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THE SMITHSONIAN

Established in 1846, the Smithsonian—the world’s largest museum and research complex—includes 19 museums and galleries and the National Zoological Park. The total number of artifacts, works of art, and specimens in the Smithsonian’s collection is estimated at 137 million. The Smithsonian is a renowned research center, dedicated to public education, national service, and scholarship in the arts, sciences, and history.
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SPACE

When you look into the blackness of the night sky, you are peering into the fathomless depths of the Universe. Stars, planets, and galaxies stretch into space, not just farther than you can see, but farther than you can imagine.
**THE UNIVERSE**

The Universe is the whole of existence—all of space, matter, energy, and time. The Universe is so vast that it seems unimaginable, but we do know that it has been steadily expanding following its beginning 13.8 billion years ago in an explosive event called the Big Bang.

**UNDERSTANDING THE UNIVERSE**

People used to think of the Universe as a giant sphere, but we now know that things are not so simple. The Universe probably has no center or outer edge. Only a fraction of it—the observable Universe—is visible to us. The whole Universe may be vastly bigger than this, perhaps infinitely so.

**The shape of space**

The three dimensions of space are bent by the force of gravity from matter in the Universe into a fourth dimension that we can’t see. This is hard to visualize, so scientists use the metaphor of a two-dimensional rubber sheet to explain the idea. The mass of the Universe could bend this rubber sheet in one of three ways, depending on how densely packed with matter the Universe is. Most scientists now think the shape of the Universe is flat.

**Looking back in time**

Because light takes time to travel, when we look into space we are looking back in time. The most distant objects visible are galaxies photographed by the Hubble Telescope. We see them as they were 13 billion years ago. The Universe extends far beyond these, but it’s impossible to see objects much further because their light hasn’t had time to reach us.

**Furthest objects**

The light from the faintest galaxies in this photo from the Hubble Space Telescope took 13 billion years to reach Earth.

**What’s the matter?**

The elements hydrogen and helium make up 98 percent of the matter we can see in the Universe. But there doesn’t seem to be enough matter to account for the way stars and galaxies are pulled by gravity. As a result, astronomers think galaxies contain dark matter, which we cannot see. There is also an unknown force making the Universe expand, known as dark energy.

**THE SCALE OF SPACE**

The Universe is so vast that we cannot appreciate its size without making leaps of scale. In this series of pictures, each stage represents a microscopic speck of the image to its right. When dealing with the vast distances in space, miles aren’t big enough. Instead, astronomers use the speed of light as a yardstick. Light is so fast it can travel around the Earth 7.5 times in a second. One light year is the distance light travels in a year: nearly 6 trillion miles (10 trillion km).

**Earth and Moon**

Earth is 7,926 miles (12,756 km) wide. Our nearest neighbor in space—the Moon—orbits Earth at a distance of 238,855 miles (384,400 km). If Earth were the size of a soccer ball, the Moon would be the size of a cantaloupe about 69 ft (21 meters) away.

**Solar System**

The Sun’s family of eight planets occupy a region of space 5.6 billion miles (9 billion km) wide. If Earth were a soccer ball, it would take five days to walk across this part of the Solar System. The nearest star would be a 58-year walk away.

**Stellar neighborhood**

The nearest star to the Sun is Proxima Centauri, which is just over four light years away. There are around 2,000 stars within 50 light years of the Sun. These make up our stellar neighborhood, which is a tiny fraction of the Milky Way galaxy.

**CELESTIAL BODIES**

The Universe is at least 99.999999999999 percent empty space. Floating in this vast, dark void are all sorts of different objects, which astronomers call celestial bodies. They range from grains of dust to planets, stars, and galaxies. Our Solar System includes a star (the Sun) and a large family of planets and moons that formed from the same cloud of gas that gave birth to the Sun. In recent years, planets have been seen around hundreds of other stars, showing that our Solar System may be one of billions in our galaxy.

Asteroid

Rocky lumps left over from the formation of the Solar System are called asteroids. They range in size from boulders to bodies close to the size of a dwarf planet.
The Milky Way is a vast cloud of 200 billion stars. Its shape resembles a pair of fried eggs held back to back, with a central bulge surrounded by a flat disk. It measures 100,000 light years across the disk and 2,000 light years deep through the bulge.

### Local Group of galaxies
The Milky Way is just one of perhaps seven trillion galaxies in the observable Universe. Galaxies exist in groups called clusters, held together by gravity. The Milky Way is part of a cluster known as the Local Group, which is about 10 million light years wide.

### Supercluster
Clusters of galaxies exist in even larger groupings called superclusters. We live in the Virgo Supercluster, which is one of millions of superclusters in the known Universe. Between these are immense empty areas called cosmic voids.

### Universe
Superclusters are thought to form a vast web of filaments riddled with enormous voids containing no galaxies. The true size of the Universe is a mystery, and only a fraction of it is visible to us. The Universe may even be infinite in size.
The Big Bang

About 14 billion years ago, the Universe materialized out of nothing for unknown reasons. Infinitely smaller than an atom to begin with, the Universe expanded to billions of miles across in under a second—an event called the Big Bang.

Time came into existence when the Universe began, so the question "What happened before?" has no meaning. Space also came into existence. The Big Bang was not an explosion of matter through space—it was an expansion of space itself.

At first the Universe consisted of pure energy, but within a trillionth of a second some of this energy turned into matter, forming a vast soup of subatomic particles (particles smaller than atoms). It took nearly 400,000 years for the particles to cool down enough to form atoms, and then another 300 million years before the atoms formed planets, stars, and galaxies. The expansion that began in the Big Bang continues to this day, and most scientists think it will carry on forever.

The Universe began as something called a singularity: a point of zero size but infinite density.

The expanding Universe

The illustration below does not show the shape of the Universe, which is unknown. Instead, it is a timeline that shows how the Universe has expanded and changed since the Big Bang. We know the Universe is expanding because the most distant galaxies are rushing apart at rapid speeds. By running the clock backward, astronomers figured out that the expansion began 13.8 billion years ago at a single point: the Big Bang.
The Universe is now about 1 microsecond old and 60 billion miles (100 billion km) wide. The leftover particles begin to form protons and neutrons—the particles that today make up the nuclei of atoms. But the Universe is too hot for atoms to form yet. Light cannot pass through the sea of particles, so the young Universe resembles a dense fog.

After 379,000 years, the Universe cools enough for atoms to form. The Universe is now an enormous cloud of hydrogen and helium. Light can pass through space more easily, and the Universe becomes transparent.

Half a million years after the Big Bang, matter is spread out almost evenly in the Universe, but tiny ripples exist. Working on these denser patches, gravity begins pulling the matter into clumps.

At 300 million years, stars appear. Stars form when great clouds of gas are pulled into tight knots by gravity. The pressure and heat become so intense in the dense pockets of gas that nuclear reactions begin, igniting the star.

At 500 million years, the first galaxies are forming. Galaxies are enormous clouds of stars, held together by gravity.

Now 5 billion years old, the Universe consists of vast clusters of galaxies arranged in threads, with gigantic voids between them. The voids get ever bigger as space continues to expand. At 8 billion years, the expansion of the Universe begins to accelerate.

Our Solar System forms at 9 billion years. When the Universe is 20 billion years old, the Sun will expand in size and destroy Earth.

The Universe will carry on expanding forever, becoming cold and dark everywhere.

**Discovery of the Big Bang**
The first scientific evidence for the Big Bang was found in 1929, when astronomers discovered that light from distant galaxies is reddened. This color change happens when objects are moving away from us, making lightwaves stretch out and change color. The more distant the galaxies are, the faster they are rushing away. This shows that the whole Universe is expanding.

**Big Bang afterglow**
More evidence of the Big Bang came in the 1960s, when astronomers detected faint microwave radiation coming from every point in the sky. This mysterious energy is the faded remains of the intense burst of energy released in the Big Bang.

**Changing elements**
For hundreds of millions of years, the Universe consisted almost entirely of hydrogen and helium—the very simplest chemical elements. After stars appeared, new elements began to be made in the cores of dying stars. All the complex elements in our bodies were forged in dying stars this way.

**Big Bounce theory**
What caused the Big Bang? We may never know for sure, but some scientists have suggested that there may have been lots of big bangs, with the Universe expanding after each one and then shrinking again. This theory is called the Big Bounce because the process repeats itself.
Galaxies

Our Sun belongs to a giant whirlpool of stars called the Milky Way. Huge collections of stars are called galaxies, and like all galaxies the Milky Way is unimaginably vast.

Galaxies come in many shapes and sizes. Some are spirals like our own galaxy, but others are fuzzy balls or shapeless clouds. The smallest have just a few million stars. The largest contain trillions.

Although they look packed with stars, galaxies are mostly empty space. If you made a scale model of the Milky Way with a grain of sand for each star, the nearest star to the Sun would be 4 miles (6 km) away. The furthest would be 80,000 miles (130,000 km) away. The stars in a galaxy are held together by gravity and travel slowly around the galactic heart. In many galaxies, including ours, a supermassive black hole lies hidden in the center. Stars and other material are sucked into this cosmic plughole by gravity and disappear forever.

The Milky Way

If you could look down on the Milky Way galaxy from above, the view would be like flying over a glimmering city at night. Most of the galaxy’s 200 billion stars are in the central bulge. Curving around this are two vast spiral arms and several smaller arms. The Milky Way is thought to be a barred spiral (see panel), but we can’t see its shape clearly from Earth since we view it from the inside. In the night sky, the Milky Way appears only as a milky band of light.
### Galaxy shapes

Astronomers classify galaxies into just a few main types, depending on the shape we observe from Earth.

- **Spiral**
  - A central hub of stars is surrounded by spiral arms curving out.
  - How spiral arms form
    - The stars in a galaxy orbit the center, taking millions of years to make one circuit. Spiral arms appear where stars pass in and out of crowded areas, like cars passing temporarily through a traffic jam. One theory is that these traffic jams happen because the orbits of different stars don’t line up neatly.

- **Barred spiral**
  - A straight bar runs across the center, connecting spiral arms.

- **Elliptical**
  - More than half of all galaxies are simple ball shapes.

- **Irregular**
  - Galaxies with no clear shape are classified as irregular.

### How spiral arms form

The stars in a galaxy orbit the center, taking millions of years to make one circuit. Spiral arms appear where stars pass in and out of crowded areas, like cars passing temporarily through a traffic jam. One theory is that these traffic jams happen because the orbits of different stars don’t line up neatly.

#### If stars all had neat, parallel orbits, the galaxy would have no spiral arms.

#### If stars’ orbits don’t line up neatly, crowded zones form, giving the galaxy spiral arms.

### Colliding galaxies

Sometimes galaxies crash and tear each other apart. Individual stars don’t collide, but gas clouds do, and gravity pulls the colliding galaxies into new shapes.

#### End of the Milky Way

In 4 billion years our galaxy will collide with the Andromeda galaxy. This artist’s impression shows what the sky might look like as they merge.
Star birth

Stars have been forming throughout the Universe for most of its life. They take shape in vast clouds where thousands of stars are born at a time.

The clouds that give birth to the stars are cold and dense and consist mainly of hydrogen gas. The newly formed stars are huge spinning globes of hot, glowing gas—mainly hydrogen, with helium and small amounts of other elements. Much of this material is packed tightly into the stars’ cores, and it is here that nuclear reactions release energy in the form of heat and light.

How new stars form

The star-forming process begins when the cloud becomes unstable and breaks up into fragments. Gravity pulls the material in a fragment into an ever-tighter clump, and the clump slowly forms a sphere as it shrinks. Now a protostar, this star-to-be keeps on shrinking, its core getting denser and hotter. Eventually the pressure and temperature are so high that nuclear reactions begin, and the star starts to shine.

Starbirth nebulas

Clouds of gas and dust in space are called nebulas. Much of the gas and dust in a nebula is debris from old stars that exploded when they ran out of fuel. Over millions of years, this material is recycled to make new stars. Starbirth nebulas are among the most beautiful objects in space, their colorful clouds illuminated from within by the blue light of newborn stars.

Orion Nebula

The Orion Nebula is one of the closest star-forming regions to Earth. In the night sky it looks like a fuzzy star in the sword of Orion. In reality, it is a vast cloud of gas and dust thousands of times bigger than the Solar System.
Types of star
A star begins to shine when nuclear reactions in its core convert hydrogen into helium and release energy. It is then called a main sequence star. Not all main sequence stars are the same—they differ in size, temperature, color, brightness, and the amount of matter they contain. When stars begin to run out of fuel and near the end of their lives, they stop being main sequence stars and may swell up and turn into red giants or shrink to become white dwarfs.

Classifying stars
The Hertzsprung-Russell diagram is a famous graph that astronomers use to classify stars. The graph plots brightness against temperature and reveals that there are distinct groupings of stars, such as red giants (dying stars) and main sequence stars (ordinary stars). Astronomers also classify stars by color, which is linked to their temperature: hot stars are blue; cooler stars are orange or red.

Star clusters
Stars are not formed singly—they are born in clusters from the same cloud of material at roughly the same time. Eventually, the stars of a cluster will drift apart and exist alone in space, or with a close companion or two. Our Sun, like about half of the stars nearest to us, is alone. About a third of the stars in the night sky are in pairs, bound together by gravity.

Pleiades cluster
A handful of the 5,000 or so stars that make up the Pleiades cluster can be seen with the naked eye. In about 250 million years time, the stars will have dispersed and the cluster will no longer exist.
Four ways to die
Stars can die in four different ways, all of which are shown on these pages. Our Sun, a typical star, will follow the central path, but not yet—it has enough fuel to keep shining for 5 billion years. When larger stars die, they turn hydrogen into heavier chemical elements such as carbon and oxygen, which are later recycled to form new stars and planets. All the atoms in your body were created this way.

Medium stars
When a Sunlike star has used up the hydrogen in its core, nuclear fusion spreads outside the core, making the star expand into a red giant. The core collapses until it is hot and dense enough to fuse helium, but eventually it runs out of helium too. Finally, it becomes a white dwarf, and its outer layers spread into space as a cloud of debris.

Massive stars
Stars over eight times more massive than our Sun end their lives in strange and violent ways. The heat and pressure inside the core become so great that nuclear fusion can not only fuse hydrogen atoms together to form helium but can fuse helium and larger atoms to create elements such as carbon or oxygen. As this takes place, the star swells into the largest star of all: a supergiant.

Star death
All stars eventually run out of fuel and die. Most fade away quietly, but the most massive stars self-destruct in a huge explosion that can outshine an entire galaxy.

Like Earth, stars generate the force of gravity, which squeezes their hot cores. The more matter a star has, the greater the force of gravity and the hotter and denser the core becomes. The way a star dies depends on how much matter it contains (its mass) and how powerfully its core is squeezed by gravity.

Stars make heat and light by the process of nuclear fusion: hydrogen atoms in the core crash together to form helium, releasing energy. In small stars, when hydrogen in the core runs out, the star's light slowly fades. But in more massive stars, the core is so hot and dense that fusion can spread beyond it, changing the star's appearance. The most massive stars are eventually overwhelmed by their own gravity, which crushes them so violently that they collapse into a pinprick to create a black hole.

Stable star
Every young star goes through a stable phase in which it shines steadily.

5 billion tons—the weight of one teaspoonful of material from the core of a neutron star.

Supergiant stars can grow to 1 billion times the volume of our Sun.
Light intensity fades as fuel runs out.

Star continues to shrink and fade.

Light becomes increasingly dim.

Finally, its fuel used up and its light extinguished, the star becomes a black dwarf—an Earth-sized cinder.

Red giant
Nuclear fusion spreads to the layer around the core, heating it up and making the star expand. Nearby planets may be swallowed up by the growing giant.

Planetary nebula
The star’s outer layers disperse into space as a glowing cloud of wreckage—a planetary nebula. The material in this cloud will eventually be recycled to form new stars.

White dwarf
All that remains is the dying core—a white dwarf. This Earth-sized star will slowly fade and become a cold, dead black dwarf.

Neutron star
Up to three times heavier than the Sun, yet just a few miles wide, neutron stars are unimaginably dense, fast-spinning stars.

Red supergiant
The star has grown into a supergiant. Nuclear fusion carries on inside the core, forcing atoms together to form heavier and heavier elements, until the star’s core turns into iron. When this happens, the core no longer generates enough outward pressure to resist the crushing force of gravity, and the whole star suddenly collapses, causing a catastrophic explosion—a supernova.

Supernova
The star self-destructs in an explosion brighter than a billion suns. Its outer layers are blasted into space, but its massive core continues to collapse in on itself. What happens next depends on how massive the core is. A smaller core becomes a neutron star, but a massive core never stops collapsing. It shrinks until it’s billions of times smaller than an atom and becomes a black hole.

Black hole
The force of gravity close to a black hole is so intense that nothing can escape from it—not even light. Anything falling inside is torn apart by gravity and then crushed into a point of infinite density.

1 teaspoonful of material from a red giant weighs less than a grain of salt.

1,600 light years—the distance from Earth to the nearest black hole.
THE UNIVERSE

The Sun

The Sun is a nearly perfect sphere of hot, glowing gas. Its source of power lies buried deep in the central core, where a nuclear furnace rages nonstop, turning matter into pure heat and light.

Slightly bigger than a typical star, the Sun is large enough by volume to swallow 1.3 million Earths. It contains 99.8 percent of all the matter in the Solar System, and the force of gravity generated by this enormous mass keeps the planets trapped in orbit around it. Seen from Earth, the Sun is a life-sustaining source of light and warmth that shines steadily on us. Closer views, however, reveal a world of astonishing violence, its seething surface bursting with vast eruptions that hurl fiery gases into space.

Inside the Sun

Scientists divide the Sun’s interior into three distinct layers: the core, the radiative zone, and the convective zone. All three are made solely of gas, but the gas gets hotter and denser toward the center. In the core, the temperature soars to 27 million °F (15 million °C) and the gas is 150 times more dense than water.
Solar flare
A sudden burst of energy from the Sun's surface is called a solar flare. Flares are often followed by a coronal mass ejection (see panel).

Sunspots
Cooler, darker patches on the Sun are called sunspots. The number of sunspots rises and falls over an 11-year cycle.

Grainy surface
The bubbles of hot gas that rise up inside the Sun make its surface look grainy. There are some 4 million granules on the Sun's face, each about 600 miles (1,000 km) wide and lasting for around eight minutes.

Energy release
It takes only eight minutes for light from the Sun to reach Earth, but it can take 100,000 years for energy released in the Sun's core to travel to the surface and emerge as light. The journey is slow because the energy is absorbed and reemitted by trillions of atoms as it passes through the dense radiative zone.

Rotation
Like all objects in space, the Sun rotates. Unlike the Earth, which rotates as a solid object, the Sun is a ball of gas and turns at different speeds in different places. The equator takes 25 Earth days to rotate once, but the polar regions take 34 days.

Mass ejections
Vast bubbles of superhot gas (plasma), each with a mass of around 1.1 billion tons, erupt from the Sun up to three times a day. Called coronal mass ejections, these bubbles grow millions of miles wide in a few hours and then burst, sending a blast of charged particles hurtling across the Solar System. The blast waves sometimes collide with the Earth, lighting up the polar skies with unusually brilliant auroras.
Asteroid
Asteroids are giant space rocks that drift around the inner Solar System. Most lie in a belt between Mars and Jupiter, but some occasionally come dangerously close to the Earth. The smallest are the size of houses, while the largest are big enough to be classified as dwarf planets. Scientists think asteroids are leftovers from the material that formed the planets. All of them together amount to less than a twentieth of the Moon’s mass.

Sun
The Sun is like a vast nuclear power station that produces energy by converting hydrogen into helium. It is the only star we can study close up.

Mercury
The closest planet to the Sun, Mercury is also the smallest planet. Its surface is scarred by ancient craters.

Venus
Though similar in size to Earth, Venus is a hellish world where any visiting astronaut would be crushed and boiled alive.

Earth
Our home planet is the only place known to support life, thanks to the liquid water on its surface.

Saturn
The second biggest planet is striking for the dazzling system of bright rings that encircle it. It has 62 moons and dozens more moonlets.

Mars
Mars is a bitterly cold, desert world. Like Earth, it has mountains, canyons, and icy poles.

Orbital distance
The scale bar below shows the relative distances of the planets from the Sun. The distance between one planet and the next increases greatly as we move out through the Solar System.
The Solar System

The force of gravity generated by the Sun's vast mass keeps a family of planets and other bodies trapped in orbit around it. Together, the Sun and all these bodies make up our Solar System.

Our Sun formed from a great cloud of dust and gas around 4.6 billion years ago. Vast amounts of matter were drawn in by the developing star, but not all of it was fully absorbed. A tiny fraction of leftover material—a mere 0.14 percent of the Solar System's mass—formed a disc of gas and dust encircling the newborn star. Over millions of years, the grains of dust in this disc clumped together, growing into ever larger bodies until they grew to the size of planets, pulled into spheres by their own gravity. In the inner Solar System, where the Sun's heat was too intense for gases to condense, planets formed from rock and metal. In the outer Solar System, gases condensed to form much bigger planets.

Today the Solar System has eight planets, more than 100 moons, an unknown number of dwarf planets, and countless millions of comets and asteroids.

Orbits

Every major body in the Solar System orbits the Sun counterclockwise. The planets are on near-circular orbits in the same plane as the disc of gas and dust from which they formed. Many smaller objects, such as dwarf planets Pluto and Eris, have stretched orbits tilted to this plane. Comets arrive from all directions.

How orbits work

English scientist Isaac Newton was the first person to realize why moons and planets travel in orbits: because they are trapped by gravity. To explain his theory, he drew a giant cannon firing cannonballs off Earth. If a cannonball moved fast enough, the curve of its path as it fell back would be gentler than the curve of Earth's shape, and it would never land—it would stay in orbit.

Dwarf planets

Dwarf planets are round in shape but smaller than true planets, and their gravity is not strong enough to sweep their region of space clear of smaller debris. The most famous dwarf planet is Pluto, which was classified as a true planet until 2006.
Inner planets

Mercury, Venus, Earth, and Mars are the Solar System's inner planets. On the face of it, they are worlds apart—but underneath the surface, it is a different story.

The inner planets all formed from the same material about 4.6 billion years ago. All are a mix of rock and metal, with interiors that are roughly divided into layers. The heavier metals are concentrated toward the center, while the lighter rock is on top.

Each of these planets was bombarded by asteroids and comets early in the Solar System's history, and each has been affected by volcanic activity too. Mercury's heavily cratered face still bears the scars of the early bombardment, but the surfaces of the other three worlds have changed over time.

**Mercury profile**
- Diameter: 3,032 miles (4,879 km)
- Average surface temperature: 333°F (167°C)
- One spin on axis: 58.6 Earth days
- One orbit of Sun: 88 Earth days
- Number of moons: 0

**Mercury in the Sun's glare**
Mercury is the smallest of the Solar System's planets and lies closest to the Sun. It is a lifeless world that has hardly changed in 3 billion years. The planet's entire surface is pitted with craters formed when asteroids crashed into it while Mercury was young. The craters range from small, bowl-shaped ones to the huge Caloris Basin, which is nearly one-third the width of the planet.

Mercury orbits the Sun more quickly than any other planet, but it rotates slowly: for every two orbits, it spins around just three times. So a “day” on Mercury (sunrise to sunrise) takes 176 Earth days. Such long days and nights, coupled with a very thin atmosphere, give Mercury the greatest surface temperature range of all the planets. In the daytime, the surface is hot enough to melt lead, but at night it's cold enough to liquefy air.

**Lava land**

Venus is sometimes described as Earth's twin because it's almost the same size as our planet and has a similar internal structure. But the two worlds are very different.

Any astronaut who tried to walk on Venus would be killed in seconds. The surface is as hot as the inside of a pizza oven, and the crushing air pressure is 90 times greater than that on Earth.

Venus's deadly surface is hidden from our view by thick cloud cover, but orbiting spacecraft have used radar to see through the gloom, and landers have touched down to take photos. Venus is a world of volcanoes, many thought to be active, and its surface is littered with broken rock from solidified lava. It is permanently overcast, with a sickly yellowish light filtering through the cloud. Venus spins more slowly than any other planet. It also spins in the opposite direction (clockwise) to every planet apart from Uranus.

**Venus profile**
- Diameter: 7,521 miles (12,104 km)
- Average surface temperature: 867°F (464°C)
- One spin on axis: 243 Earth days
- One orbit of Sun: 224.7 Earth days
- Number of moons: 0

**Venus in the Sun's glare**

Venus is hot because of a process called the greenhouse effect. The Sun's heat passes through the atmosphere and warms the ground, which then reemits warmth. The reemitted warmth is trapped by the atmosphere, much as glass traps heat in a greenhouse.

