Panting helps a dog stay cool. When saliva evaporates from the tongue and mouth, it has a cooling effect that helps reduce the dog's body heat. Unlike people, dogs cannot cool themselves by perspiring. They have sweat glands only in their feet, and the glands have little effect on body temperature.

The body of a dog

Dogs vary greatly in size. The smallest breed of dog is the chihuahua. Most chihuahuas stand about 5 inches (13 centimeters) tall at the shoulder. Most chihuahuas weigh no more than 6 pounds (2.7 kilograms). The heaviest dogs are mastiffs and St. Bernards. Large male mastiffs and St. Bernards may weigh 200 pounds (90 kilograms). The tallest dogs are the Irish wolfhound and the Great Dane, both of which can reach heights of 39 inches (99 centimeters) tall at the shoulder.

The shape and other characteristics of a dog's body also vary widely from breed to breed. Dog breeds look so different from one another that it may be hard to believe that they are closely related. Nevertheless, dogs all have the same basic physical features. Except for limitations in size, all breeds can mate with one another and produce offspring.

Body structure is primarily determined by the dog's skeleton, which has an average of 320 bones. The exact number of bones varies, depending on the length of the dog's tail. A male dog has one more bone than a female of the same breed because he has a bone called the *os penis* in his penis.

Some breeds, such as the Boston terrier and the bulldog, are born with short tails. Other breeds, including poodles, cocker spaniels, schnauzers, and boxers, are born with long tails, but a veterinarian may *dock* (cut off) the tail a few days after birth. This surgery does not benefit the dog and is only done because some people prefer the appearance of a docked tail.

Most dogs have long legs. But some breeds, such as dachshunds, carry a gene for dwarfism that makes the leg bones extremely short and thick.

The shape of the skull determines whether a dog has a long, slender face like that of a collie or a short, broad face like that of the bulldog, pug, and Pekingese. Long-faced dogs have eyes that are nearer the sides of their heads, giving them a wide field of vision. Dogs with broad skulls have eyes that look forward like those of

Dog terms

Bitch is an adult female dog.
Breed standard is an official description of a breed.
Canine is another word for *dog* or *doglike.* The term comes from *canis,* the Latin word for *dog.*
Dog is an adult male dog. However, the term is generally used for all dogs, regardless of age or sex.
Litter is a group of puppies born at one time to one female.
Mixed-breed means a dog whose parents belong to different breeds or have mixed ancestry themselves.
Pedigree is a record of a purebred dog's ancestors.
Puppy is a dog less than 1 year old.
Purebred means a dog whose parents belong to the same breed.
Studbook is a book in which breeders register the pedigrees of dogs.
Whelp is an unweaned puppy—that is, one that still feeds on its mother's milk. The term also means to give birth to puppies.

and Southern states, especially Texas, Oklahoma, Kansas, Nebraska, and Iowa. However, tornadoes also strike other parts of the world. Areas where tornadoes occur include much of Europe, Japan, parts of China, South Africa, and parts of Argentina and Brazil. Australia ranks second to the United States in number of twisters. Many tornadoes also strike Bangladesh and eastern India.

How a tornado forms

The most damaging tornadoes form in storms called *supercells.* A supercell is a large, powerful thunderstorm. It contains a rapidly rotating air mass called a *mesocyclone*. For a supercell to form, and perhaps spawn a tornado, several basic conditions must exist. There must be an adequate supply of moisture to feed the storm. There must be a layer of warm, moist air near the ground and a layer of cool air above. Finally, the winds at higher elevations must differ from those at lower levels in speed, direction, or both.

Moisture. The first requirement for most tornadoes is moisture. In Tornado Alley, air from the Gulf of Mexico provides the moisture to fuel a twister. The warm water of the Gulf evaporates into the air.

Tornadoes and other severe storms often form along a *dryline.* In North America, the dryline is a boundary separating warm, moist air from the Gulf of Mexico and hot, dry air from the west.

If the humidity is high and rain-cooled air enters the main *updraft* (upward flow of air), a *wall cloud* forms. A wall cloud is a low-hanging, dark cloud. Most funnel clouds develop from a wall cloud. If the humidity is low beneath the wall cloud, a tornado may develop only a column of dust with no visible funnel-shaped cloud.