**Greenhouse effect**
Venus is hot because of a process called the greenhouse effect. The Sun's heat passes through the atmosphere and warms the ground, which then reemits warmth. The reemitted warmth is trapped by the atmosphere, much as glass traps heat in a greenhouse.
Like Earth, Mars has a crust made of solid rock. The reddish color comes from iron oxide (rust) in the soil. Like all the inner planets, Mars has a core made of red-hot iron.

**Living world**

Third out from the Sun, Earth is the largest of the inner planets. It’s the only planet with liquid water flowing freely on the surface, and it’s the only planet in the Universe known to sustain life.

Earth's surface consists of vast oceans (71 percent), continents of land, and two polar ice caps—all supported by a thin, rocky crust. The crust is broken into seven huge segments and many smaller ones. Called tectonic plates, these giant slabs of rock creep slowly over Earth's surface, pushed by churning movements in the softer, hot rock that fills most of Earth's interior. As tectonic plates move, they bump into each other and grind past one another, generating immense forces that thrust up mountain ranges, unleash volcanic eruptions, and trigger earthquakes. These powerful forces continually change Earth's appearance, as do the actions of wind and water—and the planet's 7 billion human inhabitants.

**Earth profile**

- **Diameter**: 7,926 miles (12,756 km)
- **Average surface temperature**: 59°F (15°C)
- **One spin on axis**: 23.9 hours
- **One orbit of Sun**: 365.3 days
- **Number of moons**: 1

**The red planet**

The second smallest planet in the Solar System, Mars is half the size of Earth. It’s sometimes called the red planet because of its rusty coloring. A vast canyon called Valles Marineris stretches a quarter of the way around this frozen desert world. It formed long ago when the crust of the young planet split open. Elsewhere are dusty plains strewn with boulders and giant, extinct volcanoes, including Olympus Mons—the Solar System's largest volcano.

**Mars profile**

- **Diameter**: 4,220 miles (6,792 km)
- **Average surface temperature**: -81°F (-63°C)
- **One spin on axis**: 24.6 hours
- **One orbit of Sun**: 687 Earth days
- **Number of moons**: 2

**Rocky floodplain**

Mars hasn't always been a desert. Dry river beds show that water flowed here long ago. Floods swept rocks across the land and dumped them on floodplains like the one below. Mars may even have been warm and wet enough for life to flourish.
**King of the planets**
Mighty Jupiter is the fifth planet from the Sun and the largest in the Solar System—so big, in fact, that it’s 2.5 times more massive than all the other planets put together. Its strong gravitational pull greatly affects the orbits of other bodies in the Solar System.

Jupiter’s fast rate of spin has stretched its surface clouds into bands, with spots (storms) and ripples where neighboring bands swirl together.

Several craft have visited Jupiter, including Galileo, which orbited from 1995 to 2003.

**Jupiter profile**
- Diameter: 88,846 miles (142,984 km)
- Average surface temperature: -186°F (-121°C)
- One spin on axis: 9.9 hours
- One orbit of Sun: 11.9 Earth years
- Number of moons: 67

**The Jupiter system**
Like a king surrounded by his courtiers, Jupiter is circled by a great number of moons. The inner moons, including the four largest, are shown below. Ganymede, the largest, is bigger than the planet Mercury. Most of Jupiter’s other moons are probably asteroids captured by the planet’s gravity.

**Blue planet**
Neptune, the eighth and furthest of the planets from the Sun, was discovered in 1846. Astronomers had noticed Uranus wasn’t following its expected path—there seemed to be an unseen body, perhaps an undiscovered planet, pulling on it. Two mathematicians—John Couch Adams in England and Urbain Le Verrier in France—calculated where in the sky the undiscovered planet must be. Within days, Neptune was spotted from an observatory in Germany.

Neptune is slightly smaller than Uranus and looks bluer because its atmosphere contains more methane. It has a deep, fluid mantle that is hot and dense and contains water, ammonia, and methane. Neptune also has a barely visible system of rings. Its biggest moon, Triton, resembles Pluto and was likely captured by Neptune’s gravity in an encounter billions of years ago.

**Neptune profile**
- Diameter: 30,775 miles (49,528 km)
- Average surface temperature: -330°F (-201°C)
- One spin on axis: 16.1 hours
- One orbit of Sun: 163.7 Earth years
- Number of moons: 13

**Fastest known winds**
When Voyager 2 flew past Neptune in 1989, it photographed white clouds blown into streaks by winds of up to 1,300 mph (2,100 kph)—the fastest sustained winds in the Solar System. This violent weather is thought to be powered by heat from inside Neptune since the planet is too far from the Sun to absorb much of its warmth.
Outer planets

Four gigantic planets dominate the outer Solar System. Very different from the rocky, inner planets, these strange worlds are huge globes of gas and liquid, with no solid surface and hundreds of moons.

After the Sun first formed, its heat drove gases out of the inner Solar System, leaving behind heavier compounds such as rock and metal. The rock and metal formed the solid inner planets, while the gases formed the outer planets. Astronomers call the outer planets gas giants, though they consist mostly of liquid and they have solid cores. These four worlds have much in common. All have numerous moons, a deep, stormy atmosphere, and a set of rings made of flecks of rock or ice.

**Saturn profile**
- Diameter: 74,898 miles (120,536 km)
- Average surface temperature: -292°F (-180°C)
- One spin on axis: 10.7 hours
- One orbit of Sun: 29.5 Earth years
- Number of moons: 62

**Ring system**
Saturn’s main rings are 220,000 miles (360,000 km) wide, yet they are only 30 ft (10 m) thick. A scale model of the rings made with a sheet of paper would be 2 miles (3 km) wide. Beyond the main rings are hazy outer rings, photographed by Cassini while the Sun was behind Saturn (below).

**Uranus profile**
- Diameter: 36,763 miles (51,118 km)
- Average surface temperature: -315°F (-193°C)
- One spin on axis: 17.2 hours
- One orbit of Sun: 84 Earth years
- Number of moons: 27

**Topsy-turvy world**
Uranus, the seventh planet from the Sun, was unknown to ancient astronomers, even though it is just visible with the naked eye in perfectly clear and dark skies. It was discovered by musician William Herschel from his back garden in Bath, England, in 1781.

Uranus is similar to Neptune but has a paler blue, almost featureless face. It is the coldest of all the planets and generates very little heat from within. It orbits on its side—perhaps because it was knocked over by a collision with another planet early in its history. Its extreme tilt gives it very long seasons.

Uranus has a faint set of rings, which were discovered in 1977. The planet’s moons are all named after characters in works by William Shakespeare or the English poet Alexander Pope.
The Moon

The Moon is Earth's closest neighbor in space and looms larger than any other object in the night sky. Its cratered surface may be cold and lifeless, but deep inside the Moon is a gigantic ball of white-hot iron.

Earth and Moon have existed together in space ever since the Moon formed as the result of a cosmic collision. It orbits around our planet, keeping the same face toward us at all times. As we gaze on its sunlit surface, we look at a landscape that has barely changed since 3.5 billion years ago. Back then, the young Moon was bombarded by asteroids. For millions of years they blasted out surface material and formed craters. The largest of these were then flooded with volcanic lava, creating dark, flat plains that look like seas.

Lunar craters
Craters exist all over the Moon. They range from small bowl-shaped hollows a few miles wide to the vast South Pole–Aitken Basin, which is 1,600 miles (2,500 km) in diameter. Many craters, like Eratosthenes (above), have central hills that formed as the ground rebounded after the asteroid struck.

Lunar maria
Dark, flat areas known as maria, or seas, are huge plains of solidified lava.

Lunar layers
Like Earth, the Moon is made of different layers that separated out long ago, when its whole interior was molten. Lightweight minerals rose to the top, and heavier metals sank to the center. The outermost layer is a thin crust of rock like the rock on Earth. Under this is the mantle—a deep layer of rock that gets hotter toward the center. The bottom part of the mantle is partly molten. In the Moon's center is an iron core heated to about 2,600°F (1,400°C) by energy from radioactive elements. Scientists think the outer core is molten but the inner core is squeezed solid by the pressure of the rock around it.

Moon profile
Diameter .................. 2,159 miles (3,474 km)
Average surface temperature .......... -63°F (-53°C)
Length of lunar day .................. 27 Earth days
Time to orbit Earth .................. 27 Earth days
Gravity (Earth = 1) ........................ 0.17

How the Moon formed
Scientists think the Moon formed as a result of a collision between Earth and a planet 4.5 billion years ago. The debris was pulled together by gravity and became the Moon.

Impact
A planet smashes into Earth and blasts molten rock into space.

Moon formation
A disc of debris forms. The particles slowly join to form a Moon.

Phases of the Moon
As the Moon orbits the Earth, a changing amount of its face is bathed in sunlight. The different shapes we see are the Moon's phases. One cycle of phases lasts 29.5 days.
Hadley Rille
A deep gorge named Hadley Rille cuts through flat plains at the edge of the Moon’s Sea of Showers, winding for more than 60 miles (100 km). How it formed is a mystery, but it might be an ancient lava channel. In July 1971, Apollo astronauts drove their rover to the edge of Hadley Rille to take photographs and study it.
**SPACE EXPLORATION**

Stars and planets have fascinated people since ancient times, but it wasn’t until the 20th century that exploring space became possible. In recent decades we have sent astronauts to the Moon, robotic spacecraft to the outer reaches of the Solar System, and used huge telescopes to peer across the vastness of the Universe.

**OBSERVING THE SKIES**
For centuries, astronomers have observed the heavens with their eyes alone or used simple telescopes that magnify the view. But the visible light we see is just one part of a much bigger spectrum of electromagnetic rays that reaches Earth from space. Stars and other objects also emit invisible radio waves, X-rays, infrared, and ultraviolet rays. Modern telescopes can see all of these, and each type of radiation reveals something different.

**Capturing light**
Telescopes come in many different styles and designs, but basically all do the same thing: collect electromagnetic radiation from space and focus it to create an image. Earth’s atmosphere can block or blur the image, so some telescopes are located on high mountaintops or even launched into space.

**Mapping the stars**
Because Earth is surrounded by space, when we look at the night sky it seems as though all the stars are pinned to the inside of a giant sphere. Astronomers call this the celestial sphere and use it to map the positions of stars and planets. Vertical and horizontal lines are used to divide the celestial sphere into a grid, just like the grid of longitude and latitude lines used to map Earth’s surface.

**EXPLORING THE PLANETS**
The planets are too far for manned missions, so robotic spacecraft are sent instead. The first to visit another planet was Mariner 2, a US craft that flew past Venus in 1962. Since then, and despite a number of early failures, hundreds of spacecraft have visited the Solar System’s planets, moons, asteroids, and comets. Most spacecraft either fly past or orbit their target, but some also release landers that touch down on the surface.

**Robot explorers**
Robotic spacecraft can visit places too far or dangerous for human beings. Launched into space by rocket, they travel vast distances across space and may take years to reach their target. There are various types of spacecraft, each suited to a particular mission.

**Flyby spacecraft**
Some spacecraft observe a target as they fly past. NASA’s famous Voyager 1 and Voyager 2 flew past several planets.

**Orbiter**
An orbiter flies around a planet repeatedly, giving it plenty of time to study its target. Orbiters have visited the Moon and all the planets except Uranus and Neptune.

**LAUNCH VEHICLES**
Space is only 60 miles (100 km) above the Earth’s surface and takes less than 10 minutes to reach in a rocket. Although the journey is short, it takes tremendous power to escape the pull of Earth’s gravity. Launch vehicles are built to make the journey only one time, and most of their weight is fuel.

**World's largest rockets**
Saturn V, which sent astronauts to the Moon, was the largest rocket ever built. Its Soviet rival, the N1, was launched four times but each attempt ended in disaster.

**Launch sites**
Many countries have spaceflight launch sites. Sites closer to the equator can launch heavier cargo, because rockets there are given a boost by the speed of Earth’s spin.

**Major launch sites**
- Cape Canaveral, FL
- Baikonur, Kazakhstan
- Xichang, China
**ATMOSPHERIC PROBE**
This type of craft enters a planet’s atmosphere. The *Galileo* probe dove into Jupiter’s stormy atmosphere in 2005.

**LANDER**
Some craft can touch down on the surface of another world. In 1976, *Viking 1* became the first craft to successfully land on Mars.

**ROVER**
A rover is a robotic lander with wheels that can drive around. Rovers sent to Mars have studied its rocks for signs of ancient life.

**PENETRATOR**
A penetrator is designed to hit its target at high speed and bury itself. In 2005, *Deep Impact* penetrated the surface of a comet.

**SATELLITES**
About 1,000 operational satellites orbit the Earth, carrying out tasks such as beaming TV signals around the world, gathering data for weather forecasters, and spying for the military. Many thousands more pieces of space junk—old satellites, discarded rocket parts, and debris from collisions—also circle our planet. The growing cloud of space debris is a hazard to spacecraft.

**Satellite orbits**
Some satellites are a few hundred miles above Earth’s surface, but others are much further. Some of the highest ones, such as weather, TV, and phone satellites, have geostationary orbits, which means they stay over a fixed point on Earth. Satellites with lower orbits change position all the time.

**LIVING IN SPACE**
Astronauts must adapt to a zero-gravity environment when living in space. Although floating weightlessly can be fun, it can also cause medical problems.

**Effects on the body**
When the human body spends a long time in space, it changes. Without gravity pulling on the spine, the body gets about 2 in (5 cm) taller. Body fluids that flow downward on Earth build up in the head. This gives astronauts swollen faces and blocked noses, making food seem tasteless. When astronauts come back to Earth, the return of full gravity can make them feel extremely weak.

**Space stations**
A space station is a crewed satellite—a kind of orbiting laboratory in which astronauts and scientists live and work. The USSR launched the first station, *Salyut 1*, in 1971. The US soon followed with *Skylab*, in 1973. Russia’s *Mir*, in use from 1986 to 2001, was the most successful station until the US, Russia, and more than 10 other countries joined forces to build the *International Space Station*. In orbit since 1998, China’s own space station prototype, *Tiangong-1*, was launched in 2011.

**Solar System missions**
In little more than 50 years, around 200 spacecraft have left Earth’s orbit and headed off to explore the Solar System. More than half the missions have been to Earth’s nearest neighbors in space: the Moon and the planets Mars and Venus.
A brief history of astronomy

Many ancient cultures followed the Sun and stars in order to keep track of the time of year, and by Ancient Greek times, astronomers had already worked out that Earth is round. Today, powerful telescopes allow us to peer so far into space that we can look back in time almost to the birth of the Universe.

Astronomical calendars

Many monuments built by ancient peoples, such as Stonehenge in the UK, align with the Sun. These monuments may have been used as calendars so that farmers knew when to sow crops.

Ptolemy

The Greek astronomer Ptolemy cataloged 1,022 stars in 48 constellations. He believed that Earth was the center of the Solar System and Universe, orbited by the Sun, Moon, planets, and stars.

Copernicus

Polish astronomer Nicolaus Copernicus proposed that the Sun, not Earth, is the center of the Solar System. It was a shocking idea since it meant Earth must be flying through space, spinning around.

Galileo Galilei

Italian scientist Galileo Galilei built a telescope and used it to study the night sky. He saw spots on the Sun, mountains on the Moon, and four moons orbiting the planet Jupiter.

Isaac Newton

English scientist Isaac Newton worked out the laws of gravity—the force that makes objects fall to the ground. He discovered that gravity keeps the Moon in orbit around Earth and keeps the planets in orbit around the Sun.

Modern astronomy

Today, space telescopes such as Hubble, which was launched in 1990, give us breathtaking views of distant objects in space, including the furthest galaxies ever seen.

Astronomy

People have been looking up at the night sky and marveling at its beauty and mystery for thousands of years. Today, a whole branch of science—astronomy—is devoted to studying stars.

Professional astronomers investigate not only stars but everything to do with space—from the meteors that burn up spectacularly as shooting stars in Earth’s atmosphere and the planets of the Solar System to distant galaxies billions of light years away. Astronomy makes a rewarding hobby too, and many amateur stargazers enjoy observing the night sky with backyard telescopes or binoculars. Whenever astronomers observe the sky, they are looking back in time. This is because light takes such a long time to reach us from distant objects in space. We see the Moon as it was one and a quarter seconds ago and the stars as they were hundreds of years ago.

The sky at night

Ancient stargazers saw patterns in the stars and named groups of stars after mythical beings and animals. These star patterns, called constellations, look little like the objects they are meant to represent, but we still use the old names. Today, astronomers divide the whole sky into 88 segments, each one named after the constellation within it. Star charts like the one here show which constellations are visible at a particular time and place. This chart shows the stars you can see at midnight in January from the northern hemisphere.

Orion the hunter

One of the best-known and brightest constellations is Orion the hunter, which is visible the world over. Orion includes the red giant star Betelgeuse and the blue-white supergiant Rigel—two of the brightest stars in the night sky.

Measuring brightness

The size of the white spots on the chart show how bright the stars are. Astronomers call this magnitude and measure it on a scale that runs backward—the smaller the number, the brighter the star.
**Seeing the invisible**

Professional astronomers don’t just use visible light to see the night sky. Their telescopes can also create images from wavelengths of light that our eyes cannot see, such as X-rays, radio waves, and infrared rays. The images below all show Kepler’s Supernova—the wreckage left by a giant star that exploded in 1604.

**X-ray image**

This image of Kepler’s Supernova is from the orbiting Chandra X-ray Observatory. It shows a cloud of incredibly hot gas that emits high-energy X-rays.

**Visible light image**

Very little of the object can be seen in visible light, even in this image from the Hubble Space Telescope. The bright areas are clumps of gas.

**Infrared image**

Taken by the Spitzer Space Telescope, this infrared image shows dust clouds that were heated by a shock wave from the exploding star.

**Combined image**

Combining all three sources produces a complete image: a shell of supernova debris expanding into space at 1,240 miles (2,000 km) per second.
Mission to the Moon

Humans have set foot on only one world beyond Earth: the Moon. Just 27 daredevil astronauts have traveled there, of whom 12 walked on its cratered, lifeless surface.

Eight space missions visited the Moon between 1968 and 1972 as part of NASA's Apollo program. Each mission carried three American astronauts inside an Apollo spacecraft, which was launched by a Saturn V rocket. Apollo 8 tested the craft as it orbited the Moon. Then, in a dress rehearsal prior to landing, Apollo 10 flew close to the lunar surface. The first of the six missions that successfully landed on the Moon was Apollo 11 in 1969. Astronauts Neil Armstrong and Buzz Aldrin touched down on the surface in July of that year. As Armstrong took the first historic step, he said, “That’s one small step for man, one giant leap for mankind.”

Apollo spacecraft

The Apollo spacecraft had three parts: the Command, Service, and Lunar Modules. These were all linked together for the 250,000-mile (400,000-km) trip to the Moon. Once there, the Lunar Module took two astronauts down to the Moon’s surface, while the third crew member remained in lunar orbit in the combined Command and Service Module (CSM). The top half of the Lunar Module, known as the ascent stage, later returned the two astronauts to the CSM for the journey back to Earth.

Saturn V rocket

The Apollo astronauts were blasted into space inside the nose cone of the largest rocket ever built: Saturn V. Standing nearly 364 ft (111 m) tall, the Saturn V was as tall as a 30-story building. This giant launch vehicle consisted of three rockets in one. The first two parts, or stages, lifted the Apollo craft into space, and the third stage set the spacecraft on course for the Moon.

21 hours—the length of time Apollo 11 astronauts Neil Armstrong and Buzz Aldrin spent on the Moon. Apollo 17 astronauts spent three days on the lunar surface.
There and back
Each of the six Apollo missions that landed men on the Moon took the same route, taking off from Florida, and ending with the astronauts splashing down in the Pacific Ocean.

1 Saturn V rocket carrying Apollo craft blasts off and positions craft in Earth's orbit.
2 The rocket’s third stage and Apollo craft leave Earth's orbit and head toward the Moon.
3 Combined Command and Service Module (CSM) separates from the rocket.
4 CSM turns and docks with Lunar Module. Third rocket stage is now discarded.
5 Apollo craft adjusts its course to go into lunar orbit.
6 Lunar Module transports two astronauts to lunar surface.
7 Third crew member continues to orbit the Moon in CSM.
8 Ascent stage of Lunar Module takes astronauts back to CSM, after which it is discarded.
9 CSM adjusts its course and heads back to Earth.
10 Service Module is jettisoned.
11 Command Module enters Earth's atmosphere.
12 Command Module makes a parachute landing in the sea.

The trip from the Earth to the Moon took about three days.

Landing sites
The Apollo landing sites were on the side of the Moon that faces Earth.

Docking tunnel
Astronauts used this tunnel to move between the Command and Lunar Modules.

Ascent stage
The ascent stage of the Lunar Module was the astronauts’ home while they explored the Moon.

Descent stage
This bottom half of the Lunar Module acted as the launch platform when the top half blasted off back into space. The descent stage stayed on the Moon.

Fuel tank
This tank contained fuel for the Lunar Module’s descent engine.

Descent engine
This engine was used to slow down the Lunar Module’s descent during landing.

Hatch
The astronauts climbed through a hatch to go outside.

Gas tanks
The larger tank contained helium; oxygen was held in the adjacent smaller tank.

Legs and pads
Flexible legs with wide pads on the bottom cushioned the Module’s landing and kept it stable on the surface.

Sensing probe
Probes on the legs touched the ground first during landing and sent signals to shut down the engine.

Man on the Moon
The Lunar Module was the only part of the Apollo craft to reach the Moon’s surface. Preprogrammed controls maneuvered it into position above the landing site, then an astronaut steered the craft to touchdown. Scientific equipment, a TV camera, and tools and storage boxes for rock collecting were all stored in the bottom half.

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Path to the planets
The paths of spacecraft are often carefully planned to take them close to one or more planets on the way to their final destination. Using the pull of gravity of each planet boosts their speed and saves fuel. Cassini-Huygens flew past Venus, Earth, and Jupiter on its way to Saturn.

1. Launch
2. First Venus fly-by
3. Second Venus fly-by
4. Earth fly-by
5. Jupiter fly-by
6. Arrival at Saturn

Landmark missions
Since the first spacecraft to visit a planet was launched in 1962, about 200 craft have explored the Solar System. Some of the most famous missions are shown here.

Venera 7
The first craft to touch down on another planet, Venera 7 landed on Venus in 1970. It lasted 23 minutes before the searing heat destroyed it.

Lunokhod 1
Russian-built Lunokhod 1 was the first lunar rover. It landed on the Moon in 1970 and spent 322 days exploring, traveling a total of 6.5 miles (10.5 km).

Voyager 1
Launched in 1977 and still operational, Voyager 1 is the furthest manmade object from Earth. It visited Jupiter in 1979 and Saturn in 1980.

Sojourner rover
The first rover to explore another planet was Sojourner. It reached Mars in 1997 and spent 12 weeks studying the soil and taking photos.

Rovers
A rover is a robotic vehicle built to explore the surface of a planet or moon. Four rovers have landed successfully on Mars. They receive radio commands from Earth but find their way around and carry out tasks independently.

Curiosity lands
The Curiosity rover was lowered on to Mars in 2012 by a rocket-powered craft.

Cassini-Huygens spacecraft
Cassini-Huygens is the largest spacecraft to visit another planet. It was launched in 1997 and arrived at Saturn in 2004. It had two parts: the Cassini orbiter, designed to orbit Saturn until 2017, and a probe called Huygens, which touched down on Saturn’s large moon Titan. The main aim of the mission was to discover more about Titan—the only world in the Solar System other than Earth that has a dense, nitrogen-rich atmosphere.
Exploring the planets

While manned spacecraft have ventured no further than the Earth's Moon, robotic craft have visited all the planets in the Solar System—and more than 100 moons.

Robotic spacecraft can visit places that would prove lethal to astronauts, such as the scalding surface of Venus or the deadly radiation belts around Jupiter. Packed with scientific instruments, telescopes, and cameras, they carry out dozens of experiments during their missions and capture thousands of images, which are sent back to Earth by radio.

**Triple parachute**

Packed under Huygens's back cover were three parachutes that opened in turn to slow the lander's descent onto Titan. Huygens discovered a world of freezing, orange-brown plains littered with pebbles of ice.

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98,346 mph (158,273 kph)—the top recorded speed of Cassini-Huygens.

53 spacecraft have attempted to reach the planet Mars.

27 missions to Mars have ended in failure.
Oceans of water, an oxygen-rich atmosphere, and the existence of life make Earth a unique planet. Its surface is continually changing as plates slowly shift and the relentless force of erosion reshapes the land.
Earth formed about 4.5 billion years ago, but it was a very different place then. Its surface was a hot inferno of mostly molten rock, with little or no liquid water and no oxygen in the atmosphere. Since then Earth has developed oceans, continents, an oxygen-rich atmosphere—and life.

**Inside our planet**
Earth’s interior has layers. Scientists discovered this by studying the paths by which earthquake waves pass through the planet.

**Thickness**
- 3.7–56 miles (6–90 km)
- 1,790 miles (2,880 km)
- 1,400 miles (2,255 km)
- 755 miles (1,215 km)

**WHAT’S IN A LAYER?**
Earth’s crust and mantle are mostly made of minerals called silicates, which are a combination of silicon dioxide and metal oxides. The mantle is rich in magnesium-containing silicates, while the two different types of crust have less magnesium and more aluminum and calcium. The core is dominated by metallic iron. No part of it has ever been brought to the surface, but its composition has been worked out by scientific methods such as studying earthquake waves.

**CRUST**
Different types of crust make up Earth’s surface and its ocean floor. The crust under the surface is thicker and contains more rock types.

**MANTLE**
This rocky layer is denser than the crust. It is mostly solid, although it can very slowly deform and flow.

**OUTER CORE**
The only liquid layer, the outer core is mainly iron but also contains some nickel and small amounts of other substances.

**INNER CORE**
This is solid, and is mostly iron with some nickel. Its temperature is very hot—about 9,900°F (5,400°C).

**Earth’s atmosphere**
The atmosphere of Earth is made up of several different gases.

- **NITROGEN** – 78%
  A gas that can be fixed in the soil as well as loose in the atmosphere. Plants need nitrogen from the soil to survive.

- **OXYGEN** – 21%
  Essential for animals to breathe. Oxygen was absent until microbes evolved that could use sunlight to turn carbon dioxide and water into carbohydrates, releasing oxygen.

- **ARGIN** – 0.9%
  An inert gas (one that doesn’t react with other substances).

- **OTHER** – 0.1%
  These include carbon dioxide (CO₂), which was once abundant, but is now mostly incorporated into materials such as limestone rock.

**THE OCEANS**
Earth’s surface and atmosphere contain the equivalent of 333 million miles³ (1.39 billion km³) of water. There are regions of deep ocean as well as shallow seas that cover areas around the edges of the continents—these are called continental shelves. Earth’s surface has not always been as dominated by liquid water. In the past, during ice ages when the polar ice caps were much thicker and more extensive, so much water became locked up in them that sea level was at least 400 ft (120 m) lower than it is today, exposing the continental shelves as dry land.

**Water world**
Almost three-quarters of Earth’s surface is water. Over 97 percent of Earth’s water is found in the oceans.
Continental drift

Over millions of years, tectonic plates have moved, shifting around the continents on Earth’s surface. Chunks of continents split away and push into each other, creating new land masses and moving the oceans in a process called “continental drift.”

- North America, Europe, and parts of Asia are one landmass
- India moves north
- South America separates from Africa
- Australia moves into the Pacific Ocean
- Australia has separated from Antarctica, and India has collided with Asia, forming the Himalayas.

Plate movement

The continents get rearranged because they are carried along as parts of moving plates. This process has been going on for billions of years, and is thought to be caused by slow, heat-driven movements in Earth’s mantle.

Looking at Earth

Our planet is far from smooth—its continents and ocean floors are scarred and pitted with marks caused by movement of plates. Earth’s place in space also affects its shape, as constantly spinning makes it bulge out around the middle so it is not a perfect sphere. Spinning also creates a magnetic safety field around the planet.

Mountains make up about one-fifth of the Earth’s landscape.

Earth’s surface

The solid surface of the Earth ranges from about 35,750 ft (10,900 m) below sea level in the Challenger Deep (part of the Pacific’s Mariana trench) to 29,029 ft (8,848 m) above sea level at the summit of Everest, which may be rising at about 0.16 in (4 mm) per year. The surface of most land areas is less than 1,650 ft (500 m) above sea level.

Elevation
- Over 13,125 ft (4,000 m)
- 6,500–13,125 ft (2,000–4,000 m)
- 3,300–6,500 ft (1,000–2,000 m)
- 1,600–3,300 ft (500–1,000 m)
- 800–1,600 ft (250–500 m)
- 300–800 ft (100–250 m)
- 0–300 ft (0–100 m)

Sea depth
- 0–800 ft (0–250 m)
- 800–6,500 ft (250–2,000 m)
- 6,500–13,000 ft (2,000–4,000 m)
- Below 13,000 ft (4,000 m)

A spinning planet

Earth’s gravity would pull it into the shape of a sphere, but its rotation makes it bulge slightly. This means its diameter at the equator is 25 miles (41 km) more than the distance between its poles.

Not quite round

At the moment, scientists think that Earth’s equatorial bulge is growing at a rate of 0.3 in (7 mm) every 10 years.

Magnetic Earth

Because Earth’s outer core is liquid, the planet’s rotation stirs it into motion. This motion causes electric currents to develop in the liquid iron itself. Any pattern of electric currents creates a magnetic field, and in Earth’s case, the field is similar to what would be produced by a large bar magnet inside the planet. The field protects Earth from damage by harmful, energetic particles that come from the Sun.

The magnetic field

The magnetic poles do not coincide exactly with the geographic (rotational) poles, and they gradually change position over time.

Mountains and trenches

Earth’s solid surface is far from flat. This map shows its elevations and depths—from the highest mountain peaks to the deepest ocean trenches.
Inside the Earth

We can’t explore much of the Earth—our deepest mines only travel about a mile into the crust. However, there are scientific ways to find out what it is like inside.

Geologists are able to study rocks from all depths within the Earth’s crust, because collisions between continents push up rock that used to be below the surface, forming mountains. In some areas, collisions have even unearthed vast swathes of the mantle. Volcanoes also sometimes erupt lumps of rock from the mantle. Under the mantle is the core, which has never been seen at the surface. However, scientists have used the waves from earthquakes to work out that the core is split into two layers—a liquid outer core and a solid inner core.

Volcanoes in Hawaii
The Hawaiian Islands in the mid-Pacific have been built by volcanic eruptions. The rock that formed them was pushed to the Earth’s surface by hot rock moving upward in the mantle.

9,900°F (5,400°C) – the approximate temperature of Earth’s inner core.

Layered Earth
Earth is made up of many rocky layers. The top layer is the crust. Below that, uniform and slightly denser rock forms the mantle. The crust and the top of the mantle form a single rigid layer together, which is called the lithosphere. This is broken into sections called tectonic plates. Below the lithosphere is the asthenosphere. Only tiny parts of the asthenosphere are liquid, but it is soft enough to move, pushing around the plates above. Under the mantle lies the core. The outer core is a liquid mix of iron and sulfur, while the inner core is solid iron and nickel.
The atmosphere
Earth's atmosphere is made up of gases, which are held in place by gravity. There is no clear boundary to the outer edge of the atmosphere—it just fades into space. Outer space is generally thought to begin about 62 miles (100 km) above the surface.

There are four main layers inside the Earth. From the outside in, they are the crust, mantle, outer core, and inner core.

Lithosphere
The rigid outer shell, made of the crust and the top layer of the mantle.

Mantle
A solid layer that is Earth's thickest.

Outer core
Molten iron and sulfur. Currents in this liquid generate Earth's magnetic field.

Inner core
A ball of iron and nickel, which is very hot but solid because of the immense pressure.

Mantle plume
An upwelling within the mantle sends magma to volcanoes.

Hot spot
A volcanic site above a mantle plume.

Exosphere
This is the outer zone. Gas molecules can escape into space from here.

South American coast

Crust
Earth's outer layer, which is distinct from the mantle, though both are made of rock.

The troposphere
All weather occurs in this layer.

Clouds

Troposphere
Absorption of ultraviolet sunlight adds energy to the stratosphere, so temperature increases with height here.

Stratosphere
In this zone, temperature increases with height.

Mesosphere
A zone where temperature decreases with height.

Thermosphere
In this zone, temperature increases with height.

Meteors
Weather balloon

Aurora

Satellite

80 MILES 130 KM

80 MILES 130 KM

50 MILES 80 KM

50 MILES 80 KM

30 MILES 50 KM

30 MILES 50 KM

10 MILES 16 KM

10 MILES 16 KM

Airplane

Clouds

Clouds
What makes a climate?

A climate is an average weather pattern that occurs in a set area over many years. The climate experienced at a certain location is influenced by its distance from the equator, elevation above sea level, the amount of sunlight it gets, and how nearby circulation patterns in the ocean and atmosphere affect it.

**Temperature**

Places near the Earth's equator generally have higher average temperatures and more diverse ecosystems.

**Rainfall**

Atmospheric circulation creates zones of high and low rainfall around the Earth—some areas get more rain than others.

**The seasons**

There are four seasons in a year: spring, summer, fall, and winter. Each has its own climate conditions and hours of daylight. The seasons differ in the northern and southern hemispheres and are more distinct further away from the equator, because of the tilt of the Earth's axis of rotation.

**Temperature**

Places near the Earth's equator generally have higher average temperatures and more diverse ecosystems.

**Rainfall**

Atmospheric circulation creates zones of high and low rainfall around the Earth—some areas get more rain than others.

**Earth's biomes**

Communities of plants and animals are different as a result of the climate they develop in. There are five main groups of communities, or biomes—water, deserts, forests, grasslands, and tundra. Most of these biomes can be broken down further: for example, there are coniferous forests, deciduous forests, and tropical rainforests.

The size and location of Earth's biomes has changed very slowly over geological time. The most recent changes have mainly been caused by human activity.

1.5 million species of plants and animals live in tropical rainforests.
Earth's climate

Earth is the only planet in the Solar System that supports life. It can do this because it has a unique atmosphere, water, and weather that living organisms can survive in.

Almost every part of our planet is occupied by some form of life—from the deepest oceans to the highest mountains. However, the different climates across the world affect how many and what type of species live in each place. Tropical regions are teeming with life while only extreme survivors can live in polar wastes and deserts.
**SHIFTING PLATES**

Earth’s surface appears to be still, but it is actually a collection of plates that is always moving. These plates move around due to currents deep inside the Earth. Plates that are under oceans are much thinner and less dense than those under continents—where they push into each other the oceanic plate gets forced down underneath the continental plate.

**Jigsaw planet**

Tectonic plates fit together to make up Earth’s surface. They move constantly, and can change our planet’s features, depending on how they meet. Where they push together, mountains and volcanoes form. Where they pull apart, new ocean floor is created.

**THE LARGEST TECTONIC PLATE IS THE PACIFIC PLATE. IT IS THE ONLY LARGE PLATE THAT DOESN’T CARRY A CONTINENT.**

**How plates move**

No one knows exactly why tectonic plates move, but scientists think it is likely that they shift around on top of currents in the mantle layer underneath. These currents are thought to move in steady loops—rising when an area is heated by processes at the center of Earth, then sinking down again when they are cooled by moving nearer to the surface.

**TECTONIC EARTH**

The outside layer of the Earth is broken up into giant pieces called tectonic plates. Over millions of years these plates move, bump together, overlap, and slide past each other, in the process making new areas of ocean floor, building mountains, causing earthquakes, and creating volcanoes.

**EARTHQUAKES**

Most earthquakes happen where tectonic plates rub against each other, in places called faults. Some faults move with a steady, very gradual creep. In other places, a length of fault can remain locked for years, decades, or centuries, before giving way in a few seconds. Earthquakes are caused by the shaking of the ground after a rupture like this. The shallower the depth where the rupture begins, the more severe the shaking is at the surface.

**Measuring quakes**

The magnitude of an earthquake is a measure of the energy it releases. It can be measured using the Richter scale, where a difference of one point corresponds to a 30-fold difference in energy. The intensity of an earthquake can be measured using the Mercalli Intensity scale (below), which grades earthquakes from I to XII, according to their effects.

<table>
<thead>
<tr>
<th>Intensity</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I-II</td>
<td>Hardly felt by people, but can be measured by instruments.</td>
</tr>
<tr>
<td>III-IV</td>
<td>Felt indoors as a quick vibration. Hanging objects swing slightly.</td>
</tr>
<tr>
<td>V-VI</td>
<td>Rocking motion felt by most people, buildings tremble.</td>
</tr>
<tr>
<td>IX-XI</td>
<td>Most buildings destroyed, underground pipes torn apart.</td>
</tr>
<tr>
<td>XII</td>
<td>Almost all buildings destroyed, rivers change course.</td>
</tr>
</tbody>
</table>

**Living with earthquakes**

Earthquakes can occur anywhere in the world, but the most damaging ones usually happen near plate boundaries. Earthquakes can be very dangerous—buildings can fall down and huge cracks open up in the ground. In earthquake-prone areas, buildings can be designed to sway when there is an earthquake, so that they are not shaken apart. Their foundations must be built in solid rock rather than on sandy or wet ground.

**Biggest quakes**

There have been many powerful earthquakes in the last 100 years. The largest, in Chile, was strong enough to move rivers.
**VOLCANOES**

A volcano occurs where molten rock called magma erupts up from under Earth’s surface. An exploding volcano is one of the most incredible and dangerous sights on our planet. Volcanoes often form near the boundaries between tectonic plates, but they can also form elsewhere, at hotspots where hot rock moves upward from deep inside the Earth. There are about 550 active volcanoes on land, and more under the sea.

**Eruption types**

Volcanoes can erupt with massive force, a small explosion, or even just a steady dribble. The way each volcano erupts depends on how thick its magma is and how much gas is in the magma. In a gas-rich magma, violent expansion of bubbles can shatter the magma and project volcanic ash into the sky with huge force, creating an ash cloud. More gentle eruptions feed lava flows that ooze slowly down the side of the volcano.

**Ash columns**

When volcanoes erupt, they can create tall columns of ash. The height of these columns varies, depending on the amount of energy in the eruption, and how much magma is thrown out. The most energetic phase of a major volcanic eruption can last for many hours.

**Volcanic fallout**

If there is wind, a volcanic ash cloud will be blown to one side of the volcano, so that ash from the cloud falls to the ground in a belt that can extend hundreds of miles away from the volcano. Although it is cold by the time it reaches the ground, ash fallout can strip the leaves from plants and is dangerous to inhale. Aircraft must avoid flying through airborne ash, because it can clog up their engines.

**What falls where?**

The larger fragments created in an eruption, such as bombs and cinders, fall closest to the volcano. Fine ash travels the furthest.

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**Lava**

Hot, molten rock that flows across the ground is called lava. It keeps this name even after it has cooled down and solidified into rock. Lava comes in different forms, depending on what it is made of, how stiff or runny it is, and how fast it flows.

**A’a lava**
This is a thick lava flow made of basalt. Its surface is made up of loose, broken, and sharp chunks of lava that can tumble down the front of the lava flow as it moves.

**Pahoehoe lava**
This is a basalt lava with an unbroken surface. As it flows, its surface skin is gradually stretched. The end result can end up looking either smooth or ropelike.

**Blocky lava**
These chunks of lava form when stiff-flowing lava breaks up into angular blocks. These lava blocks have smoother faces than a’a lava.
Plate tectonics

Earth's surface may seem fixed but in fact is made up of lots of huge slabs called tectonic plates. These plates move slowly but constantly, and movements between them create earthquakes and volcanoes.

Most tectonic plates carry both oceans and continents, though a few are almost entirely oceanic. Where two plates pull apart under an ocean, new ocean floor is formed. Where plates are pushed together, dramatic changes to the landscape can occur. If both edges are continental, a huge mountain range will form in the collision zone. If one plate is oceanic and the other continental, the oceanic edge will usually be pushed under its neighbor. Fiery volcanoes occur along the edges of these boundaries, which are called subduction zones.

Earth's plates

The top layer of Earth is like a jigsaw, with seven or eight large plates and dozens of smaller, more fragmented plates. These plates float around, moving on top of the hotter layers below. Their slow, steady movement can change the size of the oceans, and carry continents around the globe.

Key

1. Pacific
2. North American
3. Eurasian
4. African (Nubian)
5. African (Somalian)
6. Antarctic
7. Australian
8. South American
9. Nazca
10. Indian
11. Sunda
12. Philippine
13. Arabian
14. Okhotsk
15. Caribbean
16. Cocos
17. Yangtze
18. Scotia
19. Caroline
20. North Andes
21. Altiplano
22. Anatolian
23. Banda
24. Burma
25. Okinawa
26. Woodlark
27. Mariana
28. New Hebrides
29. Aegean
30. Timor
31. Bird's Head
32. North Bismarck
33. South Sandwich
34. South Shetland
35. Panama
36. South Bismarck
37. Maoke
38. Solomon

Plate boundaries

The edges of tectonic plates meet up in different ways. The plates move apart, toward each other, or past each other. Earthquakes can occur in any of these circumstances, and studying earthquakes can help us work out where plate boundaries lie. Sometimes there are so many cracks that it is impossible to tell exactly where one plate ends and the next one begins.

Convergent

Where a plate with oceanic crust moves toward a plate with thicker, continental crust, it will be pushed down, or subducted. The oceanic plate then melts, and can create volcanoes as magma bubbles up to the surface. If two continents collide, they will push up against each other, creating mountain ranges.
40,000 miles (65,000 km)—the length of the underwater mountain chains formed by mid-ocean ridges.

55 million years ago, the Indian and Asian plates crashed together, creating the Himalayas.

In (2 cm) per year—the speed of seafloor spreading in the north Atlantic Ocean.

Transform
When plates slide past each other, they create a transform boundary. Movement at these plate edges is not smooth and gradual—it is very jerky, and earthquakes occur when a sudden shift releases huge amounts of energy. Volcanoes are rare at these boundaries, because little or no magma is created.

Divergent
Where plates pull apart, they create a divergent boundary. When this happens under oceans, rock from the mantle is drawn up into the gap and some of it melts as it rises, creating new oceanic crust. As new crust is formed, other parts of crust are destroyed at convergent boundaries—so Earth stays the same size.

Plate movement

Earthquakes

Ridge

Magma

Controversial boundary
Scientists disagree on whether the Indian and Australian plates are separate—some think they are a huge, single, Indo-Australian plate.

The Challenger Deep
This is the deepest known point on Earth, at 35,800 ft (10,911 m) below sea level.

Fresh break
This new rift is causing the African plate to slowly split down the middle, creating two new plates—Nubian and Somalian.

Continental plate
The Eurasian plate is 85 percent land, with only 15 percent water.
Where molten rock erupts from an opening on Earth's surface, volcanoes develop. Most of them form near the edges of tectonic plates.

Molten rock called magma is formed in a few places deep in Earth's crust or even in the mantle. If magma reaches the surface it is called lava. Large volcanoes called stratovolcanoes are built by a series of eruptions, with each one adding a layer of solidified lava and ash on top of the last. Volcanoes are classified as active, dormant, or extinct, based on how often they erupt. An active volcano is one that is known to have erupted in recent history. A volcano that has not erupted recently but might erupt again is dormant. A volcano that has stopped erupting altogether is extinct. Some small volcanoes erupt just once, while a large volcano can erupt thousands of times over its lifetime.

Volcanic eruption
Magma works its way through solid rock and up toward the Earth's surface. As it rises, gas bubbles in the magma grow, increasing its speed until it erupts to the surface. The violent expansion of these gas bubbles can shatter the magma, shooting it out explosively as ash or bigger lumps called bombs. If there is not an explosion, the magma flows down the side of the volcano in a molten stream called a lava flow.
Types of volcanoes
The size and shape of a volcano are determined by several factors: the type of magma that erupts from it; the amount of magma that erupts; and whether it produces explosive or non-explosive eruptions.

Shield volcano
The biggest but most gently sloping type. Formed mostly by runny lava called basalt.

Stratovolcano
The steepest large volcano, formed of alternating layers of ash and lava.

Caldera
The remains of a stratovolcano after a super-eruption empties most of its magma chamber.

Cinder cone
A small, steep mound that grows where very sticky lava has erupted.

Fumarole
Vent in the ground from which hot gas and steam escape—often sulfur-rich and very smelly.

Geyser
A jet of water driven into the sky by expanding steam.

Laccolith
A pocket of magma that has forced the rock around it to move and make space for it.

Dike
A vertical magma seam.

Sill
A horizontal seam of magma, usually between layers of bedrock.

Extinct conduit
The position of the active conduit may change during a volcano’s lifetime.

Magma chamber
Magma collects under an active volcano, sometimes over an area many miles wide.

Main vent
The site of most of a volcano’s eruptions.

Main conduit
The “pipe” through which magma rises to reach the vent.

Lava bomb
A lump of rock thrown out by an explosive eruption.

Pyroclastic flow
A fast, dangerous flow of hot gas, ash, and rocks.

Secondary vent
Small hole through which magma escapes.

Secondary conduit
A branch off from the main conduit.
Earthquakes
A natural part of our planet’s workings, earthquakes can be terrifying and destructive events. Some trigger powerful ocean waves called tsunamis.

Earth’s outer shell is made up of huge slabs called tectonic plates. These plates are constantly moving, and push past each other with hard, jerky movements. In some places, the opposing masses of rock become locked together by friction. In these periods, there is a gradual buildup of strain in the locked-up area. Eventually, the pressure becomes so high that there is a sudden shift between the blocks of rock, or a massive break, usually on or near lines on the Earth’s surface called faults. As this happens, energy is released in the form of powerful shock waves, or vibrations, causing an earthquake.

When an earthquake happens under the seafloor, it can create a tsunami.

How a tsunami happens
Many types of events can cause tsunamis, including big volcanic eruptions near or in the sea, landslides into the ocean, and even asteroid impacts. However, the most common cause is a huge earthquake under the seafloor, usually where the edge of one tectonic plate rises above another.

1. Seafloor rupture
A large rupture below the seafloor causes an earthquake. At the same time, a huge block of seabed is suddenly thrust upward. This in turn pushes up the seawater above, triggering a tsunami wave at the ocean surface.

2. Wave origination
At the sea surface, the sudden upthrust of a mass of water from below sets off a series of high-energy waves. These start traveling over the sea surface at a speed of over 500 mph (800 kph).

Energy waves
Earthquakes produce massive waves, which can produce shaking, up-and-down movements, and loud noises.

Inside a fault
Faults at the boundaries of tectonic plates are prone to earthquakes. Here, two plates move past each other in opposite directions. Occasionally, the movement becomes stuck and stress builds up between the plates. Eventually, the buildup of stress causes a sudden shift or rupture, releasing vast amounts of energy.

Seawater movements
As each wave passes, there is a circular movement of seawater under it.

Wave height increase
A tsunami wave grows higher as the seafloor under it slopes upward toward the shore.
The largest earthquake ever recorded occurred off the coast of Chile in 1960. It caused a devastating tsunami.

**Shock waves**

Earthquakes produce two types of shock waves, called P and S waves, which travel through parts of Earth’s interior. Scientists can work out where and when a quake happened by detecting these waves as they arrive back at the surface.

1. **Amplification**
   
   When a tsunami wave approaches a shore, it slows down and its height increases. The upward-sloping seabed creates a resistance to the water movement—it pushes the water so that the wave is amplified (gets bigger).

2. **Inundation**
   
   When a tsunami wave hits a shore, it doesn’t usually break and collapse. Instead, it continues to surge forward for a considerable distance, flooding the whole coast. The powerful rush of water can smash buildings and carry cars and people away.

3. **Crest of wave**
   
   The top of a large tsunami wave usually foams as it approaches the shore.

4. **Sea drawback**
   
   Sometimes water is drawn away from the shore a few minutes before a tsunami wave arrives.

5. **Buildings in danger**
   
   Few buildings can survive the onslaught of a large tsunami wave—many are destroyed or swept away.

6. **Sea becomes shallower**
   
   As the seabed shelves upward, it also slows the approaching wave.

7. **Low-height waves**
   
   In the open ocean, each wave has a low amplitude (height) and may pass unnoticed.

8. **P-waves change direction slightly as they cross layers**

9. **Epicenter of earthquake**

10. **P-waves and S-waves**

11. **NO P-WAVES**

12. **NO S-WAVES**

**Living on the edge**

Some countries are more affected by earthquakes than others, because they sit on the boundaries between tectonic plates. This map shows the ten countries with most earthquake fatalities.