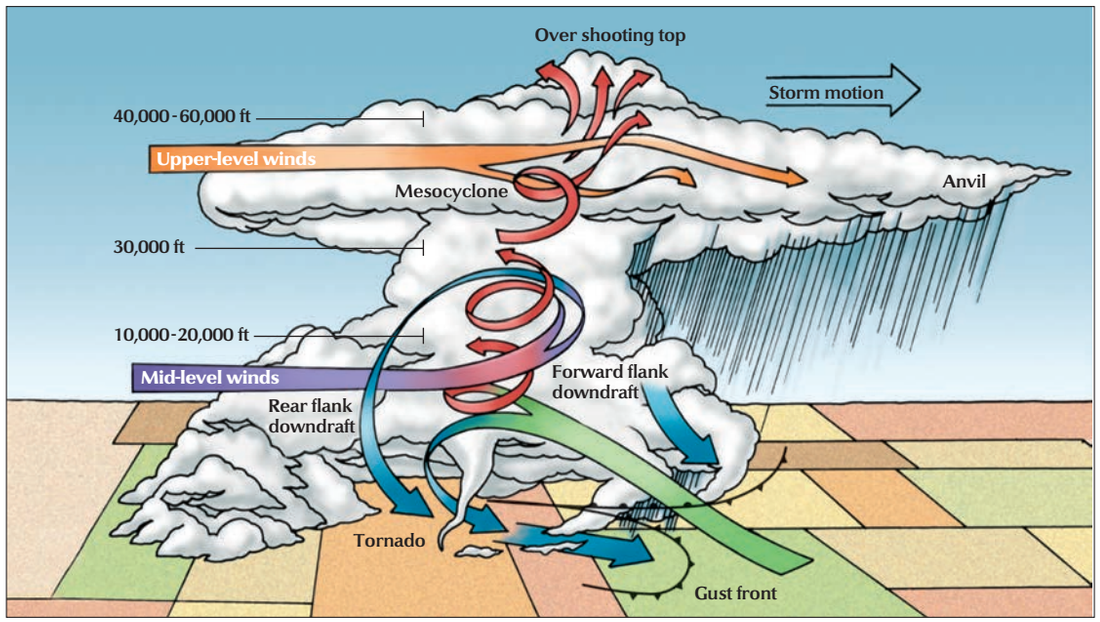
Air temperature. If there is warm, moist air at a lower altitude and cold, dry air at a higher altitude, the warmer air may become buoyant and rise rapidly. The air cools as it rises. The faster the warm air rises, the larger and more violent the storm and the more likely it will spawn a tornado. Storms may develop when warm air rides up over a shallow layer of cooler air. Storms may also form when moist air lifts over mountains, hills, or other high spots.

Often, a *front* powers an updraft of warm, moist air. A front is the boundary between two air masses of different densities resulting from a difference in temperature, humidity, or both. As the warm, less dense air rises, it begins to cool. The moisture it holds condenses into water droplets, forming a cloud. When the air rises high enough and becomes cold enough, its moisture turns into ice crystals. High in the atmosphere, often far above 35,000 feet (10,700 meters), the cloud stops rising. Upon reaching its maximum height, its top spreads out in the shape of an anvil. Anvil-shaped storm clouds often produce thunder, heavy rain, lightning, and hail. In the right conditions, a deadly tornado may form under the base of the cloud.

Winds. Another requirement for a supercell is that winds at higher elevations greatly differ from those at lower levels in speed, direction, or both. A difference in wind speed or direction is called *wind shear.* Wind shear makes the column of rising air begin to rotate. At first, the swirling air forms a broad, horizontal tube. As the storm develops, the tube tilts upright. It becomes the rotating column of air called a mesocyclone.

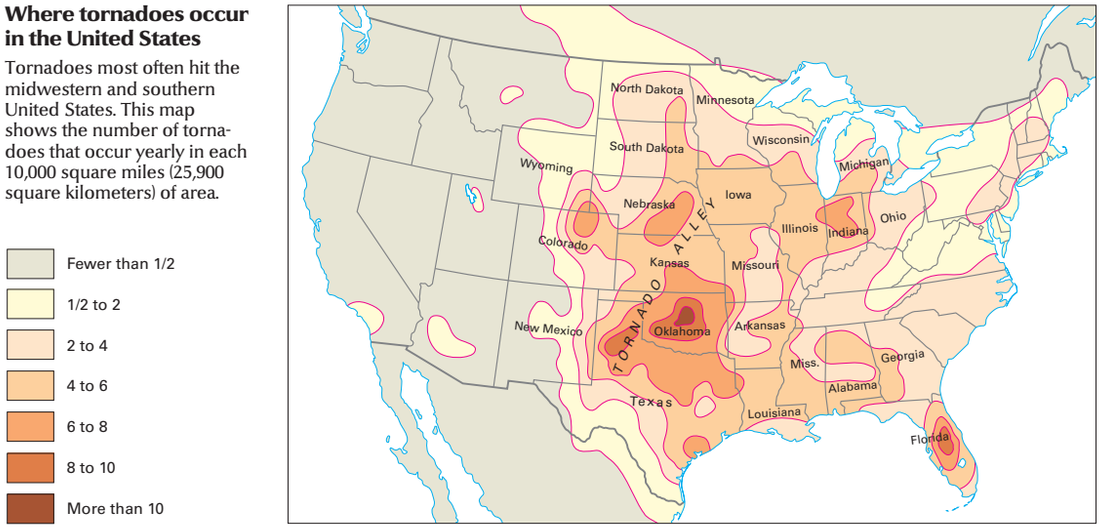
A tornado is a rapidly rotating column of air that can develop under a large, anvil-shaped thundercloud. Within such a cloud, winds of varying direction, elevation, and speed may contribute to the formation of a large, rotating wind pattern called a *mesocyclone.* Under certain conditions, a smaller, swiftly rotating column of air called a *funnel cloud* can develop within the mesocyclone. If the funnel cloud reaches down to the ground, it becomes a tornado.