**1,000 miles**

The length of the rupture under the seafloor that caused the 2004 Indian Ocean tsunami.
EARTH’S RESOURCES

Earth contains many useful and essential natural resources, which have been used heavily by humans in recent centuries. These resources include water and food, fuel and building materials, and the means to make more complex things like metals and plastics. Many resources have a limited supply, and using them has an impact on the environment.

ROCKS AND MINERALS

Over the more than four billion years of Earth’s development, thousands of different minerals have formed and combined into hundreds of rock types. Humans have found many uses for these rocks and minerals, from building materials to the manufacture of metals. However, some of the most useful and valuable minerals are rare. Mining and quarrying them is often dangerous and dirty.

Rocks
Humans have used naturally occurring rocks for thousands of years, originally as tools and then for many other purposes, such as the building of houses, factories, and roads.

Minerals
Earth has thousands of naturally occurring minerals. Many of these, such as metal ores, sulfur, and mica, are used in industry. Other examples include gold, silver, and quartz.

Gemstones
When minerals are cut and polished, they are known as gems. One useful gem is diamond, famous for its hardness and ability to cut through most other materials. Some other gems have practical uses, but most are valued for their beauty and rarity. Gems can be cut into many different shapes and are typically used in jewelry or other decorative objects.

Cut gems
Gems can be cut into many different shapes. When cut correctly, gemstones reflect light in many directions, making them glitter.

ENERGY

Human life requires energy in the form of light, heat, and food. Earth’s energy comes from a variety of sources but mostly from the heat of the Sun and the Earth’s hot interior. This is a lot of heat, but capturing, storing, and transporting enough of this energy to meet all our needs is difficult and requires complicated and expensive technology.

Fossil fuels
Fuels such as coal, oil, gas and peat have long been used to heat homes and power machinery. Earth’s fossil fuels took hundreds of millions of years to form, but a significant portion of them have been burned up in just a hundred years. Fossil fuels are formed as time, pressure, and heat transform organic plant and animal remains into hydrocarbons—oil and gas.

Nuclear energy
This energy is produced by the strong force that holds protons and neutrons together inside atomic nuclei. Nuclear energy can be harnessed, and produces low carbon emissions compared to fossil fuels. However, disadvantages include the risk of releasing radiation.

Renewable energy
There are alternative energy sources to fossil fuels, which are more sustainable and better for the environment.

Solar
Light energy created from the Sun can be captured and turned into electricity using solar panels.

Wind
Wind turbines allow us to harness the power of wind. Turbines work best on high ground.

Geothermal
Earth’s internal heat comes close to the surface in volcanic regions and can be used to heat water.

Biofuels
Fuels produced from organic matter such as plants, fats, and waste are called biofuels.

Wood
Burning wood for heat and cooking is the most ancient form of energy supply.
AGRICULTURE
Growing food plants and looking after animals that will be eaten is called agriculture. Today, the global population of around seven billion people largely relies on a few cereal crops to provide its essential foods. These crops include corn, wheat, rice, potatoes, cassava, soybeans, and sweet potatoes. Protein from livestock such as fish, cattle, pigs, and poultry makes up less than 20 percent of total global food.

Farming
Farming began 10,000 years ago, in the Middle East. The first farmers grew cereal crops, like wheat, and reared animals for their meat and milk. Modern agriculture has moved on a lot since then. New machine-based techniques let farmers produce much bigger yields from their land. Other innovations include irrigation, pesticides, new plants, new animal breeds, and global transport—farmers can now send their produce all over the world.

Fishing
Fish are one of the most nutritious supplies of protein and have been eaten for thousands of years. Modern fishing techniques allow large quantities of wild fish to be harvested from the world’s seas and oceans. Although international limits have been introduced, many popular fish species are now endangered. One solution to overfishing is to rear fish for human consumption in fish farms.

Forestry
Forests provide habitats and food for most of Earth’s land-based wildlife, and help control global warming by removing carbon dioxide from the atmosphere. However, forests are also in danger—they are being cut down to supply fuel and lumber for building.

Well-managed forest
Forests can be managed in a way that lets people harvest their produce, such as lumber, without destroying them.

SUSTAINABILITY
Earth's natural resources are limited. If demand for essential resources keeps increasing, they will become rare and expensive. To sustain life as we know it, we must make sure that our resources do not run out.

Human impact
Population growth means that we are using up more and more of the Earth's resources, changing the landscape, and damaging the environment around us. One way to reduce the negative impact people have on the environment is to make sure that as much garbage as possible is recycled, instead of being dumped in a landfill.

Pollution
All over the world, factories, power plants, farms, businesses, and homes produce huge amounts of pollution by releasing chemicals and other substances that pollute, or dirty, the natural environment. As people's use of energy and other resources grows, Earth is becoming more polluted.

The effect of industry
Different countries produce different amounts of pollution. These are the world's top five polluters.
Rocks
A rock is a hard natural object made of mineral grains (crystals), held together in a compact structure. There are hundreds of different kinds of rock, but they are grouped into three main types—igneous, sedimentary, and metamorphic—depending on how they were formed.

Igneous
These form when hot liquid rock, called magma or lava, cools down and solidifies.

Sedimentary
These form when particles from other, older rocks are compressed and stick together.

Metamorphic
These rocks form when older rocks are changed by heat and pressure.

Minerals
Rocks are made up of minerals. There are thousands of minerals, but only around 30 are found at Earth's surface. Most minerals are crystals—their atoms are arranged in regular patterns, giving them simple geometric shapes. Each mineral has its own chemical composition and physical properties.

Native elements
These minerals each contain a single chemical element, such as sulfur, carbon, or a metal such as copper.

Compounds
These minerals contain two or more chemical elements. For example, Fluorite contains calcium and fluorine.

Measuring hardness
Minerals can be soft, like gypsum, or very hard, like diamond. Different scales are used to express hardness. "Mohs scale" is based on comparing the hardness of ten minerals, while "absolute" hardness is based on precise laboratory testing.

The rock cycle
Rocks transform from one type into another in an endless cycle. Many factors contribute to this process, both on the Earth's surface and in its interior. On the surface, rock is broken down by weathering, and glaciers, rivers, and winds erode rocks by carrying particles of them away. Sediment made of tiny particles of rock and mud forms in places like lake bottoms, coasts, and seabeds. Inside the Earth, heat, pressure, and melting change sedimentary and igneous rock into metamorphic rock, and volcanoes are formed that create new igneous rock.
Rocks and minerals

Our planet is mostly made of solid rock. Rock is what gives Earth its features—mountains, canyons, and plains. Minerals are the building blocks of every type of rock.

Most of Earth’s rocks are hidden under a layer of soil and vegetation, but in some places they are visible at the surface, in landscape features such as mountains and canyons. Many different types of rock have developed over billions of years, through a variety of processes. These include volcanic activity, which creates rocks at or near the surface, the formation of sediments in places like the seafloor, and changes in form—called metamorphism—brought about by heat and pressure deep within our planet. These processes are linked in a never-ending cycle, known as the rock cycle.
WEATHER

The constantly changing condition of Earth’s atmosphere creates our weather—clear skies, wind, cloud, rain, and snow. The amount of sunshine we get and how strong it is determines the temperature and pressure in the atmosphere. The amount of moisture it contains determines how high up clouds form and whether they produce mist, rain, or snow, as well as when storms occur. When we study the weather, we can see predictable seasonal patterns around the world, known as climates.

WEATHER SYSTEMS

Patterns of weather depend on the nature of the local air mass and pressure system, which can change over the course of a year. For example, in the summer, continental land surfaces heat up, making warm, dry air rise. This produces a low pressure weather system, which draws in more warm air from the surroundings and can cause storms. In winter, continental land surfaces cool, and colder, dense air sinks down from the atmosphere above.

Pressure fronts

A pressure front divides two different air masses. Air masses with differing moisture content, density, temperature, and pressure do not mix easily, and the front between them is often marked by rising banks of clouds. For example, a low pressure air mass with warm air will rise up above a high pressure air mass with cold air. Any moisture carried by the warm air will condense as the air cools, forming clouds and possibly rain.

Cold front
- When cold air pushes into warm air, it forms a cold front, and the warm air is forced to rise up quickly, creating a steep bank of storm clouds with heavy rain.

Warm front
- At a warm front, cold air is replaced by warm air, which slowly rises up a shallow slope of cold air, forming clouds followed by rain as the air cools.

Occluded front
- An occluded front forms when fast-moving cold air overtakes a slower-moving warm front, lifting the warm air mass up and causing prolonged rain.

Stationary front
- A stationary front forms between two air masses that are similar, and does not move much. It can last for several days and often creates prolonged rain.

Monsoons

Monsoon winds are massive seasonal winds that bring heavy summer rain to subtropical regions, such as Southeast Asia and India. In winter, they bring dry, cooler weather. Monsoon winds are strongest in Asia, but they also occur in West Africa, northern Australia, and parts of North and South America. Monsoon winds change direction between summer and winter.

Summer
- In summer, the South Asian monsoon blows from the Indian Ocean across India, bringing the torrential rains of the wet season, which are essential for the growth of the continent’s staple food crops.

Winter
- In winter, the South Asian monsoon reverses, bringing the warm dry winds and fine weather of the dry season across the Indian continent and out into the Indian Ocean.

WEATHER FRONTS ARE BOUNDARIES BETWEEN AIR MASSES OF DIFFERENT TEMPERATURES, MOISTURE, AND PRESSURE.

Hurricanes

A hurricane is a huge, rotating tropical storm with high winds and very heavy rain. These storms start from a cluster of thunderstorms, which develop over warm tropical seawater in late summer, then merge together into a larger, spiral hurricane. Their intense low pressure draws in warm, moist winds, which spiral upward as they spin faster. The rapidly rising air then cools, forming towering storm clouds and torrential rains. When they reach land, hurricanes cause flooding and are highly destructive.

The view from above
- A satellite view of a hurricane from above shows its spiral shape and a clear central eye.
**WIND**

Winds are common in the Earth’s atmosphere. They vary in scale and intensity from gentle breezes to violent storms like tornadoes, and can be daily or seasonal.

### What is wind?

Wind is the movement of air from an area of high pressure to an area of low pressure. The greater the difference between the areas of pressure, the faster the wind moves. Wind speed is measured using the Beaufort scale, which ranges from 0 to 12. At 12 on the scale, hurricane wind speeds can reach 300 mph (480 kph).

### Wind types

- **Precipitation**
  - **Rain**
  - **Snow**
  - **Sleet**
  - **Fog**
  - **Hail**

- **Cloud types**
  - **Cumulus**
  - **Stratus**
  - **Cirrus**

- **Cloud names**
  - **Cirrus**
  - **Cirrostratus**
  - **Cirrocumulus**
  - **Altostratus**
  - **Alto cumulus**
  - **Altocumulus**
  - **Stratocumulus**
  - **Cumulus**
  - **Nimbostratus**
  - **Cumulonimbus**

### Cloud formation

When the Sun shines on ponds and lakes, some of the water they hold evaporates into the warm air. This warm water vapor then rises and away from Earth’s surface. As the air rises, it cools. Because cold air cannot hold as much moisture as warm air, the water vapor condenses, and forms clouds. Clouds are named according to their shape, size, and how high up they form in the atmosphere.

### Types of precipitation

- **Rain**
  - Clouds are made up of tiny droplets of water. Rain falls when these droplets become too heavy to float in the air.

- **Snow**
  - Snowflakes form when water droplets freeze into crystals, which then stick together as they fall through very cold air.

- **Sleet**
  - Sleet is a mixture of snow and rain. It forms when rain begins to freeze or when snow begins to melt in air that is above freezing.

- **Fog**
  - Fog forms near ground level, when warm, moisture-laden air is cooled by contact with a cold ground or sea surface.

- **Hail**
  - Hailstones are ice pellets that grow from ice crystals in freezing storm clouds. The taller the cloud, the bigger the hailstones.

### Thunderstorms

Thunderstorms are rotating columns of air that can be violently destructive. They are characterized by a central spinning, funnel-shaped column of air, which extends from the clouds to the ground. They have the power to destroy crops and buildings. Tornado formation is associated with summer storms, especially in the US.

### Lightning

The movement of hail and ice in a thundercloud causes an electric charge to build up, which zaps down as lightning.
Hurricanes

Earth's most destructive storms occur in tropical regions, above warm waters. They produce torrential rains and extremely fast winds, which can exceed 155 mph (248 kph).

Hurricanes form in late summer, above warm waters. They begin when clusters of thunderstorms whirl together, evolving into complex structures with vast spiral bands of rain. The low pressure created by these structures draws warm, moist air across the ocean. This air then rises, releasing torrential rains and heat energy. Wind speeds above 74 mph (120 kph) combine with the low pressure to create storm surges of seawater many feet high that flood over coastal regions as the hurricane nears land. When hurricanes pass over land, they are no longer fed by heat from the warm ocean water, and they soon lose force—but often not before they inflict massive damage with their heavy winds, torrential rains, and gigantic waves.

Naming the storm

Hurricanes have the same structure and evolve in the same way wherever they are. However, how they are named depends on the part of the world where they occur. This map shows what they are called in different parts of the world.
Hurricanes are the result of interaction between heat, water, and wind. As clouds produce rain, they release heat and rise to about 5 miles (8 km) above sea level. Here, increasing pressure pushes the uppermost clouds outward, lowering the pressure at sea level. This causes wind speeds to increase and draw in even more heat and moisture from the ocean surface.

Large hurricanes can be over 990 miles (600 km) wide.

4 Hurricane
As storm clouds and winds reach speeds above 120 kph (74 mph), they are drawn into a spiral form. Rising warm air in the storm clouds is replaced by descending cooler air and light winds within a central eye.

**How a hurricane forms**

Ascending warm, moist air
Air is heated by warm ocean waters, picks up water, and rises upward.

Descending cool, dry air
Cool, dry air sinks down toward the ocean's surface.

Eye wall
A ring of destructive thunderstorms and rain bands around the eye.

Eye
A calm, cloud-free area of sinking air and light winds. The eye is usually between 20 and 30 miles (32–48 km) wide.

Spiral rain bands
Rising warm air creates long, curved bands of thunderstorms inside the hurricane.

Surface winds
Low pressure at the water's surface creates warm winds that move in a counterclockwise direction. These winds pick up speed toward the eye.
The water cycle

Earth's water is always on the move, traveling endlessly around our planet in a process known as the water cycle. Without water, life on Earth would not be possible.

Earth’s water is stored in many forms, including oceans, rivers, lakes, glaciers, and groundwater. This water moves around constantly. The water cycle begins when the Sun’s heat makes water evaporate into the atmosphere, where it becomes clouds, dew, or fog. This water falls back down to Earth’s surface as rain or snow, then streams and rivers carry it to lakes or the sea, where it eventually evaporates and the whole cycle begins again.

The presence of water on the Earth is what gives our planet its wet and warm atmosphere. The atmosphere protects the Earth from the Sun’s radiation, which has allowed the evolution and survival of life on Earth. Earth is thought to be the only planet in the Universe to support life.

Water on the move

All water on Earth is included in the constant circulation of the water cycle. Even the snow on mountain peaks or in the ice sheets of the Antarctic is a part of the cycle—eventually, it will melt and be on the move again. Underground water is also involved—it flows in a similar way to rivers, despite being hidden out of sight.

Lake types

Lakes are formed when water fills hollows in the landscape. Most lakes contain fresh water, though they can also be salty. They range in size from ponds to large lakes and even inland seas. The depression lakes are formed in various ways and may be millions of years old or newly man-made. Lakes are not permanent—they can gradually disappear as layers of sediment build up in them.

**Fault lake**
Movement of tectonic plates can create long hollows, which fill with water.

**Caldera lake**
A circular lake is created when rainwater fills the hole left in a volcano’s summit after an eruption.

**Kettle lake**
A steep-sided circular lake, formed when an underground block of ice melts.

**Man-made lake**
People make lakes to generate hydroelectricity and create reservoirs of clean water.
The world’s largest river is the Amazon, which holds around 20 percent of the world’s flowing fresh water.

A drop of water can spend as little as nine days or as long as 40,000 years moving through the water cycle.

97 percent of the world’s water supply is stored in the oceans.

Evaporation from sea
The Sun heats the surface of the ocean, so that some of the water evaporates and rises into the air as water vapor.

Condensation
Heated, rising water vapor cools and condenses, forming clouds.

Forests and plants
Plants help soil retain moisture but also release water into the atmosphere.

Evaporation
Heat from the Sun draws moisture from the ground into the air.

Clouds carry water inland
Winds blow moisture-laden clouds inland.

Cloud movement
Clouds are moved by wind and heat energy.

River flow
Rivers steadily transport water to the oceans.

Ocean water
Seawater is salty because it contains dissolved minerals.

Bedrock
Solid rock that occurs below soil and soft sediment.

Water table
Ground that is saturated with water.

Rivers flow into seas
Eventually, downhill flow means rivers flow into the oceans.

Rivers
When rain falls, the water drains from high ground to lower ground. Small channels of water join up, forming streams and rivers that flow into the sea or fill dips in the landscape to create lakes. The shape and character of a river varies—they are fast and narrow at their source and get steadily wider and slower toward the mouth.

Upper course
Where rivers begin they are very fast-flowing. The water is full of sand and pebbles, which erode and deepen the stream channel.

Middle course
On lower, flatter ground, rivers begin to slow down. They develop bends called meanders, and there is an increased risk of flooding.

Lower course
As they reach lower ground, rivers widen and slow, then flow into lakes or the ocean. Sediment carried by the water is left behind as the river slows.
SHAPING THE LAND

The landscape may look unchangeable, but it has been shaped by the forces of wind and water over millions of years. Together, they break down, or erode, rocks into tiny fragments called sediment, then carry them away. This is usually a very slow process, but extreme events, such as floods and hurricanes, can speed it up.

WIND

You’ve probably had sand blown in your face on the beach, so you’ll know that winds can be strong enough to pick up dust, grit, sand, and soil particles. These sediment particles can be carried over huge distances. Wind erosion and deposition (the laying down of sediment) typically happen in dry places with little vegetation to protect the rocks. Characterized by low rainfall, these environments are known as deserts and often contain sand dunes.

Sand dunes

The more powerful a wind is, the further it can carry sediment particles before dropping them to the ground. As they roll and bounce on the ground, these particles create small, wave-shaped ripples. These ripples sometimes build-up into larger formations, called dunes. With persistent winds, sand dunes can grow to many feet high and several miles long.

Crescent (barchan) dunes

Winds of varying strength and sand content form crescent-shaped dunes with "horns" pointing downwind.

Star dunes

These dunes form when the wind direction constantly changes. They may grow to a considerable height.

Wind erosion

Over time, the constant lashing of winds can wear away at exposed rock surfaces. This wind erosion produces weird-looking and unstable formations, which eventually collapse in most cases. Even very hard rocks may be slowly shaped and polished by sand blasting. Barren landscapes can be created if all the soil in an area is blown away by the wind.

Rocky arch

Sand-blasting can create strange shapes from rocks, such as this natural arch in the Arches National Park in Utah.

COAST

Coasts are constantly being shaped by nature. Where coasts are exposed, the action of powerful ocean currents and waves wears away the landscape to form cliffs and headlands. On more sheltered coasts, sediments build up to form sandy beaches, dunes, mudflats, and salt marshes. Rivers also affect coasts as they lose energy and leave behind the sediments they carry when they approach the sea.

Coastal erosion

Pounding relentlessly, day after day, waves play a key role in shaping the coastline. They break against the shore with immense force, dislodging weak or loose rock material and grinding it into pebbles. Repeatedly hurled back against the shore by the waves, the pebbles themselves increase the waves’ erosive action.

Deposition

Rivers laden with sediment dump their cargo at river mouths to form wide shallow areas called estuaries. Sea waves and currents wash much of the sediment along the coastline. The mud and sand form beaches, sand dunes, and headlands, which help to protect the coastline from erosion.
The salty waters of the oceans cover about three-quarters of the Earth's entire surface. Heat from the Sun evaporates ocean water, which rises into the atmosphere and forms clouds. This airborne moisture eventually falls to the ground as rain. Some rainwater soaks into the soil or becomes stored in rocks underground. The rest of the water runs off the land to form rivers, which return the water to the sea, completing a process that is known as the water cycle.

Rivers
Water flows down slopes under the influence of gravity. As a result, Earth's surface water runs off the land as mountain streams, which join to form larger rivers that carve out valleys as they flow down toward the sea. The more powerful the flow of the river, the more loose sediment, such as mud and sand, it can carry.

World's longest rivers
The Nile is the world's longest river, stretching for 4,130 miles (6,650 km). The Amazon, although not as long, carries more water—about one-fifth of all the river water on Earth.

Waterfalls
The ability of a river to erode its valley depends upon the hardness of the rock over which it flows. Soft rock erodes more quickly than hard rock. In places where the river's course takes it over both hard and soft rock surfaces, the different rates of erosion may gradually lead to the formation of waterfalls.

Glaciers
Ice is hard and brittle but it can also flow slowly when under pressure in moving channels of ice called glaciers. Glaciers pick up pieces of grit and rock fragments as they move along, which grind over the landscape, carving out a deep valley underneath the ice.

Rain
Earth's atmosphere contains tiny particles of moisture in the form of clouds, fog, and steam. Temperature and pressure changes cause the moisture to condense into larger, heavier drops, which fall back down to Earth as rain, hail, or snow. The impact of raindrops hitting the ground can move particles of soil or sand.

Essential water
Rainwater is vital for life—it nourishes all plants and animals that live on land.

Oxbow lakes
On low-lying land, the course of a river may bend to form snakelike meanders. If a meander curves too much, it will eventually become completely cut off from the main river. The result is a U-shaped body of water known as an oxbow lake.

Waterfalls are always small—they'll split into two drops if they grow bigger than 0.25 in (4 mm).
Caves

Underground passages and caves are found in rocky landscapes across the world. They are common in areas with a lot of limestone.

Cave systems form when acidic water etches its way through rock. Rainwater becomes acidic when it takes in carbon dioxide from the atmosphere, while groundwater can pick up acids from soil. The water causes existing cracks in the rock to widen into passages, which the water flows through, creating channels. Over time, the flowing water opens up passages and caverns, and more rocks weaken and fall, creating larger caverns. The surfaces of these caverns can become covered with a variety of crystalline deposits, which form when mineral-enriched water evaporates, leaving behind solid structures called stalactites and stalagmites.

Inside Earth

The gradual weathering of limestone rock by acidic water can create incredible cave systems. Over thousands of years, small caves steadily grow, creating huge caverns, while small cracks in the rock become large tunnels. When these link up, huge interlinked networks are created, filled with thousands of stalactites and stalagmites. With the right safety equipment, these caves can be exciting environments for people to explore.
Tham Hinboum cave in Laos has the world's longest navigable underground river—it is over 4.5 miles (7 km) long.

92 ft (28 m)—the length of the world's longest stalactite, which is in Gruta do Janelao cave in Brazil.

How gorges form
The development of cave systems means large amounts of limestone rock is removed from a landscape. Underground cavities are enlarged by rock falls and form caves. Eventually, the caves roofs collapse, creating sinkholes, which can then merge to form larger sunken regions with steep sides, known as gorges.

1,000 years—the time it takes for 1 in³ (16 cm³) of stalactite or stalagmite to grow.
Glaciers develop when mountain snow builds up into masses of ice. If there is a slope, the glacier then moves steadily downhill, carving its way through the landscape.

From the poles to the equator, glaciers develop wherever it is cold enough for winter snowfall to survive the summer thaw. Layers of snow compress into glacial ice and move downhill due to the influence of gravity. Glaciers follow existing river valleys and may merge together into much larger ice sheets.

Over hundreds of thousands of years, glaciers have a huge impact on the landscape around them. Rocky debris becomes embedded in glaciers, and cuts into the landscape, changing the shape of the valleys they move through. This debris is then dumped onto surrounding landscapes wherever the glacier comes to rest and melts.
After the glacier

Glaciers leave many signs behind when they have passed through an area. Rock debris called moraine is left in piles. Valleys are gouged into deep U-shapes with close vertical sides, and are often flooded with melt water. Rocks are scratched by other rocks and debris that is carried along by the gritty ice, and even huge boulders can be relocated.

In some places, Antarctica’s ice sheet is more than 2.6 miles (4.2 km) thick. 32 percent of land was covered with glacial ice in the last ice age.

How glacial ice forms

Glacial ice forms gradually, when fresh snow is steadily weighed down by the accumulation of newer flakes. Eventually, this compression turns light snow into dense ice with few air bubbles.

- **Airborne snow**: Fresh snow falls, formed of delicate six-sided crystals.
- **Ground snow**: Within days, flakes are broken by the weight of new snowfall.
- **Granular ice**: Within a year, the fragments form round, dense grains.
- **Firm**: The grains steadily get smaller and more tightly packed.
- **Glacial ice**: Firm grains are packed together to create larger ice crystals.

70 percent of Earth's fresh water is stored as glacial ice.
EARTH’S OCEANS

The blue waters of Earth’s oceans cover almost three quarters of our planet, dominating its surface. The world beneath the water’s surface is Earth's most mysterious and least explored region. Fifty percent of the world’s species live in the oceans, which have been home to life since it first evolved, over 4 billion years ago.

THE SEAFLOOR

The ocean floor is just as varied as land. Its features are mainly created by the movement of the plates that make up Earth’s crust. Where plates move apart, ridges open and create new ocean floor. Where plates collide, old rock is pushed into Earth's interior, forming deep trenches. Volcanic islands erupt from the ocean floor and some even rise above sea level. They are surrounded by deep, flat abyssal plains and covered with fine-grained sediment.

Ocean features

OCEAN TRENCHES
Where two of Earth’s tectonic plates push into each other, one will be forced underneath the other in a process called subduction. Deep, valleylike trenches are formed between the plates—some can be almost 6.8 miles (11 km) deep.

VOLCANIC ISLANDS
The movement of tectonic plates under the ocean causes molten rock (magma) to bubble upward into the water. If there is a lot of magma then it rises and erupts at the surface, forming an arc-shaped series of island volcanoes.

OCEAN RIDGES
These ridges form when two of Earth’s tectonic plates pull apart and magma wells up between them, solidifying into new rock. The system of ocean ridges extends over 36,780 miles (59,200 km) around the globe.

HYDROTHERMAL VENTS
The presence of hot rocks beneath spreading ocean ridges produces numerous hot springs, known as hydrothermal vents. The heated seawater is rich in minerals and pours out onto the ocean floor, creating towerlike structures called black smokers. These extreme underwater environments are similar to those in which life first formed.

ABYSSAL PLAINS
The deep ocean floor lies more than 9,843 ft (3,000 m) below sea level. It covers 50 percent of the Earth’s surface but is the least explored part of the planet. The rugged volcanic mountain landscape of the seafloor is buried beneath fine-grained, muddy sediment, which forms a dark, featureless, intensely cold and inhospitable environment.

Hidden mountain

Measured from its underwater base to its summit, Mount Kea in Hawaii, is even taller than Mount Everest.

Mount Kea
33,476 ft (10,203 m)

13,796 ft (4,205 m) above water

19,680 ft (5,998 m) below water

SEA LEVEL

Mount Everest
29,028 ft (8,848 m)

Ocean sizes

Earth’s oceans are very different sizes. The largest ocean is the Pacific, at 63,784,076 square miles (165,200,000 kilometers²), and the smallest is the Arctic, at 5,428,600 square miles (14,060,000 kilometers²).

75% of Earth’s surface is underwater.

If the ocean waters were spread out evenly over Earth’s surface they would cover the entire surface to a depth of 8,200 ft (2,800 m).

Salty seas

All seawater is salty, but only a small percentage is actually salt. As well as salt, seawater contains over 86 chemical elements and very low concentrations of precious metals such as platinum and gold.

96.5% WATER

3.5% SALT
**Sunlight and darkness**

Sunlight cannot shine far through ocean water. Only blue light reaches water below 150 ft (45 m), and below 660 ft (200 m) there is no light at all. Ocean waters can be divided into zones depending on how much light reaches them and how cold they are—the water gets colder as it gets deeper. Each ocean zone provides a habitat for different kinds of life. Animals that live in the deeper zones have special adaptations to survive there.

### Waves

Most ocean waves are generated by wind, with wave height, spacing, and direction depending on how strong the wind is and how long it blows. Long-term winds produce giant, widely spaced waves.

### Tides

Regular rises and falls of sea level around the world are called tides. The Moon’s gravity produces two high tide bulges of ocean water, on opposite sides of the globe. Between these bulges are the low tides. As Earth rotates, the tides sweep around the globe. As well as this daily cycle, the weaker pull of the Sun produces an additional monthly cycle, with a variation in the heights of the high and low tides.

### Currents

Ocean surface water currents are driven by winds that blow from the hot tropics to cooler northern regions. They form ocean-wide flows called gyres. Oceans also have deeper currents, which are known as the Great Ocean Conveyor. These deep currents are caused by sunlight heating tropical waters. The warm water flows toward cold polar regions, where it cools and sinks, forming a deep current that flows back toward the tropics, where it warms and rises again.

**Global currents**

There are two sets of currents in Earth’s oceans—surface currents on top and deep-ocean currents further down.

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**Water on the Move**

Ocean water is in constant motion. Wind on the water’s surface creates waves. Gravity between the Sun, Moon, and Earth creates tides. Heat from the Sun generates currents around the world, as the heated water rises to the surface while cold water sinks.

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**Global currents**

There are two sets of currents in Earth’s oceans—surface currents on top and deep-ocean currents further down.
The ocean floor
The world beneath the ocean surface is as varied as the more familiar one above water, with huge mountains and volcanoes, vast plains, deep canyons and trenches, and massive ridges that snake across the seafloor.

Many seafloor features are the result of melted rock called magma rising up from inside Earth. Where tectonic plates (slabs of Earth’s outer shell) pull apart at a mid-ocean ridge, the magma solidifies and creates new seafloor. Older plate is pushed away from the ridge and eventually may move under a neighboring plate. This allows more magma to move upward, creating volcanic islands. Not all seabed features are made by magma—submarine canyons are caused by erosion around the edges of continents, and abyssal fans are created by submarine currents dropping off the silt they were carrying.
Deep-sea smokers

Usually found near mid-ocean ridges, subsea smokers grow where super hot water spurts up from the seabed. Seawater seeps down into the seafloor and gets heated. The hot water rises and surges back into the cold ocean, where minerals dissolved in it turn into solid particles, which look like smoke. The particles also build up to form solid chimneys around the plumes of hot water.

Under the sea

The seafloor lies about 2.3 miles (3.7 km) below the surface of the ocean. It is made of a rocky oceanic crust, which is covered in muddy sediment. Tectonic plates are generally made up of this oceanic crust and continental crust, along with part of the mantle layer under it. Erupting magma on the seafloor can create volcanic islands and seamounts.
Since the first living organisms appeared on Earth 3.8 billion years ago, millions of different species have evolved. Life now flourishes all over the planet, from the highest mountain peaks to the depths of the ocean.
How Life Began

Billions of years ago, a chance combination of chemicals somewhere on Earth’s surface created a substance that could soak up energy and reproduce itself—the first living organism. This was the beginning of the amazing story of life on Earth.

Early Earth
For 500 million years Earth was a giant furnace of searingly hot rock, constantly bombarded by asteroids and meteorites. As each lump of space rock crashed into the planet, its energy was converted into more heat. But these impacts also delivered chemical elements that were to be vital ingredients of life.

Chemical Cauldron
As the planet cooled, huge volcanoes filled the air with toxic gases. But they also erupted vast quantities of water vapor that cooled and fell as rain, filling the oceans. Lightning may have then triggered chemical reactions in the water, forming complex molecules that were able to make copies of themselves—the basis of life.

First Cells
The chemical processes that were essential to life needed to occur in a protected place. This was provided by a substance that could form tiny, tough-walled bubbles. These were the first living cells—microscopic packages of life-giving chemicals that became bacteria, the simplest surviving life forms.

Energy from Light
Life needs energy. The first cells used chemical energy, but about 3.5 billion years ago cells called cyanobacteria started using solar energy. They used it to make food from water and carbon dioxide, releasing vital oxygen. Similar cyanobacteria created these stromatolites on the coast of Western Australia.

Deep Heat
It is likely that the first living cells developed in warm, coastal pools of salty water. However, life may have begun in the deep ocean, around hot volcanic vents that gush energy-rich chemicals from the ocean floor. Simple organisms that still live around these vents are probably very like the earliest living cells.

Variety of Life
As soon as life began, it started to change. Living things thrive by making copies of themselves, but the copies are not exact. Over time, the differences generate new forms of life. This process of change, called evolution, has created the diversity of life on Earth.

Evolution
Every living thing is slightly different from its parents. If the difference helps it to survive, it is likely to pass on the advantage to its own young. This is the basis of evolution. Many years later, it may lead to a change that is large enough for the result to be called a different species.

Natural Selection
The main mechanism of evolution is called natural selection. Life in the natural world is a competition, with losers and winners. Those that survive and breed happen to have a combination of qualities that helps them thrive in their habitat. But if conditions change, the winners may turn into losers.

Survival of the Fittest
Most peppered moths have pale wings for camouflage. But a dark form thrived in places with smoke-blackened trees because it was less obvious to birds.

The pale moth is hard to see on the natural tree bark.

The pale moth stands out on the soot-stained tree bark.
WRITTEN IN STONE
We know that life has evolved over time because rocks contain evidence of different life forms that thrived in the distant past. These links with a vanished world are called fossils. Typical fossils preserve the forms of bones, teeth, and shells. By comparing them with those of familiar animals, scientists can piece together the story of evolution. Every new fossil that is discovered makes the picture clearer.

Fossil hunters
The scientists who study fossils are called palaeontologists. They are experts at finding, identifying, and preserving fossils. They can also work out how old each fossil is, and how it fits in with the story of evolution. They often have only fragments to work with, but a single bone can be a crucial clue.

Excavation
Palaeontologists painstakingly uncover a fossil of a 10-million-year-old rhinocerous-like animal in Nebraska.

Solving the puzzle
Fossils can be impressive, but even the biggest and best preserved are just a start. To make sense of a group of fossil bones, palaeontologists must work out how they fitted together, what the living creature might have looked like, and how it might have behaved.

CHANGING PLANET
The history of life is not a story of steady progress. Living things have faced many global disasters caused by things like asteroid impacts and climate change. Some have left very few survivors, which have had to live in an altered world. This has changed the direction of evolution several times, so new types of animals and plants have evolved while others have become extinct.

Mass extinctions
Since life began there have been five mass extinctions—catastrophic events that killed off a large proportion of life on Earth. After each extinction, life recovered slowly, and new types of animals, plants, and other living things appeared. These extinctions were caused by natural forces, but evidence suggests that we are in the early stage of a sixth mass extinction, caused by human activity.

ORDOVICIAN (440 MYA)
This extinction destroyed 60 percent of the species living in the oceans. At the time, there was little if any life on land.

DEVONIAN (358 MYA)
More than three-quarters of the species living in the Devonian Period were wiped out. Life in shallow seas was most badly affected.

PERMIAN (250 MYA)
At the end of the Permian, life suffered a global catastrophe that almost destroyed life altogether. Very few species survived.

In the past 500 million years, more than 90 percent of all life on Earth has vanished.

In the beginning
For 3 billion years, only the very simplest single-celled forms of life existed on Earth.

Complex life evolves
Multi-celled life—the first animals—only started evolving 600 million years ago (MYA).

Today
Earth forms

For about 84 percent of life's 3.8-billion-year history, the largest life forms were microscopic bacteria.

When complex life appeared, the pace of evolution accelerated to create a dazzling variety of species.

On the move
Study of the bones and joints of Tyrannosaurus rex has been used to create this computer simulation, showing that its running action was similar to that of an ostrich.

SOLVING THE PUZZLE
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In the past 500 million years, more than 90 percent of all life on Earth has vanished.
Animals have existed on Earth for more than 600 million years and humans for about 200,000 years—a tiny fraction of the time.

Geological time

The history of life is recorded by fossils preserved in rock layers. Older rocks lie beneath more recent ones, so each layer represents a span of time. Scientists divide this vast stretch of time into eras, and these are further divided into smaller time spans called periods. This geological timescale is the basis of the timeline shown here, measured in millions of years ago (MYA).

4.6 billion to 541 MYA
The huge stretch of time known as the Precambrian Period includes the 3 billion years when only the simplest single-celled life forms existed. The first animals evolved near the very end of the Precambrian.

419–358 MYA
The Devonian is known as the age of fish because so many new types evolved. Some of these fish gave rise to four-legged amphibians that were the ancestors of all land vertebrates, such as reptiles and mammals.

358–298 MYA
Life on land flourished during the Carboniferous, with dense forests of tree-sized primitive plants. Insects and spiders were common, and were hunted by large amphibians.

145–66 MYA
The Cretaceous Period saw the evolution of the first flowering plants, and some of the most spectacular dinosaurs. It ended with a mass extinction that wiped out the big dinosaurs, and ended the Mesozoic Era.

66–23 MYA
A new era, the Cenozoic, opened with the Paleogene Period—a time of slowly cooling climates when mammals evolved rapidly to take the place of the extinct dinosaurs.

35–23 MYA
The size of a modern rhinoceros, Uintatherium was a plant-eating mammal.

358–250 MYA
The early Ediacaran Period saw the first traces of complex life forms, including small, soft-bodied animals that left fossilized trails in the mud. The first animals evolved near the end of the Precambrian.

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The huge stretch of time known as the Precambrian Period includes the 3 billion years when only the simplest single-celled life forms existed. The first animals evolved near the very end of the Precambrian.

Early volcanoes
Water vapor erupting from ancient volcanoes created the oceans where life evolved.

Comets
Space debris bombarded Earth in the early Precambrian, including icy comets that melted into the oceans.
The Precambrian Period makes up 88 percent of the entire history of Earth.

Insectswere the first flying animals. Today, these thriving life forms make up more than 75 percent of all animal species.

380 million years ago, the first vertebrate animals crawled on to land.

201–145 MYA
The dinosaurs flourished during the Jurassic Period, rising to become the dominant animals on land. They included gigantic plant-eaters and powerful predators.

Morganucodon
The small, insect-eating Morganucodon was one of the first mammals.

Eudimorphodon
One of the earliest pterosaurs, Eudimorphodon had wings of stretched skin, and probably flew well.

Plateosaurus
This long-necked dinosaur could reach up to gather leaves high in the treetops.

252–201 MYA
Life recovered slowly from the Permian extinction that ended the Palaeozoic Era. But by the end of the Triassic Period, the first of the dinosaurs had evolved, along with the earliest airborne pterosaurs and the first true mammals.

Dimetrodon
The fossils of this sail-backed carnivore are among the most common fossils of this period.

298–252 MYA
The Permian saw the dominance of reptiles and the ancestors of mammals, but ended in a catastrophic extinction.

The fossils of this first bony fish with hinged, movable jaws. Meanwhile, life had spread on to land in the form of simple green plants.

Sacabambaspis
This armored animal had very close-set eyes that faced forward. It had no jawbones, like all the earliest fish.

443–419 MYA
The Silurian Period saw the appearance of the first bony fish with hinged, movable jaws. Meanwhile, life had spread on to land in the form of simple green plants.

Cooksonia
Found in most parts of the world, Cooksonia was one of the oldest plants to have stems.

Marrella
About 1 in (2 cm) long, Marrella lived on the seabed. It had jointed legs like a crab and spines running along its body.

485–443 MYA
Life flourished in the oceans during the Ordovician. Many different types of fish evolved during this period along with other animals such as trilobites. But the Ordovician Period ended with one of the biggest extinction events in history.

541–485 MYA
Fossils of complex animals became common in rocks of the Cambrian Period, at the start of the Palaeozoic Era. Many of these creatures had evolved with hard shells, which is why they survived as fossils.

Marrella
About 1 in (2 cm) long, Marrella lived on the seabed. It had jointed legs like a crab and spines running along its body.

Homo neanderthalensis
These tough, strongly built people were adapted for life in icy climates.

2 MYA to the present
This period of dramatic climate changes has had long ice ages with warmer phases like the one we live in today. Despite this, modern humans—Homo sapiens—slowly spread all around the world.

Australopithecus afarensis
This early hominid could have been the first to walk upright, 4 million years ago.

23–2 MYA
The cooling climate trend continued in the Neogene. Modern types of mammals and birds appeared, and the australopithecine ancestors of humans evolved in Africa.

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The dinosaurs

For 165 million years, life on Earth was dominated by the most spectacular animals that have ever existed—the dinosaurs.

The Mesozoic Era was a high point in the history of life, because it was the age of dinosaurs. These fantastic creatures included the biggest, heaviest, and most terrifying of all land animals. They evolved into an amazing variety of forms, ranging from huge, armored leaf-eaters to nimble, feathered hunters, and gave rise to the birds that still flourish today.

**Family tree**

All the dinosaurs of the Mesozoic Era except the very earliest species belonged to two main groups known as the ornithischians and saurischians. The ornithischians evolved into three main types that were nearly all plant-eaters. The saurischians were divided into the mainly meat-eating theropods and the big, plant-eating sauropodomorphs.

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**Ornithischians**

The word ornithischian means “bird-hipped.” It refers to the way that the pelvic bones of these dinosaurs resemble those of birds. The ornithischians also had beaks supported by special jawbones. But confusingly the birds themselves are small theropod dinosaurs, part of the saurischian group.

**Saurischians**

The saurischian dinosaurs of the early Mesozoic Era had pelvic bones that resembled those of lizards, so the word saurischian means “lizard-hipped.” But many of the later forms evolved birdlike pelvic bones, which the birds were to inherit. Saurischians also had longer, more flexible necks than the ornithischians.

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**Marginocephalians**

These consisted of ceratopsians, like this *Pentaceratops* with its huge horned neck frill, and pachycephalosaurs with very strong, armored skulls.

**Ornithopods**

One of the most successful groups of dinosaurs, the ornithopods ranged from lightweight animals that ran on two legs to heavyweights like this *Muttaburrasaurus*. They were all plant-eaters.

**Theropods**

*Spinosaurus* was one of the biggest theropods—the group that included all the powerful hunters. They all walked on their hind legs, and many had feathers.

**Sauropodomorphs**

The sauropodomorphs included the biggest dinosaurs—colossal animals such as *Brachiosaurus*. They were all plant-eaters that supported their immense weight on four pillarlike legs resembling those of elephants. They had very long necks, which were often balanced by equally long tails.

**Treetop browser**

Its unusually high shoulders and long neck allowed *Brachiosaurus* to feed high in the treetops, like a super-sized Jurassic giraffe.

**Large body**

Its immense size allowed this dinosaur to have a very big digestive system to process its diet of tough, fibrous leaves.

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**Thyreophorans**

The thyreophorans included the heavily armored ankylosaurs and stegosaurs such as this spiny *Kentrosaurus*. 
Strong legs
Unlike modern reptiles such as crocodiles and lizards, the dinosaurs stood with their legs beneath their bodies in much the same way as mammals. We also know that many of them were warm-blooded, which allowed them to be more active than modern cold-blooded reptiles.

Dinosaur stance
All dinosaurs stood tall on straight legs, so their weight—which could be immense—was fully supported.

Crocodile stance
Modern crocodiles are close relatives of dinosaurs, but their legs do not support their bodies quite as well.

Lizard stance
Lizards usually sprawl with their legs outspread and their bellies close to the ground, which slows them down.

Reptile neighbors
The dinosaurs were not the only giant reptiles living during the Mesozoic Era. They shared their world with marine reptiles such as Mosasaurus, and pterosaurs like Pterodactylus. These animals were not dinosaurs, although the pterosaurs were close relatives. Most were hunters, and some marine reptiles had massively strong jaws. The pterosaurs were much more lightly built, with small bodies and long, efficient wings of stretched skin.

Mosasaurus
At up to 50 ft (15 m) long, Mosasaurus was a powerful predator that lived at the very end of the age of dinosaurs.

Pterodactylus
Like all pterosaurs, Pterodactylus was a warm-blooded, furry-bodied animal that probably flew as well as a bird.

The Mesozoic Era
The age of dinosaurs began 230 million years ago, during the Triassic Period. This was the first of three periods that made up the Mesozoic Era. The earliest dinosaurs had to compete with other types of reptiles, but many of these became extinct at the end of the Triassic, allowing dinosaurs to flourish during the Jurassic Period. The last period, the Cretaceous, saw the evolution of an amazing variety of dinosaurs, including the fearsome tyrannosaurs.

Triassic Earth
From 252 to 201 million years ago, all the continents were joined together in a huge supercontinent with a vast desert at its heart. Most plants and animals lived near the fringes.

Jurassic Earth
The supercontinent split in two near the beginning of the Jurassic Period. The deserts shrank, and the growth of lush forests provided food for huge plant-eating dinosaurs.

Cretaceous Earth
The Jurassic Period gave way to the Cretaceous 145 million years ago. The continents became more fragmented, allowing many different types of dinosaurs to evolve in various lands.

Catastrophe
The Mesozoic Era ended 66 million years ago with a mass extinction event that eliminated all dinosaurs except the birds. It may have been caused by the impact of a giant asteroid in what is now Mexico. At the same time, huge volcanoes were erupting in India, and the combination must have had catastrophic effects on the climate.

Asteroid impact
The asteroid that hit Mexico 66 million years ago was at least 6 miles (10 km) wide. The high-speed impact of such a huge rock would have filled the atmosphere with debris and dust, blotting out the Sun for many years.

Scientists still do not know what really killed off the big dinosaurs, or how birds, crocodiles, and other animals managed to survive.

FOSSIL REMAINS TELL US THAT THE BIGGEST PTEROSAUR WAS THE SIZE OF A SMALL PLANE, WITH AN AMAZING 39 FT (12 M) WINGSpan.
**Tyrannosaurus rex**

The most powerful land predator that has ever existed was a giant theropod dinosaur—a super-sized killer armed with massive jaws and teeth that could bite through solid bone.

The tyrannosaurs were the most deadly hunters of the entire 165-million-year Mesozoic Era—the age of dinosaurs. The biggest and most famous of them, *Tyrannosaurus rex*, evolved only near the end of the era, a few million years before the global catastrophe that wiped out all the giant dinosaurs. It was specialized for killing—inflicting huge bites that crippled its prey or caused it to die of shock. It would then rip its victim apart, biting out great chunks of meat and swallowing them whole.

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**FORWARD-FACING EYES**

The eyes faced further forward than those of most dinosaurs. This gave *Tyrannosaurus* the binocular vision it needed to judge distances accurately and target its prey.

**LUNGS**

The lungs were like those of birds—super efficient for gathering the oxygen needed to power the hunter's huge muscles.

**RIBCAKE**

Strong ribs protected the dinosaur's heart, lungs, and other vital organs from damage.

**LOWER JAW**

The jaws were deep and short, allowing the jaw muscles to exert huge pressure.

**MASSIVE NECK MUSCLES**

The weight of the head was supported by very strong neck muscles. These also helped with tearing prey apart.

**BONE-CRUSHING TEETH**

*Tyrannosaurus* teeth were bigger and stronger than those of any meat-eating dinosaur found so far. The biggest were at least 8 in (20 cm) long. They were more like spears than teeth—sharp-pointed to pierce thick skin and muscle, yet deep-rooted and very tough to give them the strength to bite clean through the bones of their victims.

**AIR SACS**

Air passed right through the lungs and into a network of air sacs before it was pumped out again. This allowed the lungs to absorb more oxygen with each breath.

**SKELETAL STRUCTURES**

- **Shoulder Blade**
- **Air Sac**
- **Small Arms**
- **Gizzard**
- **Heart**
- **Birdlike Feet**
- **Air Passes Right Through The Lungs**
- **Ribcage**

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**HOW LIFE BEGAN**

28 years—the age of a dinosaur known as Sue, the biggest *Tyrannosaurus* to be exhibited so far.
Intestine
As a dedicated hunter, Tyrannosaurus only ate meat. This is easy to digest, so the dinosaur almost certainly had a relatively short intestine.

Backbone
The vertebrae that made up the flexible backbone had tall spines linked to strong muscles, giving excellent back strength.

Tail muscle
Massive muscles flanking the bones of the tail provided strength as well as the weight needed for balance.

Long, heavy tail
Extending well beyond the hips, the long tail balanced the dinosaur's heavy head as it charged into the attack on its hind legs.

Hip bone
Like most theropods, the tyrannosaurs had massive bones extending forward from their hips that helped support their intestines.

Powerful muscular legs
Like all the theropod dinosaurs, Tyrannosaurus stood on just two powerful hind legs. These were very muscular at the top, but slim near the ankle for speed.

Stout claws
Each foot was equipped with stout, strong claws to grip the ground. It is possible that this animal could run very well, despite its weight.