WORLD BOOK illustration by Rolin Graphics



Where tornadoes occur in the United States

Tornadoes most often hit the midwestern and southern United States. This map shows the number of tornadoes that occur yearly in each 10,000 square miles (25,900 square kilometers) of area.



WORLD BOOK map

Most tornadoes occur in supercells. But some appear in a large group of storms called a *mesoscale convective system* (MCS). *Mesoscale* means *medium-sized. Convective* refers to *convection,* the turbulent upward and downward motions of air among the storms. An MCS is a cluster of thunderstorms that act as a system and often produce severe weather.

The life of a tornado

Tornadoes occur most often during the spring and early summer. Most happen in the late afternoon and early evening. The majority of tornadoes develop from severe thunderstorms. A hurricane, when it makes landfall, can also generate tornadoes.

The first sign of an approaching tornado may be light rain. Heavier rain follows and then rain mixed with hail. The hailstones may grow to the size of golf balls or even oranges. After the hail ends, a tornado may strike. In most tornadoes, a funnel-shaped cloud forms and descends from the wall cloud until it touches the ground. However, there might be a tornado even if the air is too dry for a visible funnel cloud to form. Sometimes, the first sign of a tornado is dust swirling just above the ground.

Some tornadoes contain smaller, short-lived, rotating columns of air called *suction spots* or *suction vortices.* The suction spots revolve around the center of the tornado and can inflict great damage to small areas. When these smaller vortices form, the overall vortex or rotating tornado cloud tends to be wide.

Tornadoes form over water as well as over land. Tornadoes over water, called *waterspouts,* carry large amounts of mist and spray. Waterspouts occur frequently in summer over the Florida Keys. Waterspouts also form elsewhere in the Gulf, along the Atlantic and Pacific coasts, over the Great Lakes, and even over the Great Salt Lake in Utah.

A few small tornadoes begin near the ground and build upward, instead of descending from the clouds. These storms are often called *landspouts* because they look like waterspouts over land.

Damage by tornadoes

Most tornado damage results from the wind. Each time the wind speed doubles, the force of the wind increases four times. For example, the force of the wind at 220 miles (350 kilometers) per hour is four times as great as the force at 110 miles (175 kilometers) per hour. This tremendous strength may knock over buildings and trees. Other damage occurs when gusts of wind pick up objects and hurl them through the air.

The Fujita scale. Scientists estimate the wind speed of a tornado by the damage it inflicts. For years, they used a system called the Fujita scale. The Japanese-born weather scientist T. Theodore Fujita developed the scale in 1971. In the early 2000's, scientists developed a revised system called the Enhanced Fujita scale. On the Enhanced Fujita scale, EF0 is the weakest rating and EF5 is the strongest. An EF5 tornado can remove a house from its foundation.

Air pressure. Air rising from the ground in the vortex of a tornado creates an area of low air pressure near the ground. For this reason, some people open their windows if a tornado threatens. This precaution is meant to help equalize the indoor pressure with the air outside. The people fear that the air pressure outside the building might drop so suddenly that the structure would explode outward. Safety experts know, however, that air moves in and out of most buildings quickly. The air pressure remains nearly equal inside and out, even during a tornado. Open windows do not reduce the damage. Instead, they may increase the destruction if the wind hurls loose objects through the openings.

Forecasting tornadoes

Meteorologists (scientists who study weather) hope to learn more about tornadoes to better forecast these destructive storms. They can predict with some accuracy 12 to 48 hours in advance if severe weather, and possibly a tornado, threatens an area. Forecasts are made using data from weather balloons, radar, and satellites.

In the United States, the National Weather Service is-