Shock tactics
Typical carnivorous dinosaurs had teeth like knife blades, ideal for slicing through skin and flesh. But these bladelike teeth were very slender and likely to snap off if the dinosaur bit into something hard. Tyrannosaurus and its relatives were different. Their teeth were sturdy spikes that could punch through virtually anything. This allowed tyrannosaurs to charge straight into the attack on their powerful hind legs. Most of the dinosaurs they preyed upon didn’t stand a chance.

Fact file
When: 68–66 MYA (late Cretaceous)
Habitat: North America
Diet: Carnivore
Length: Up to 40 ft (12.4 m)

Tyrannosaurus had the most powerful bite of any land animal that has ever lived—at least four times the strength of an alligator’s.

3 million years—the length of time that Tyrannosaurus may have terrorized the Earth.

Tyrannosaurs weighed as much as an adult male African elephant. More than 30 fossil Tyrannosaurus specimens have been discovered.

Intestine
As a dedicated hunter, Tyrannosaurus only ate meat. This is easy to digest, so the dinosaur almost certainly had a relatively short intestine.
How fossils form

Fossils are a window on a lost world. They are our only evidence of spectacular creatures that lived long ago, and of the process of evolution that created them.

A fossil is something that preserves the form or traces of a living thing that died many millions of years ago. When something dies, its remains are usually broken up and attacked by decay organisms that completely destroy it. But some parts are more likely to survive than others, especially the shells, bones, and teeth of dead animals. If they escape destruction for long enough and are buried below ground, they may be replaced by minerals dissolved in groundwater. These can then harden to stone, creating a typical fossil.

A long process

Most of the time, fossilization is a gradual process. After thousands of years, a shell or bone can look as if it has been buried for just a few weeks, especially if it has been frozen. Creating a stony fossil usually takes millions of years as the body tissue of an animal is gradually replaced with the minerals that will eventually turn it to stone. The result often mimics the original in every tiny detail, and this gives scientists vital clues about the animal and how it lived in the distant past.

Types of fossil

Many fossils are shells or bones that have been turned to stone, but there are other types of fossils. Some are animals that were not turned to stone but simply preserved, like flies in amber. Stony fossils can preserve an impression of something rather than its entire form, such as a footprint. These types of trace fossil can tell us a lot about how long-extinct animals lived.

Preserved in amber

This mosquito was trapped in sticky tree resin millions of years ago, and preserved because the resin hardened into a fossilized form called amber.

Flooded landscape

The dinosaurs have died out and the land is now covered by seawater.

Triceratops

This leaf-eater lived alongside Tyrannosaurus, and was among its main prey.

Megalodon

A colossal relative of the great white shark, this was the biggest killer in the oceans 20 million years ago.

Deadly battle

Badly injured in a battle with a rival, a Tyrannosaurus rex stumbles into a river and dies. Its huge body settles on the riverbed, where its skin and flesh start to decay.

Bare bones

Lack of oxygen deep in the river slows the decay process. Eventually, the body of the Tyrannosaurus is reduced to a bare skeleton, but the bones stay intact as they were in life.

Deep burial

Mud settling on the riverbed buries the skeleton. Then, millions of years later, rising sea level floods the area with seawater, and the mud is covered with a pale layer of marine sediment.
The first known dinosaur fossils were identified in 1824—the teeth and bones of Megalosaurus.

3,450 The age in millions of years of the oldest known fossils.

In China, dinosaur fossils were once thought to be the bones of dragons.

From wood to stone
Plants are fossilized as well as animal remains. Entire tree trunks can be turned to stone (a process known as petrification), which preserves the cell structure of the timber.

Bone to mineral
As the sediment layers get deeper, dissolved minerals turn them into solid rocks such as chalk and shale. The minerals seep into the buried bones, slowly turning them to stone.

Leaving an impression
Sometimes an organism, such as this marine animal *Dickinsonia*, sinks into soft mud that turns to rock, but then dissolves to leave an impression of its shape called a mold.

Surface erosion
A river changing its course cuts away the pale chalk rock, exposing the frozen body of the mammoth.

Excavation
Long after the end of the ice age, more erosion cuts into the dark shale and reveals the dinosaur fossil. Scientists known as palaeontologists begin a careful excavation.

Dolphins
New life forms inhabit the oceans.

Buried in ice
A mammoth dies and is buried in the frozen ground.

Roaming mammoth
Mammoths were common on the northern grasslands during the last ice age.

Well preserved
Thousands of years later, the deep-frozen mammoth is amazingly well preserved with hair, vital organs, and even its last meal.

Erosion exposes the mass of ice containing the mammoth’s body.

Reconstruction
A well-preserved, fossilized skeleton can be put back together to show what the animal was like. Scientists can also use computers to model its muscles and other organs, and work out how it moved.

Exposed fossil
Palaeontologist

Ice age
Closer to our own time, an ice age turns so much water to ice that sea level falls. Mammoths roaming the half-frozen tundra occasionally stumble into swamps, die, and freeze solid.

Surface erosion
A river changing its course cuts away the pale chalk rock, exposing the frozen body of the mammoth. But the skeleton of the *Tyrannosaurus* is still hidden deep below ground.
LIFE ON EARTH

There is life almost everywhere on Earth, but some regions have many more species than others. Such areas are known as biodiversity hotspots. The warm tropics are the richest—especially tropical rainforests and tropical coral reefs. These habitats offer many ways in which organisms can survive, encouraging the evolution of different types of life.

Key
- Major biodiversity hotspots
- North America
- South America
- Europe
- Africa
- Asia
- Australasia

How many?

Compared to plants, fungi, and protists, the animal kingdom has the largest total number of named species. Bacteria and archaea numbers run into millions and are impossible to estimate.

How many?

<table>
<thead>
<tr>
<th>Life Form</th>
<th>Estimated Number of Species</th>
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<tbody>
<tr>
<td>Plants</td>
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<tr>
<td>Animals</td>
<td>1,367,555</td>
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<td>Fungi and protists</td>
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Scientists estimate that there could be up to 8.7 million undiscovered species of animals.

Classification of life

Each of the six kingdoms of life is divided into several phyla of similar organisms. These are split into classes, orders, and families. Within each family there are usually groups of closely related organisms, each called a genus. This normally contains several individual species.

Classifying a tiger

The scientific name of an organism is made up of its genus and species. The tiger is in the genus Panthera, so its scientific name is Panthera tigris.

**Kingdoms**

- **Animals**
- **Plants**
- **Fungi and protists**

**Classification of animals**

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<th>Kingdom</th>
<th>Phylum</th>
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<th>Order</th>
<th>Family</th>
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ESSENTIALS FOR LIFE
All living things share certain basic needs. They must have water, for without it the chemistry of life is not possible. The fact that Earth has liquid water on its surface is the main reason why life evolved on this planet.

Living requirements
While all living things need the same essentials, many have more specific requirements. For example, plants and animals get their energy in very different ways—plants need sunlight, while animals need energy-rich food. But few forms of life can manage without most of these basic necessities.

Energy pyramid
Most natural habitats have many organisms that produce food, and several levels of food consumers. This patch of wild grassland supports several rabbits, which are primary consumers, fewer weasels that prey on the rabbits, and only one fox—the top predator. There are fewer consumers at the upper levels, because at each level some energy is turned into activity and heat instead of food for the next link in the chain. This means that it takes a lot of grass to support one fox, and explains why foxes are much rarer than rabbits.

UNDER THREAT
In every kingdom of life there are species that are threatened with extinction. There are many reasons for this, but most of them are the result of human activity. Some animals are deliberately killed, including rare species. Vast areas of wild habitat have been destroyed, denying wildlife its basic needs such as living space and food. But creating wildlife reserves can help save many species.

Food chain
All living things need energy. Plants and some other organisms gather energy from sunlight and use it to make sugar. Animals eat the plants and turn the sugar back into energy and body tissues. Other animals eat the plant-eaters, so the energy—along with vital nutrients—passes down a food chain. But eventually, the energy and nutrients are turned into a form that can be recycled by plants.

Plants
The destruction of habitats such as tropical rainforests is threatening the amazing diversity of plant life.

Fish
Although fish are not as threatened as some animals, pollution and overfishing have made many species scarce.

Amphibians
Hardest hit of all are the frogs, salamanders, and other amphibians, with a third of all known species vanishing fast.

Reptiles
Recent research shows that more than a fifth of the reptile species living worldwide are under serious threat.

Birds
Hunting and loss of their natural habitats have made the future uncertain for at least 12 percent of bird species.

Mammals
One in every five mammal species is threatened, including giants such as rhinos and elephants.
Plant life
From creeping mosses to majestic trees, there are plants growing all around us. They create most of the food that supports animal life on land. They also produce most of the oxygen that is in the air we breathe.

Plants are multicelled living things that mostly grow on land or in fresh water. Nearly all plants use the energy of sunlight to turn water and carbon dioxide into oxygen and sugar—a process called photosynthesis. They use the sugar to make the complex materials that form their roots, stems, and leaves. The most primitive types of plants can only grow close to the ground in damp places, but others grow tall and broad, covering the land with green vegetation that provides living space and vital food for animals.

Vital water
All plants need water. Most plants soak it up from the ground, then draw it up through their stems and use it to make sugar. Water pressure inside a soft-stemmed plant holds it up, so if it runs out of water, the plant wilts and collapses. But many plants have strong, woody stems that do not wilt, and their strength allows the biggest trees to spread their leaves high above ground level.

Types of plants
There are two main groups of plants. Nonvascular plants, such as mosses, were the first plants to evolve. Unlike vascular plants, they do not have internal vein systems that allow water and sap to flow all around the plant.

Nonvascular
- Mosses absorb water directly into their leaves, so mosses live in wet places where they will not dry out. They cling to rocks and trees with rootlike fibers, forming cushions that soak up water like sponges.

Vascular
- Most plants absorb water through their roots, which are connected to the rest of the plant by a network of veins called the vascular system. This allows trees to grow high above the damp ground.

Flowering plants
Primitive plants, such as mosses and ferns, do not have flowers or seeds. These nonflowering plants are now far outnumbered by flowering plants, which evolved during the dinosaur era around 200 million years ago. Flowers produce pollen, which is carried to other flowers of the same species, fertilizing them so they form seeds.

Wind pollination
Some flowering plants such as grasses and many trees produce a lot of pollen that blows away on the wind. Some of it may land on plants of the same species, and pollinate (fertilize) their flowers. These plants have small, plain flowers.

Animal pollination
Many plants have colorful, often fragrant flowers that contain sugary nectar. The nectar attracts hungry animals, such as hummingbirds, bats, or insects. As they drink the nectar, the animals get dusted with pollen, which they then carry directly to other flowers as they search for more nectar.
How plants grow

When the seed of a flowering plant is warm and moist enough, it sprouts and starts to grow into a seedling plant. A root pushes down into the soil to draw up water that fuels the growth of a stem. In many plants, the stem carries two leaves formed from the two halves of the seed.

1 Germination
A seed has a tough skin that protects it for many months or even years. But eventually, moisture makes the seed swell and split open.

2 Roots
The seed sprouts a root that grows downward. Fine hairs on the root absorb water and dissolved minerals from the soil.

3 Stem
A loop at the top of the shoot pushes up, pulling the two halves of the seed into the light. They become the plant’s first pair of leaves.

Life cycle

Some plants live for many years, flowering every year. They are called perennials. Others, called annuals, live for one growing season and produce tough-skinned seeds that survive the hard times. Many of these short-lived plants grow in places that have very cold winters or scorching summers. Biennials live for two growing seasons, surviving the cold or dry season as energy-packed roots.

Extraordinary plants

Most plants get nearly all their essential nutrients from the soil, stay rooted in one place, and harness the energy of sunlight to make food. But a few plants have evolved other ways of living in places where ordinary plants might struggle to survive.

Venus flytrap
This amazing plant traps insects and digests them. Nutrients from the insect allow the plant to live in places where the soil is poor. When the plant finishes its meal a week later, the leaf opens up again to trap another insect.

Evergreen or deciduous

Many tropical plants grow all year round. But other plants must cope with cold winters that stop their growth and could kill them. Some survive by being very tough, but others have evolved ways of shutting down until the warm weather returns.

Evergreen trees
Many conifers, such as these firs, have tough, needle-shaped leaves that can survive freezing. They stay green all winter, so they are always ready to soak up solar energy and make food.

Deciduous trees
Oaks and similar trees have thin, very efficient leaves that make all the food that the tree needs in summer. In winter, the leaves fall off and new ones grow in spring.

Ferocactus
During floods, the cactus’s hooked spines catch on floating debris that carries the plant to new places.

Thyme broomrape
This plant cannot make its own food. It lives by attaching its roots to thyme plants and stealing their sap.

Biennial
Some plants have a two-year life cycle. A carrot seed grows and produces leaves that make food. It stores the food in a thick, juicy root that survives the cold winter. In spring, the root produces flowers that scatter seeds.

Perennial
These plants survive for many years, but may lose their leaves in cold or dry seasons. A mature oak tree produces flowers and seeds during each growing season, and the seeds grow into new young trees.
Green energy

Animals must find food, but green plants make their own using energy from sunlight to turn carbon dioxide and water into sugar. This process is called photosynthesis.

A plant’s leaves act like solar panels. They soak up solar energy to fuel a chemical reaction that combines carbon, hydrogen, and oxygen to form glucose—a type of sugar. This reaction also releases oxygen into the air. The plant uses the glucose to make cellulose (plant fiber), and combines it with nutrients from the ground to make proteins that are used for growth.

Cross section through a leaf

Inside a leaf are thousands of microscopic cells that act as food factories. Each cell contains tiny structures called chloroplasts that are filled with green chlorophyll—a chemical that absorbs sunlight and turns it into the chemical energy needed for photosynthesis. Other cells form the skin of the leaf, while a network of transport vessels supply the leaf with water and carry away sugar in the form of sugary liquid sap.
Plants only look green because of the green chlorophyll in their cells.

There are up to 500,000 chloroplasts in every square millimeter of leaf.

Protective cuticle
A coating of transparent wax forms a waterproof layer on the upper side of the leaf.

Upper epidermis
A thin layer of cells forms the upper skin. The cells produce the waxy cuticle that controls water loss by evaporation.

Palisade cell
These tall, cylindrical cells are the main food producers of the leaf. Each palisade cell is packed with chloroplasts that absorb solar energy and use it to make sugar.

Chloroplast
Small green structures called chloroplasts turn sunlight into chemical energy and use this to split water into hydrogen and oxygen. Then they combine the hydrogen with carbon dioxide to form glucose—the plant’s food.

Vein
The veins transport liquids to all parts of the plant. Each vein is a bundle of tubular fibers made up of chains of long, hollow cells with walls of tough cellulose.

Lower epidermis
The skin and waxy cuticle of the underside is thinner because it does not face the Sun.

Xylem vessel
Some of the tubes within veins draw water up from the roots of the plant. This root sap contains the dissolved minerals that the plant needs to make proteins.

Phloem vessel
Sugar made in the leaves is dissolved in water and carried to other parts of the plant through the phloem vessels.

Water pathway
In daylight, the stomata in a plant’s leaves open up and allow water vapor to escape. The water vapor is replaced by water drawn up through the xylem vessels from the plant stem and roots. This draws more water up from the soil, along with the dissolved minerals that the plant needs to build its tissues. This process is called transpiration.

Oxygen factory
Photosynthesis by plants creates most of the food on Earth and nearly all the oxygen that we breathe. In a single year, one mature tree releases enough oxygen to support ten people.

Nearly 40 percent of the world’s oxygen is produced in the tropical rainforests.
INVERTEBRATES

Most of the animals that live around us on land and in the oceans are invertebrates—animals that do not have backbones and jointed internal skeletons like ours. Many have tough external skeletons, while others have hard shells. But many more have soft, muscular bodies with no hard skeletal parts at all.

Outnumbered

Most of the biggest, most visible animals on Earth are vertebrates, including humans. But the total number of vertebrate species is surprisingly tiny compared to the amazing diversity of invertebrate species.

Amazing Variety

Invertebrates come in every imaginable shape and size, from microscopic worms to giant squid. Some are familiar, like the insects that buzz around our homes, while others can seem like creatures from another planet.

Invertebrate groups

The animal kingdom is divided into 35 major groups, each called a phylum, and each phylum is divided into classes. The vertebrates make up just one phylum. Here are a few of the many phyla and classes of invertebrates.

1. Sponges
   - 10,000 species
   - They may look like plants but sponges are the simplest animals of all—they don’t even have a nervous system.

2. Cnidarians
   - 11,000 species
   - Sea anemones, jellyfish, and corals like this one are all aquatic animals armed with stinging tentacles, which they use to catch prey.

3. Echinoderms
   - 7,000 species
   - Meaning “spiny skin,” echinoderms include starfish, sea urchins, and sea cucumbers.

4. Mollusks
   - 110,000 species
   - The clams, snails, and cephalopods (octopuses and relatives) form the second-largest group.

5. Annelid Worms
   - 20,000 species
   - This earthworm belongs to one of several groups of soft-bodied animals that we call worms.

6. Arachnids
   - 103,000 species
   - Venomous scorpions, spiders, and their relatives form a class of land-living arthropods.

7. Crustaceans
   - 70,000 species
   - Crabs and other armored sea creatures with jointed legs are the most familiar crustaceans.

8. Insects
   - 1.1 million species
   - This huge arthropod group outnumbers all the other animal species put together.

9. Ctenophores
   - 200 species
   - The comb jellies and their relatives are very simple animals that drift with the ocean currents.

10. Echinoderms
    - 7,000 species
    - Meaning “spiny skin,” echinoderms include starfish, sea urchins, and sea cucumbers.

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Arthropods

The biggest invertebrate group consists of the arthropods. They include the insects, spiders and scorpions, and crustaceans. Adult arthropods have tough, jointed external skeletons or exoskeletons, several pairs of jointed legs, and—in the case of insects—wings.

Success Story

Arthropods account for more than 80 percent of all known animal species. They are the most successful animals on Earth, conquering land, sea, and air. Scientists discover about 25 new arthropod species every day, and there are countless more waiting to be discovered.

Inside Out

The tough exoskeleton of an adult arthropod is made of chitin, which is similar to the substance that forms your fingernails. In some marine crustaceans such as this lobster, the chitin is reinforced with chalky minerals. Its exoskeleton is a series of rigid segments that enclose the animal’s soft tissues. These are linked by thinner, flexible sections, forming joints that allow the animal’s body and legs to move.

Tight Fit

A hard exoskeleton cannot stretch, so as an arthropod grows it has to shed its old, tight exoskeleton and develop a bigger one. When it does this, it emerges with a soft skin that inflates to a larger size before it hardens. The complex life cycles of many arthropods mean that they often change shape as well as size when they molt.

Cicada Life Cycle

Like many insects, a cicada hatches from its egg as a wingless larva, or nymph, that eventually becomes a winged adult.
TAKING ROOT
Although many invertebrates live on land, the most diverse types live underwater. This has allowed some to evolve a completely different way of life, because instead of having to go in search of food, they can wait for food to drift their way, carried by the water. They don’t need legs or fins, and many never move at all. These invertebrates spend their entire adult lives rooted to one spot, more like plants than typical animals.

WONDERFUL FORMS
Many invertebrates such as insects have the familiar form of a head equipped with a brain and two eyes, attached to a body that has an equal number of legs and even wings on each side. But other invertebrates have a very different body plan.

Stars and suckers
An adult echinoderm such as a starfish has radial symmetry—its body parts are arranged like the spokes of a wheel. It has no head, and its mouth is in the middle of its body. An octopus or a squid has a strange body plan, with muscular, sucker-covered tentacles that sprout from its head and surround its mouth.

Fully armed
Found throughout the world’s oceans, octopuses are intelligent animals. They use their strong, suckered tentacles to grasp prey.

Protective shells
The soft bodies of many mollusks are protected by shells made from chalky minerals. Snails and similar animals have one shell, while bivalves such as clams have two.

As the animals grow, they add extra layers of minerals to their shells, so the shells grow too. They are often lined with a beautiful, iridescent layer called mother-of-pearl.

WONDERFUL FORMS
Many marine invertebrates that spend their lives rooted to one spot live together in large groups known as colonies. Often these are individual animals that settle in the same place because it is an ideal habitat. But other colonial invertebrates are linked to each other, like the twigs of a tree. They share the same body fluid circulation, but each has its own mouth and digestive system.

Mussel colony
These mussels have all settled on this rocky tidal shore because there is so much food for them to eat when they are submerged at high tide. They are not linked to each other—they just need the same conditions to survive.

Underwater garden
Reef corals grow in warm, clear sunlit water on shallow tropical shores, just below the low tide line.

Reef corals
Each head of coral on this reef is a colony of interlinked animals called coral polyps. They are like tiny sea anemones that feed for themselves, but together they form the distinctive structure of a particular coral species.

Drifting colonies
Some colonial invertebrates look like individual animals, such as the amazing Portuguese man-of-war. It looks like a jellyfish, but it is actually a collection of interconnected animals, each with its own function. One is the float, while others gather food, defend the colony, or produce young.

Stinging tentacles
The Portuguese man-of-war drifts on the ocean surface, trailing long venomous tentacles to ensnare its prey.
Insects

Both in terms of species and sheer numbers, insects outnumber all other animals on Earth. They are the most plentiful creatures on the planet.

More than a million different species of insects have been scientifically named and described, and thousands more are discovered every year. Thanks to their amazing adaptations, they flourish in every land habitat and play a key role in the global ecosystem, recycling dead plants and animals, pollinating flowering plants, and providing food for a host of bigger animals. In fact, insects are so vital to life on Earth that we could not survive without them.

Insect anatomy

Insects are the most numerous of the arthropods—animals with tough external skeletons and jointed legs. The bodies of all adult insects are divided into three sections—the head, thorax, and segmented abdomen. All adult insects have six legs, and most have one or two pairs of wings. But their young, or larvae, are much more variable.

Jaws

This wasp has biting jaws, or mandibles, that pinch together. They have hard, sharp edges that allow the wasp to cut and mash up its prey. Many insects have similar jaws, but the mouthparts of others are highly modified for soaking up liquids, sipping nectar, and even sucking blood.

Antennae

The long antennae are covered in nerve endings that detect chemical signals. Some insects can pick up scents from more than 1 mile (1.6 km) away.

Head

An insect’s head is a strong capsule containing its brain and carrying most of its sense organs. It swivels on a very mobile neck joint.

Claws

Each foot has sharp claws for clinging to surfaces and holding onto prey. Some insects such as blow flies also have sticky foot pads.

Thorax

The central section of an insect’s body is called the thorax. It carries the legs and wings, and in most insects it is packed with powerful wing muscles.

Waist

Wasps need to curl their tails forward to use their stingers, so they have narrow, flexible waists.

Legs

Each insect leg is made up of a series of stiff tubes, hinged together with flexible joints and operated by internal muscles.

Compound vision

The eyes of adult insects are made up of thousands of tiny lenses, each with its own set of light sensors. Every lens sees a dot of color, and the dots add up to form a mosaic image. The more lenses, the more detail the insects see. This system is very sensitive to movement.

Sensitive bristles

Many fine, touch-sensitive bristles on the insect’s body help to detect air movement.

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Wings
Most adult insects have wings. These are flat plates of chitin—the tough material that encases the body. They are powered by muscles inside the thorax.

Veins
A network of fine tubes called veins stiffens the wings so they can flex and twist in flight without collapsing under the strain.

Abdomen
The segmented, flexible abdomen contains most of an insect’s vital organs, such as its stomach.

Warning pattern
Vivid, contrasting stripes of black and yellow warn birds that this wasp has a stinger in its tail, and help the wasp stay out of trouble.

Painful sting
Most insects are harmless, but this wasp has a stinger that it uses to kill prey or defend itself and its nest.

Features
Adult insects are very variable in shape and size, but nearly all of them share a few key features.

Looking at insects
Insects have been classified into about 29 orders, and within each order the insects share the same features. Shown below are some of the major orders.

- **Dragonflies and damselflies**
  5,600 species
  Large eyes and wings, and slender bodies.

- **Beetles**
  370,000 species
  Toughened front wings that help protect the hind wings.

- **Butterflies and moths**
  165,000 species
  Nectar-feeding mouthparts, and overlapping scales on their bodies and wings.

- **Flies**
  150,000 species
  Single pair of functional wings, with small balancing organs called halteres.

- **Ants, bees, and wasps**
  198,000 species
  Have narrow waists and many live in colonies.

- **Crickets and grasshoppers**
  25,000 species
  Powerful hind legs and chewing mouthparts.

FOR EVERY HUMAN BEING ON THE PLANET THERE ARE 200 MILLION INSECTS.

The first winged insects appeared more than 350 million years ago.

A big dragonfly may have up to 30,000 tiny lenses in each eye.

The number of beats a second a midge flaps its wings.

The percentage of all known animal species that are insects—and almost half of them are beetles.
In Mexico, millions of monarch butterflies spend the winter in the same trees each year.

1. **Larva**
   The female butterfly lays her tiny pale green eggs on milkweed plants. Each egg is the size of a pinhead, with a beautifully sculpted shell. Several days later, the egg develops into a baby caterpillar that chews its way out, then eats the shell before it starts feeding on the leaf.

2. **Growing caterpillar**
   The caterpillar spends its days eating, growing bigger all the time, and shedding its skin five times. Toxins in the milkweed leaf become concentrated in its body as it eats, making it poisonous to birds.

3. **Firm grip**
   After about 14 days, the fully grown caterpillar crawls up a twig and attaches itself by its stumpy back legs, hanging from a pad of strong silk.

4. **New skin**
   A few hours after attaching itself to its twig, the caterpillar sheds its skin again—but this time the striped skin is pushed off to reveal a bright green chrysalis.

5. **Chrysalis**
   Eventually, the new chrysalis pushes its old skin right up to the top. After reattaching itself to its silk pad with a thin black stem, it wriggles until the old skin falls away.

6. **Metamorphosis**
   Once the chrysalis is free of its old skin it gets shorter, smoother, and its color changes to a duller green. Inside, its body is being completely rebuilt to become an adult butterfly.

7. **Taking shape**
   After nine or ten days, the chrysalis darkens as the skin of the butterfly’s body turns black. The vivid black and orange pattern of the wings also becomes visible.

From egg to butterfly

The metamorphosis from newly laid egg to adult monarch butterfly takes about a month. The egg hatches as a tiny caterpillar that eats voraciously for two weeks, bulking up its body until it is big enough for the pupa stage—the ten days that see it turned into a butterfly.
The number of butterfly species that live worldwide.

3,000 miles (4,800 km)—the distance that some monarchs migrate.

50 million—the number of years that butterflies have existed on Earth.

The number of days that a typical monarch butterfly lives as an adult. But the ones that migrate south may live for eight months.

An extraordinary journey
Monarch butterflies spend the winter asleep in the warm woods of Mexico and California. In spring, they wake up and fly north to find milkweed plants, which do not grow in the warm southwest. They lay their eggs and die. The next generation flies further north and does the same. After two more generations they reach the Canadian border. Then the fourth generation migrates all the way back south again—clear across the US.

Butterfly lifecycle

The beautiful monarch butterfly starts life as a wingless caterpillar that spends most of its time eating. Its metamorphosis into a butterfly is one of the most dramatic changes in nature.

Some insects hatch from their eggs as miniatures of their parents. As they grow they have to keep shedding their hard external skeletons, which is difficult and dangerous. But many insects, such as butterflies, moths, beetles, and flies, have evolved a better solution. They do all their growing during a stage of life called a larva—a sausage-shaped creature that can shed its skin easily. When the larva is fully grown, it enters a phase called a pupa, or chrysalis in butterflies. During this stage it is transformed into a winged adult.

Within two hours of emerging, the butterfly is ready for its first flight. It flexes its wings a few times before launching itself into the air. It will find some sweet nectar to drink, then start looking for a mate so it can breed and create a new generation of caterpillars.

**Butterfly lifecycle**

**Warning colors**
The adult still contains the poisons that it picked up as a caterpillar, and its bright colors warn birds of this.

**Antennae**
The long antennae are mainly for detecting scents such as the fragrance of nectar-rich flowers.

**Eyes**
Like other adult insects, a butterfly has compound eyes made up of many microscopic lenses.

**Scale-covered wings**
Tiny scales cover the wings like roof tiles. These give the wings their color.
VERTEBRATES

Most of the more obvious animals that live around us are vertebrates—animals with flexible backbones and internal skeletons. They are the mammals (which include humans), birds, reptiles, amphibians, and three types of fish. Compared to the immense diversity of animal life in general, there are relatively few species of vertebrates, but they include the biggest animals now living on land and in the oceans, as well as the largest that have ever lived—the giant dinosaurs.

BODY PLAN

Apart from a few primitive jawless fish, all vertebrates have flexible spines made of chains of small bones called vertebrae. They also have strong skulls. Fish have other skeletal elements that support their gills and stiffen their fins. All other vertebrates—even snakes and whales—have evolved from ancestors that were the first four-legged land vertebrates, or tetrapods.

Tetrapods

Modern lungfish and coelacanths belong to an ancient group of fish equipped with four fleshy fins supported by strong bones. About 380 million years ago, some of these lobe-finned fish were living in freshwater swamps, where they started using their fins as legs. Eventually, they crawled right out of the water to become the earliest amphibians.

Eusthenopteron

This lobe-finned fish had muscular, limblike fins.

Tiktaalik

Stronger fins allowed Tiktaalik to climb out of the water.

Acanthostega

This was probably the first vertebrate animal to have feet and toes.

In the lineup

Apart from whales, the largest living vertebrates include the sharks, elephants, hippos, giraffes, bears, and big cats. But these animals would have been dwarfed by some of the dinosaurs that lived in the distant past.

SUPER-SIZED ANIMALS

All the biggest animals that have ever lived are, or were, vertebrates. This is largely because the strong internal skeleton allows a very heavy creature to support its own weight. Some extinct dinosaurs such as Argentinosaurus were probably as heavy as is possible for a land animal. The only known vertebrate that weighs more is the blue whale, which relies on the water for support.

Diplodocus

One of the largest dinosaurs, this 115 ft (35 m) giant was a plant eater. It lived during the Jurassic Period, about 150 million years ago.

Blue Whale

This is probably the heaviest animal that has ever existed—weighing anything up to 170 tons. Its heart alone is the size of a small car.

Whale Shark

This is the biggest fish in the sea, growing to 39 ft (12 m) long. Although a shark, it feeds on tiny shrimplike creatures and small fish.

Giraffe

Its incredibly long neck gives the giraffe a total height of up to 20 ft (6 m). It towers above all other animals—even elephants.
**Internal skeletons**

The body of a fish such as a shark is supported by the water, so it does not need a weight-bearing skeleton. Its main function is to protect and support delicate organs like the brain and gills, and anchor the muscles. But the skeleton of a land vertebrate such as a dog has to support the weight of the animal, so its bones—especially its leg bones—must be much stronger than those of a fish.

**Shark**
- A shark does not need to support its weight with its fins, so it can have a skeleton of flexible cartilage—the material that stiffens our ears. The "bones" of some fins are not even attached to its spine.

**Dog**
- All the bones of a dog's body are linked to form a strong, weight-bearing skeleton. Other bones protect the dog's vital organs.

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**DIPLODOCUS REMAINS**

*Indicate that it was up to 118 ft (36 m) long—this is the length of three school buses.*

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**AFRICAN ELEPHANT**
- A big male African elephant can weigh 11 tons, making it the largest living land animal— but smaller than many dinosaurs.

**POLAR BEAR**
- The massively built polar bear can kill a seal with a swipe of its paw.

**HIPPOPOTAMUS**
- One of the largest and heaviest land mammals, the hippo can weigh up to 3 tons. Its closest living relatives are whales.

**TIGER**
- The biggest of all cats, the tiger can grow to 11 ft (3.3 m) long from head to tail. It is a formidable predator, but now very rare.
Fish

The first vertebrates, or animals with backbones, to evolve were fish. They now make up about half of all vertebrate species, and include many of the most spectacular animals on the planet.

Fish are vertebrates that have always lived underwater, since the evolution of their earliest ancestors around 530 million years ago. Other vertebrates, including whales and seals, also live in the water, but they must breathe air and they have many other features that show their ancestors were land animals. By contrast, a fish's skeleton, internal organs, gills, skin, muscles, and senses are specialized for aquatic life, and they are amazingly efficient.

Key features

Although fish vary greatly in their size, shape, and habits—and even in their basic biology Nearly all species of fish share some key features.

Types of fish

The term "fish" covers three groups of very different, unrelated animals that share the same aquatic habitat and have many of the same adaptations to it. These are the few surviving species of jawless fish, the bony fish such as tuna (which form by far the biggest group), and the cartilaginous fish such as sharks.

Jawless fish

The earliest fish to evolve had muscular mouths with no jawbones. There were many types, but today the jawless fish are reduced to around 43 species of lampreys, which have suckerlike mouths lined with rasping teeth.

Bony fish

There are at least 32,300 species of fish with skeletons made of hard bone. They include a wide range of body forms—such as eels, flatfish, and seahorses—but most have the streamlined shape of this bluefin tuna.

Cartilaginous fish

The 1,200 species of sharks, rays, and chimaeras have skeletons made of flexible cartilage—the same kind of tissue that supports our ears. Many sharks, including this shortfin mako, are highly efficient predators.

Inside a fish

Almost all fish spend their entire lives underwater and extract vital oxygen from the water using gills. Their bodies are supported by the water, so the main function of their muscles and skeleton is movement. Their fins help them swim and steer, and the bodies of typical fish are streamlined so that they use as little energy as possible as they move through the water.

Swim bladder

A bony fish has a gas-filled swim bladder that acts as a float. The fish can rise or sink in the water by adding or removing gas. Sharks and other cartilaginous fish do not have a swim bladder.

Eyes

These are specially adapted to suit the way light passes through water.

Gills

Blood flowing through the delicate, thin-walled gills absorbs oxygen from the water and discards carbon dioxide as waste. Water flows into the fish's mouth, then through the gills and out through a flap or slits at the back of the head.

Pelvic fins

This type of fish has two sets of paired fins—pectoral fins near the gills (not shown) and pelvic fins midway along the body. The fish uses them for steering.
How fish swim
Typical fish swim by flexing their bodies in a series of waves that push against the water. Long-bodied eels wriggle like snakes, but with other fish most of the movement is near the tail. Rays use a different method, “flying” through the water with their winglike pectoral fins. Many small fish swim with their body fins, using them like oars.

S-shaped swimmers
Most fish propel themselves through the water by using their big flank muscles to flex their bodies into “S” shapes. The tail fin makes their swimming more efficient.

Tail fins
Fish tails come in many shapes and sizes. Most sharks have tails with extra-long upper lobes that act as extensions of their flexing bodies. The tail of a typical bony fish, such as a trout, is a symmetrical fan. Tuna and some other fast-swimming fish have tall, narrow, crescent-shaped tails, while the tails of ambush hunters, such as pike, are much broader.

Eggs and young
Most fish lay hundreds, thousands, or even millions of eggs, spilling them into open water where they drift on the currents. But others lay fewer eggs in secure nests, or even keep them in their bodies. Some fish, including many sharks, give birth to fully formed young.

Safe nursery
After fertilizing the eggs laid by the female, the male gold-specs jawfish gathers them into his mouth and keeps them there until they hatch. This protects the eggs from animals that would otherwise eat them.

Ready to go
Some sharks lay eggs that are secured to coral or seaweed, and the young continue to develop inside their tough-skinned protective egg cases. Others give birth to live young that are already fully developed, such as this lemon shark.
Great white shark

The most terrifying predator on the planet, the great white shark combines almost supernatural senses with a set of teeth that can slice through prey like a chainsaw.

Most sharks are efficient hunters, but the great white is in a class of its own. It is much bigger than any other killer shark and far more powerful. The great white’s super-efficient propulsion system drives it through the water at shattering speed as it charges in for the attack, and its array of senses enable the shark to target its prey in complete darkness with deadly accuracy. The shark’s broad, razor-edged teeth are specially adapted for butchering large prey, rather than simply swallowing small victims whole. Even a single bite can be lethal.

Built for speed

A typical shark swims by flexing the whole rear part of its body, but the great white is different. Its body stays rigid like a torpedo, while its massive flank muscles drive rapid, powerful strokes of its tail fin—a far more efficient system. Its body is the ideal shape for slicing through the water at high speed—broad in the middle and pointed at each end—and this gives it the ability to overtake virtually any other fish in the sea.
Vision
The shark’s eyes have internal reflectors like a cat’s eyes, increasing their sensitivity to make the most of dim underwater light.

Special sense
All the shark’s senses are highly tuned. Most amazing of all is its ability to detect the minute electrical impulses generated by the muscles of other animals. It picks these up with a network of sensors in pores on its snout called the ampullae of Lorenzini—first described by Italian physician Stefano Lorenzini in 1678.

Heart
This is heavier than the heart of a typical shark, with thicker muscle to pump blood around the body more efficiently.

Pectoral fins
The long pectoral fins help with stability and act like wings as the shark swims forward, stopping it from sinking.

Gill arches
Five gill arches on each side support and protect the delicate gills that absorb vital oxygen from the water and release waste carbon dioxide.

Nostrils
Just below the snout are the super-sensitive nostrils that enable the great white to detect a single drop of blood floating in 10 billion drops of water.

Serrated teeth
Each triangular tooth has a serrated knife edge, ideal for shearing through the tough skin, flesh, and bone of the shark’s favorite prey—warm-blooded marine mammals such as seals. The great white has up to seven rows of teeth.

Lethal jaws
The shark’s upper jawbone is only loosely attached to its skull. When it opens its mouth, ready to bite, the jaw pushes forward while the snout bends up out of the way to ensure that it gets a good grip. As its jaws snap shut, the shark jerks its head sideways so its teeth rip through its victim like a saw, slicing out a great mouthful of flesh.

Fact file
Length .................................... Up to 23 ft (7 m)
Top speed .............................. 32 mph (50 kph)
Lifespan .............................. Over 30 years
Prey ................................. Fish, turtles, and sea mammals

A GREAT WHITE SHARK SOMETIMES RAISES ITS HEAD OUT OF THE WATER TO LOOK AROUND FOR LIKELY PREY.
Amphibians

Amphibians are best known for the way that many species spend part of their lives in water and part on land. Indeed, the word amphibian means “double life.”

Early amphibians were the first vertebrates (animals with backbones) to live on land. They evolved from fish that had developed the ability to breathe air, and they have retained a few key features of their aquatic ancestors. In particular, amphibian eggs do not have tough shells to stop them from drying out, so they usually have to be laid in water. The eggs hatch as aquatic larvae, which eventually turn into air-breathing adults.

Types of amphibians

There are three groups of amphibians. The biggest and most familiar group consists of the frogs and toads, which have long hind legs specialized for leaping. The second group includes the salamanders and newts, with their long tails and short legs. The third consists of the legless, burrowing caecilians.

Frogs and toads
5,900 species
Tailless, long-legged frogs and toads live in water, on the ground, and in trees. Most frogs have smoother, shinier skin than toads, but there is no scientific difference between them.

Salamanders and newts
585 species
With their long tails and short legs, there is no real difference between newts and salamanders. Many live entirely on land, while others migrate to water to breed. A few live entirely in water.

Caecilians
190 species
Most of these tropical animals spend their lives under the ground. Legless and almost blind, they have strong skulls to push through soil, and tough skin to protect their bodies from sharp stones.

Key features

Amphibians have evolved an amazing variety of adaptations to help them survive on land, making them the most diverse group of land vertebrates. Despite this, nearly all amphibians share some key features that have a big influence on their way of life.

Evolution

Amphibians evolved from a group of fish with fleshy, leglike fins. These included the ancestors of modern, air-breathing lungfish. Around 380 million years ago, some of these lobe-finned fish began hunting small animals on land. Their descendants have changed into the modern amphibians of today.

Early amphibian

There were many types of amphibians in existence 280 million years ago, including this species, Diplocaulus—a four-legged, newtlike animal with a flattened head.

What’s inside?

All amphibians are basically four-limbed (tetrapod) vertebrates but, like other animals, they have evolved many different body forms. Salamanders and newts still have the long-tailed, short-legged form of their distant ancestors, but the legless caecilians and leaping frogs are much more specialized.

Efficient body plan

Almost 90 percent of amphibian species are frogs and toads, with short backs and long hind legs for leaping and swimming. Their heads are also very big, as this American bullfrog skeleton shows.
Colors and markings
Nearly all amphibians have poison glands in their skin, which is mostly foul-tasting to predators but sometimes lethal. Many species advertise this with vivid colors that warn their enemies to leave them alone. The color and markings of some amphibians act as camouflage, making the animals hard to see. Others change color with the seasons, becoming brighter when they are ready to breed.

Fire salamander
The dramatic color pattern of the fire salamander is a warning that its skin produces a dangerous poison.

Horned frog
The amazing camouflage of this tropical frog makes it look just like a dead leaf on the forest floor.

Common newts
When these newts are ready to breed, both the male and female develop glowing orange bellies.

Vital oxygen
Like all animals, amphibians need to breathe by taking in oxygen and expelling waste carbon dioxide. The young of many amphibians live in water, and use fishlike gills to take in oxygen. Some aquatic amphibians retain these gills throughout their adult lives, but most species develop lungs for breathing air. Amphibians can also exchange gases through their very thin, moist skin.

By breathing through its skin, the common frog can spend the entire winter asleep underwater.

Cannibal carnivores
All adult amphibians are hunters that catch and eat animals. Apart from caecilians, amphibians hunt mainly by sight, using their big eyes to watch for moving prey. Most eat insects, spiders, slugs, and other small animals, but the biggest frogs may eat small reptiles and mammals. They also eat other amphibians, including smaller frogs of their own species.

157 in (400 cm)—the distance an Australian rocket frog can cover in one leap. This is more than 80 times the length of its body, which is just 2 in (5 cm).

Leaping
Many frogs can make dramatic leaps to escape danger or catch prey. The powerful muscles of their elongated hind legs contract to propel them into the air with explosive force.
A female common frog may lay up to 2,000 eggs in the spring.

Frog lifecycle
Most amphibians begin life looking quite unlike their parents. Over time, they change shape until they reach their adult form—a process called metamorphosis.

In early spring, common frogs emerge from their winter sleep and return to the shallow pools where they began their own lives. The females lay their eggs in the water, where they are fertilized by the males and start to develop into embryos. Eventually, these hatch as tadpoles—tiny legless creatures that live underwater like fish. They feed and grow before sprouting legs and becoming more froglike. Then their tails shrink away and they climb out of the water into a new life.

Frogspawn
Frog eggs are very like those of fish. They must stay moist, so common frogs lay them in water, in clumps that are called frogspawn. Each female waits until she has a male partner, who clings to her back as she lays her eggs and immediately fertilizes them in the water. Then the pair swim off and leave the eggs to their fate.

Tiny tadpoles
When they hatch, the tadpoles are tiny black ribbons of life that cling to the waterweed. But they soon develop obvious heads and wriggling tails, and start swimming. At first, each has a pair of feathery gills, but these become hidden beneath protective flaps. They feed by scraping microscopic edible algae from rocks and plants.

Back legs develop
As the tadpoles feed, they get fatter and much bigger. At about five weeks old, a tadpole’s body is as big as a small bean, and it grows a pair of back legs. At first, these are too small and weak to be useful, so the tadpole continues on using its powerful tail for swimming. It still feeds mainly on algae, but will eat other scraps.

Changing shape
A tadpole passes through several different stages before it turns into a baby frog, and its way of life is transformed in the process. Week by week an aquatic vegetarian turns into an air-breathing hunter that lives mainly on land.

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By about 12 weeks old, the tadpoles have stopped feeding and start to change shape. Front legs grow and its plump body slims down to a more bony form with a pointed head and a broad mouth. It still swims with its tail, but spends more time clinging to rocks and plants, breathing air with its nose out of the water.

Soon after its body changes shape, the tadpole’s tail begins to shrivel up. It starts swimming using its back legs, and is soon able to hop. It has turned into a tiny froglet, no bigger than your fingernail. Now ready to hunt on land for small animals such as flies, the froglet climbs out of the water and finds a safe place to hide.

Life is very hazardous for the little froglets since they have many enemies. The survivors become breeding adults in their third year, and may grow to 4 in (10 cm) long. They often stay in the water by day, hunting on land at night when there is less risk of drying out. They eat any small animals they can catch with their sticky tongues.
Reptiles

With their scaly skins, reptiles seem like relics of a prehistoric age. However, many reptiles are not as primitive as we often think.

Modern reptiles are cold-blooded animals that evolved from amphibians, the first vertebrates to live on land. Reptiles were able to conquer dry land more effectively than amphibians because their tough, waterproof skins stop their bodies from losing vital moisture. They also do not need to find damp places to breed. This allows reptiles to live in some of the hottest, driest habitats on Earth, but very few reptiles can survive in cold places.

Key features
All surviving groups of reptiles share a few key features. The prehistoric dinosaurs were also reptiles, but different because many were warm-blooded.

Family Tree
The earliest reptiles evolved more than 310 million years ago, during the Carboniferous Period of Earth’s long history. They were four-legged, cold-blooded creatures that resembled modern lizards. But over time, the reptiles split into different groups. One group gave rise to the crocodilians, dinosaurs, and extinct pterosaurs. The other surviving groups consist of the turtles, tuataras, lizards, and snakes.

Turtles and tortoises
317 species
These animals evolved at about the same time as the first dinosaurs, but in a very different way. Their strong shells provide protection but weigh them down so much that tortoises can only move very slowly. Supported by water, turtles do not have this problem, and many are graceful swimmers.

Crocodilians
24 species
The most powerful modern reptiles are the crocodiles, alligators, gharials, and caimans—large armored predators adapted for hunting in shallow water. They are the nearest modern equivalent to dinosaurs like Tyrannosaurus, but their way of life is very different.

Snakes
3,000 species
Snakes evolved from lizards, losing their limbs and developing a specialized jaw arrangement for swallowing their prey whole. Some snakes also have a venomous bite.

Tuataras
2 species
These primitive, lizardlike reptiles belong to a group that flourished 200 million years ago, but which became virtually extinct long before the dinosaurs disappeared. Just two tuatara species survive in New Zealand, where they now live on a few small islands.

Lizards
4,500 species
The biggest group of reptiles includes a wide variety of creatures ranging from tiny geckos to the colossal Komodo dragon. Most have four legs and long tails, but some are legless. Although they generally prey on smaller animals, a few, such as the iguana, are plant-eaters.

Birds
The big dinosaurs became extinct 66 million years ago, but one group of small, feathered, warm-blooded dinosaurs survived—the ancestors of modern birds. Although their closest living relatives are the very reptilian crocodiles and alligators, birds are classified in a group of their own.

This highly venomous coral snake is found in the southeastern US.

Tuataras have been saved from likely extinction by careful conservation.

The American alligator is one of the largest living crocodilians.

The green iguana is a typical four-legged, long-tailed lizard.

With its huge paddlelike flippers, the green sea turtle swims vast distances to reach the remote beaches where it lays its eggs.
Reptile senses

Many reptiles have acute senses, especially hunters such as crocodiles and big monitor lizards. Chameleons have excellent eyesight, with eyes that can move independently to watch for danger or target prey. Snakes hunt by scent, which they gather with their forked tongues. They have no true ears, but are sensitive to vibrations passing through the ground.

Waterproof eggs

Unlike the eggs of their amphibian ancestors, reptile eggs have waterproof shells so that they do not dry out. This helps reptiles thrive in dry places, such as deserts. But the eggs need warmth to develop, so some reptiles that live in cooler climates give birth to fully formed young.

1 Egg

Just like birds' eggs, reptile eggs must be kept warm or they will not hatch. Reptiles ensure this by laying them in warm places, such as heaps of green vegetation that heat up as they decay.

2 Hatching

When the baby reptile inside the egg is ready to hatch, it slits the leathery shell open with a sharp, thornlike egg tooth on the end of its snout and pokes its head out to take its first breath of air.

3 Baby snake

Once the baby is able to breathe, it often rests inside the egg for several hours before fully emerging. This baby snake has finally decided to make a move and explore its new world.

Scaly skin

All reptiles have a tough outer skin made up of thickened scales linked by thin, flexible hinges. Together, the scales and hinges form a continuous sheet. Reptiles shed this outer skin layer throughout their lives, so any damaged or infected skin is discarded and replaced.

Crocodile

The skin of a crocodile or alligator has plates of bone buried deep within it. These bony plates strengthen the scales and help prevent the animal from getting injured by kicking, struggling prey.

Snake

Many snakes have vividly patterned skin. The color lies deep in the skin, and the outer skin layer is transparent. Snakes shed their outer skin layer in one piece, including the scales that cover their eyes.

Lizard

The scales of lizards vary greatly. Some species have small, smooth scales while others have big, sharp-edged plates. Unlike snakes, lizards shed their outer skin in large pieces.

Cold-blooded creatures

Reptiles rely on their habitats to provide the warmth that their bodies need to function. Since they do not turn energy into body heat, they can survive on far less food than mammals. However, reptiles may have to spend hours basking in the Sun to warm up in the morning, and they often have to seek shade in the middle of the day to keep themselves from overheating. The graph below shows the activity pattern of a lizard.
**Super-strong jaws**
Powered by massive cheek muscles, the crocodile's jaws snap shut with colossal force, giving its victim no chance of escape.

**Nostrils**
High-set nostrils allow the crocodile to breathe when most of its snout is submerged—a flap seals its windpipe when it opens its mouth underwater.

**Pointed snout**
Crocodiles have narrow, pointed snouts, and their upper and lower jaws are the same width.

**Night vision**
A crocodile has eyes like a cat, with big pupils that close to vertical slits in sunlight, but open wide to increase sensitivity at night. They also reflect light like cats' eyes. An extra transparent eyelid flips across each eye to protect it when submerged, but this keeps it from focusing properly underwater.

**Scaly skin**
As with other reptiles, the crocodile's skin is covered by tough, waterproof scales made of keratin—the same material that forms your fingernails.

**Webbed feet**
The toes have strong claws, and are partly webbed so that the crocodile can use its feet to maneuver underwater.

**Interlocking teeth**
A saltwater crocodile has 64 to 68 stout, pointed teeth that overlap each other when it closes its mouth. New teeth grow inside the old ones, and replace them as they wear out.

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**Crocodile**

Crocodiles are survivors from the age of dinosaurs—powerful, heavily armed reptiles that can devour any animal they seize in their fearsome jaws.

Crocodiles, alligators, and their close relatives are the biggest living reptiles. Although they look rather like lizards, they are actually more closely related to birds, and to the giant dinosaurs that disappeared from the Earth about 66 million years ago. The earliest crocodiles lived alongside the dinosaurs, and probably preyed on them using the same ambush tactics that modern saltwater crocodiles use to kill buffalo. They have not changed much since then, because they have not needed to—they have always been perfectly adapted for their way of life.

By slowing its heartbeat to just a few beats per hour, a crocodile can stay underwater for more than an hour.
Who's who?
There are 24 species of crocodiles and their relatives living in the warmer parts of the world. As well as 15 crocodile species, there are eight species of alligators and caimans, and one species of gharial. Compared to crocodiles, alligators and caimans have broader snouts with wide upper jaws that cover their lower teeth. The fish-eating gharial has a slender snout with 110 sharp teeth, ideal for catching its slippery prey.

The Saltwater Crocodile is the biggest of all crocodiles, with some males probably growing to 23 ft (7 m) or more.

Fact file
- Speed on land: 1.9 mph (3 kph)
- Speed in water: 22 mph (35 kph)
- Habitat: Rivers, estuaries, and saltwater of Southeast Asia and Australasia
- Diet: Animals up to the size of a water buffalo
- Armed with: Powerful jaws and pointed teeth
- Average length: 10-16 ft (3-5 m)

Ambush predator
A crocodile is specialized at hunting in the water. It lurks in ambush, half-submerged, and by simply breathing out it can sink like a submarine. Any prey animal that wades into the water risks being suddenly seized and dragged under to drown. The crocodile then rips the prey apart and swallows it in big chunks, relying on its powerful stomach juices to digest every scrap.

Strong legs
Unlike most reptiles, which walk with their legs splayed out and their bellies close to the ground, crocodiles have strong legs that can support their bodies in an efficient “high walk.”

Powerful tail
A swimming crocodile drives itself through the water with powerful sideways sweeps of its muscular tail, often holding its legs close to its body.

Streamlined body
Although a crocodile is relatively clumsy on land, its streamlined body allows it to move alarmingly fast in the water.

Bony armor
The big scales on a crocodile’s back are reinforced with bony plates called osteoderms, forming a protective armor.

The age in years that a crocodile can reach.
100

A crocodile’s stomach acid is ten times more powerful than a human’s.

3,000
The number of teeth that a crocodile grows and loses during its lifetime.

The time in months a large crocodile can survive between meals.
12

Alligator
Fact file
- Speed on land: 1.9 mph (3 kph)
- Speed in water: 22 mph (35 kph)
- Habitat: Rivers, estuaries, and saltwater of Southeast Asia and Australasia
- Armed with: Powerful jaws and pointed teeth
- Average length: 10-16 ft (3-5 m)

Habitat
Rivers, estuaries, and saltwater of Southeast Asia and Australasia

Diet
Animals up to the size of a water buffalo

Armed with
Powerful jaws and pointed teeth

Average length
10-16 ft (3-5 m)

100
The age in years that an alligator can reach.

3,000
The number of teeth that an alligator grows and loses during its lifetime.

The number of months an alligator can survive between meals.
12

Streamlined body
Although an alligator is relatively clumsy on land, its streamlined body allows it to move alarmingly fast in the water.

Strong legs
Unlike most reptiles, which walk with their legs splayed out and their bellies close to the ground, alligators have strong legs that can support their bodies in an efficient “high walk.”

Powerful tail
A swimming alligator drives itself through the water with powerful sideways sweeps of its muscular tail, often holding its legs close to its body.
**Birds**

With their beautiful feathers, fascinating habits, and amazing flying skills, birds are among the most colorful and intriguing of all animals.

Birds are the most familiar of all wild animals. They live all around us and are easy to watch as they search for food, build their nests, and raise their young. Like us, they use sight as their main sense and have a strong sense of color. But there is something else about birds that makes them particularly interesting. Recent research has proved that they are small, flying dinosaurs, descended from relatives of ancient hunters such as Velociraptor. Many of these long-extinct dinosaurs had warm, insulating feathers just like those of birds today, but the birds turned them to even better use—by taking to the air.

**Features**

Birds are warm-blooded vertebrates. Their bodies are covered with feathers, they lay eggs, and most birds are able to fly.

**Inside a bird**

Birds inherited several features from their dinosaur ancestors, such as warm-bloodedness, feathers, and a super-efficient breathing system. But the demands of flight encouraged the evolution of other features too, including a lightweight bill and digestive system, and an extra-strong, yet light, skeleton. Birds also have excellent hearing and vision, and some birds—for example, crows and parrots—are among the most intelligent of all animals.

**Bird anatomy**

- **Vision**: All birds have excellent eyesight, especially hunters such as hawks, eagles, and owls.
- **Bill**: The shape of a bird’s bill—long, short, straight, or curved—depends on its feeding habits.
- **Esophagus**: Food passes from the mouth to the crop along this tube.
- **Crop**: A bird can eat a lot of food very quickly by storing it in its crop before digesting it.
- **Heart**: This is big compared to the bird’s size, and it beats fast to keep the flight muscles supplied with blood.
- **Liver**: The liver processes any toxic substances in the bird’s blood and makes them harmless.
- **Intestine**: Food processed in the stomach and gizzard passes into the intestine, which absorbs vital nutrients.
- **Feet and claws**: This bird has sharp-clawed feet adapted for perching. Other birds have webbed feet for swimming, extra-long legs for wading, or powerful talons for seizing prey.
- **Lungs**: Fresh air drawn into special air sacs is pumped in only one direction through the lungs, making them more efficient than mammal lungs.
- **Kidneys**: The kidneys remove waste products from the blood, excreting it as solid waste instead of liquid urine.
- **Air sacs**: A bird has seven or nine air sacs. Some draw in fresh air and pump it through the lungs. Others pump the waste air out.
- **Gizzard**: A bird cannot chew its food with its bill. Instead, swallowed food passes into its gizzard—a tough-walled, muscular chamber that grinds the food to a pulp.
- **Feathers**: The bird’s feathers protect it, keep it warm, and enable it to fly. Like hair and claws, feathers are made from a flexible but tough protein called keratin.
**Eggs and young**
All birds reproduce by laying eggs, which vary greatly in size and color. Most birds build nests for their eggs, and use their own body heat to keep them warm until they hatch. The chicks of some birds, such as chickens and ducks, can find their own food right away. But others, including the young of most songbirds, are quite helpless, and need to be fed and kept warm by their parents for several weeks.

**Migration**
Many birds nest in the far north in summer, where the days are very long and swarming insects provide a lot of food for their young. At the end of summer, they fly south to spend the winter in warmer regions. Some birds make incredible journeys, flying huge distances across continents and oceans.

**Key**
- **American golden plover**
  After nesting in the Canadian Arctic, this shorebird flies to the grasslands of Argentina for the winter. Some birds make the flight nonstop.
- **Arctic tern**
  In the northern winter, the Arctic tern hunts in the oceans around Antarctica. It then flies halfway around the world to breed in the far north.
- **Short-tailed shearwater**
  This ocean bird makes a round trip of 18,600 miles (30,000 km) every year, breeding on the coasts of Australia and then migrating to the Arctic.
- **Common cuckoo**
  Cuckoos spend the winter south of the equator. They return to Northern Europe and Asia in spring to lay their eggs in the nests of other birds.

**Eggs and young**

**Migration**

**Key**

**Seabirds**
Many birds spend most of their lives at sea, where they feed on fish and other sea creatures, such as squid. They stay away from land for months, returning only to lay their eggs and raise their young on remote coasts. Seabirds include gannets, puffins, and seagulls, as well as giant albatrosses that soar over southern seas.

**Flightless birds**
Birds are specialized for flight, but despite this some do not fly at all—a feature of birds that have few natural predators. They include strong runners like ostriches and small island birds that have no enemies to escape from. They all have features that show their ancestors could fly, but over thousands of years they lost this ability.

**Flightless birds**

**Champion runners**
Like all flightless birds, these ostriches have short wings and small wing muscles. Although they can’t fly, they can run fast on their long, powerful legs to escape from predators, reaching speeds of up to 45 mph (72 kph).
How birds fly

Birds are masters of the air. Other animals can fly, but none can match the sheer speed, agility, and endurance of birds—qualities that have been refined by millions of years of evolution.

Birds can fly faster, higher, and further than any other animal. Many fly vast distances around the world every year, and a common swift may stay in the air for years on end without landing once. Birds have been seen flying high over the summit of Mount Everest, the highest peak on Earth. These feats are possible because a bird is highly specialized for flight. From its feathers to its bones, virtually every part of a bird’s body is modified to either permit flight or save weight and make flying easier.
Hollow bones
Flight uses a lot of energy, and this could make a bird tire very quickly. But the less a bird weighs, the less energy it uses, so every part of its body is adapted to be as light as possible. Many of the bones are incredibly slender, and only just strong enough for the job they have to do. Some of the biggest bones are hollow, but they are reinforced with internal struts to stop them from collapsing under the strain of flight.

Skull
Formed from many bones fused together, a bird’s skull is very light. It has an unusually thin cranium—the upper part that protects the bird’s brain.

Hinged jaw
Unlike a mammal, a bird has a movable upper jaw. This allows it to raise the top part of its bill when it wants to open its mouth wide.

Flight muscles
A bird’s wings are powered by massive flight muscles. They are attached to the wing bones and anchored to a deep breastbone called the keel bone.

Bill
Instead of heavy jaws and teeth, a bird has a lightweight bill made of keratin—the material that forms our fingernails. It covers a framework of thin bone attached to the skull, and it keeps growing throughout the bird’s life as it is worn away at the tip and edges.

Down feathers
Underneath the contour feathers are special down feathers close to the skin that keep the bird warm. Unlike flight feathers, they have loose, soft barbs that do not hook together. This makes the feathers fluffy, forming a layer of insulation against the cold.

Taking flight
Birds are four-limbed animals, like us, and their wings are modified arms. But the area of each wing is made much bigger by the flight feathers rooted in its skin. These overlap to form a broad surface that flexes to push air back with each downbeat, driving the bird forward. Meanwhile, the smooth, curved shape of the wing means that air flowing over it creates lift, just like air flowing over an aircraft wing, and this keeps the bird in the air.

Kingfishers, nectar-feeding hummingbirds, and kestrels have an amazing ability to hover in midair. They do this by flying upward just fast enough to push against gravity.
Mammals

Warm-bodied, often furry mammals are the animals that we find easiest to understand, and for a very good reason. We are mammals too, and share many of the features that have helped them thrive.

The first land mammals evolved from reptilelike ancestors at about the same time as the earliest dinosaurs, near the beginning of the vast span of time we call the Mesozoic Era. But while the big dinosaurs disappeared in the catastrophic extinction that marked the end of that era, around 66 million years ago, the mammals survived. They went on to colonize the entire planet, evolving adaptations that have allowed them to flourish in every possible habitat. There are mammals living everywhere, from the polar ice to the sun-scorched deserts, and from the highest mountain peaks to the deepest oceans.

Adaptable mammals

All mammals evolved from four-footed (tetrapod) ancestors that lived on dry land. Through millions of years of evolution, this basic body plan has been modified to suit the different ways that mammals live, enabling some to fly and others to survive in the ocean.

Terrestrial
Standing on four legs and with a long tail, the snow leopard has the typical body form of a land mammal. In addition, it is highly specialized for its hunting lifestyle.

Tree-dwelling
Many mammals are adapted for life in the trees, especially those that live in tropical forests. They include primates such as apes, monkeys, and this Madagascan lemur.

Aerial
Bats challenge the birds by flying on wings of skin stretched between greatly elongated finger bones. Most species hunt flying insects at night. Bats make up 20% of all mammal species.

Aquatic
Some mammals, such as seals and this blue whale, have become adapted for living in the sea. Their feet have evolved into flippers, and while seals still have four limbs, whales and dolphins have lost their hind limbs altogether.

Bringing up baby

More than 90 percent of mammal species give birth to live young, which develop to an advanced stage inside the mother’s body before they are born. These are known as placental mammals, because the unborn young are supplied with oxygen and food inside the mother through a cord linked to an organ called the placenta. In contrast, the group of pouch mammals, called marsupials, give birth to half-developed young, which crawl into a pouch on their mother’s body and stay there until they are fully formed.

Life in a pouch

A newborn marsupial is a tiny pink fleck of life, barely able to move. Despite this, the newborn crawls into its mother’s pouch, where it starts drinking an extra-rich form of milk. Here, it grows and develops until it is able to eat solid food.

Warm and safe

The joey (baby) red kangaroo, develops inside its mother’s warm pouch for six months. Once grown, the joey starts to climb out for short periods and, about six weeks later, it leaves the pouch for good.

Key features

- All mammals are warm-blooded vertebrates (animals with internal skeletons) that feed their infant young on milk.
- All 5,400 species give birth to live young, except for the platypus and spiny anteater, which lay eggs.
- More than 90 percent of mammal species give birth to live young, which develop to an advanced stage inside the mother’s body before they are born.
- The group of pouched mammals, called marsupials, give birth to half-developed young, which crawl into a pouch on their mother’s body and stay there until they are fully formed.

VERTEBRATES

WARM-BLOODED MOSTLY HAIRY
MOST GIVE BIRTH TO LIVE YOUNG
YOUNG FEED ON MILK
Warm-blooded
Mammals depend on the release of energy from food to keep their bodies at an ideal temperature of about 100°F (38°C). This ensures that all their body processes work efficiently, and enables the animals to stay active in cold weather. However, some mammals that struggle to find food in the winter months go into hibernation. They save energy by lying dormant and allowing their bodies to cool down, then they wake up again in the spring.

Sleepy dormouse
A common dormouse may hibernate for up to six months each year, allowing its body temperature to drop below a chilly 39°F (4°C).

Keeping warm
A warm-blooded mammal uses a lot of energy keeping warm, and this means that it must eat much more than a cold-blooded animal of the same size. The more body heat a mammal can retain, the less food it needs, and this is why many mammals have bodies covered in thick, warm fur. Layers of fat under the skin also keep in body heat. Fur is just thick hair—something that only mammals have, although in some species it is modified to form spines or even scales.

Senses
Many mammals are most active at night. They rely on their senses of hearing and smell, which are much more acute than ours, and also have a highly developed sense of touch. The eyes of nocturnal mammals are adapted to see in near-darkness and have many sensitive rod cells that react to very dim light. But this means that their eyes have fewer cone cells that detect colour, so these mammals do not see colours as well as we do.

Color blind
The ancestors of dogs hunted at night, so dogs see well in the dark but are not very sensitive to color. Although they see yellow, blue, and gray, dogs are almost blind to red and green.

Diet and teeth
Most mammals have several different types of teeth in their jaws—front incisors for biting, pointed canines for gripping, and large cheek teeth for chewing. The teeth are specialized in various ways to suit each mammal’s diet and, as a result, the teeth of meat-eating hunters are very unlike those of plant-eaters.

Dolphin
Unlike other mammals, a dolphin’s teeth are all the same—simple, sharp spikes, ideal for seizing slippery fish.

Lion
A lion combines long, pointed canine teeth with scissorlike cheek teeth for slicing meat. It cannot chew at all.

Cow
The cheek teeth of a cow are flattened for chewing grass. It has lower incisor teeth, but no sharp canines.
African elephant

The biggest and heaviest of all land animals, the magnificent African elephant is a giant plant-eater with an appetite to match its size. It is famous for its intelligence and excellent memory.

With its long trunk, impressive tusks, huge ears, and above all its colossal size, the African elephant is a truly spectacular animal. It is specialized for eating huge quantities of coarse vegetation, including tough grass and tree bark, and will use its enormous strength to push trees over to get at their leaves if it is hungry enough. But the elephant can also be gentle and sensitive, and has a close-knit family life.

Starting life

A baby elephant grows inside its mother’s womb for 22 months—almost two years. This gestation time is longer than that of any other mammal, including giant whales. The baby reaches full development during the tropical dry season, and is born at the start of the rainy season when there is plenty of grass for its mother to eat and turn into milk.
When an elephant wades across a deep river, it breathes by holding its trunk above the surface like a snorkel.

Skull and teeth
The bones of the skull are honeycombed with air spaces to reduce weight. But together with the teeth and tusks, it still makes up almost a quarter of the elephant’s total weight. Huge, ridged cheek teeth—one or two on each side of each jaw—grind the elephant’s fibrous food to a pulp. Over time, they move forward, like a conveyor belt, so old, worn teeth fall out, and are replaced by new teeth sliding up from behind.

Tusks
The ivory tusks are extended front teeth, used for stripping bark, digging up edible roots, and as weapons. But many elephants are killed for their tusks, because their ivory is very valuable.

Ears
An African elephant’s huge ears act as heat radiators, helping the animal shed body heat under the hot African Sun.

Trunk
The muscular, sensitive trunk is an extension of the upper lip and nose. The elephant uses it for gathering food, drinking, spraying water and dust on itself, and communication.

Skin
The thick, wrinkly skin is very sensitive, and elephants spray dust on it to protect it from the Sun.

Ribcage
A network of air spaces makes the skull lighter.

Cheek teeth
have ridges across the surface that help grind food.

Family ties
Female elephants and their young live in family groups led by the oldest, wisest female, who knows where to find food and water. They have a close bond, using their trunks to touch and caress each other. When young males reach their teens, they leave to form all-male groups, but they often meet up with the family.

Fact file
Height: Up to 13 ft (4 m)
Weight: 11 tons
Lifespan: 70 years
Habitat: African savanna
Diet: Vegetation
Status: Threatened
ANIMAL INTELLIGENCE

One of the big differences between animals and other life forms is that animals have evolved networks of nerve cells. Nerves send messages flashing through an animal’s body, allowing it to respond instantly to its surroundings. Simple creatures, such as jellyfish and clams, respond automatically. More advanced animals have knots of nerve cells called brains, which allow them to remember what was good and what was bad. They can use this information to make choices about how to behave. This is the basis of intelligence.

Instinct

All animals, including humans, do a lot on instinct. An instinct is a form of behavior that doesn’t need any conscious thought. Instincts are inherited from parents. For example, a baby spider is able to spin a web without being taught because, like having eight legs, the web-making instinct is part of its inheritance. For many animals, instinct controls at least 90 percent of their actions.

Memory and learning

The brain of an insect is a tiny bundle of nerve cells, but even insects have memories. A honeybee gathering nectar remembers where the best flowers are, and passes on the information to other bees. The bigger the animal’s brain, the more it can store away in its memory. This allows it to use experience to guide its actions, instead of just reacting to what is happening at that moment. Such animals can think and learn—although as far as we know, most of what they learn is practical.

Teaching by example

A few intelligent animals can learn new skills and pass on those skills to others, teaching them by example. Mothers often teach their young in this way, but other animals living in a social group may also learn by imitating a particularly clever individual. Chimpanzees learn how to make tools like this, stripping leaves from twigs so that they can use the twigs to scoop insects out of holes. This sort of learning is known as culture, and it is the basis of human civilization.

ON THE MOVE

Animals are always moving. Some just twitch while staying rooted to one spot, but many others crawl, swim, walk, run, or fly in search of food, shelter, or breeding sites. They may wander almost at random, but others clearly know where they are going. Some of these animals have home territories, and know every rock, tree, and burrow. Many other animals, however, find their way over far greater distances, traveling across the globe to reach their destinations.

Finding the way

Migrating birds cross continents twice a year, while whales and sea turtles cross vast oceans, returning to the same places year after year. Birds may use landmarks, but this does not explain how a whale finds its way across an ocean. It seems to just know where to go. But migrating animals do not follow their instincts blindly. Birds, for example, choose their migration routes with care, and delay their departure if the weather is against them.

Navigation

Birds may use a combination of cues to help them navigate. These may include the Sun, stars, and Earth’s magnetic field, as well as landmarks such as coastlines and hills.

A DOLPHIN THAT WAS TAUGHT SIGN LANGUAGE AT A RESEARCH CENTER IN HAWAII HAS NOW LEARNED MORE THAN 60 WORDS AND CAN UNDERSTAND MORE THAN 2,000 SENTENCES.
LIVING TOGETHER
Although some animals lead solitary lives, most live with others of the same species. A few live with different animals, or even completely different types of organisms. They form relationships that often make life easier for both partners. This can allow them to survive in difficult habitats where food, shelter, or other necessities of life are hard to find.

Perfect partners

VALET SERVICE
Small coral reef fish called cleaner wrasses make a living by picking bloodsucking lice and bits of dead skin off other fish. Their customers are often big enough to eat them, but don’t because they need the service.

FOOD FACTORIES
The corals that build reefs have algae in their tissues that make food using energy from light, and this food helps feed the corals. The giant clams that live on coral reefs have the same arrangement.

APHID FARMS
Small, soft-bodied insects called aphids produce a very sugary fluid called honeydew. Ants love eating this, so they look after aphids as if they were farm animals, defending them from enemies in return for a sweet treat.

HONEYGUIDE
The black-throated honeyguide is an African bird that eats the honeycomb of wild bees. It gets stronger animals to break into the nests, dancing before them to lead them to the site. They get to enjoy some honey too.

COURTSHIP
Finding a mate and reproducing is essential to the survival of a species. Many animals have elaborate courtship routines. Often the males display to females, as with the male chameleons that glow with vivid colors to show they are eager to mate. But pairs may also perform together, like the scorpions that grip pincers and seem to waltz in the sand, and newts that dance together underwater.

Calls and songs
Sound plays an important part in courtship, especially deep in forests, where dense foliage makes it hard for animals to see each other. Male birds and tree frogs often fill the air with songs and calls as they compete to attract females and dominate rival males. The females usually choose to breed with the strongest singers, because they are also likely to be the healthiest.

Ritual dance
Birds put on the most spectacular courtship displays. On European lakes, pairs of great crested grebes engage in wonderfully complex ballets consisting of several dance routines. These are linked together in a strict sequence, which both partners must follow in perfect unison. If the dance goes well, the pair will mate and raise a family.

On its own
This caterpillar of a tropical blue morpho butterfly has just hatched from its egg. Its mother has provided for it by laying the egg on a plant that it can eat, but apart from this, the caterpillar has to fend for itself. It relies on its instincts and a defensive chemical to protect it from hungry birds, but the caterpillar will be very lucky to survive long enough to turn into an adult butterfly.

Gentle jaws
A mother crocodile stays by her nest of eggs for nearly three months, waiting for them to hatch. As soon as she hears the first squeak, she digs them out, helps the babies emerge from the eggs, and carefully carries her young to the water in her jaws. She then guards them for several months while they learn to hunt small animals for themselves.

PARENTAL CARE
Many animals, including most fish, produce hundreds or thousands of eggs, because most of the young that hatch from them will not survive. Other animals produce fewer eggs or young, but they look after them for a short while to improve their chances of survival. The parents defend their young and either feed them or show them how to find food. A few animals provide care for many months or even years, during which time they teach their offspring vital life skills.

Long childhood
A young wolf is brought up as part of a family—a wolf pack. At first, the pup is cared for by its mother, who provides nourishing milk. But gradually, it learns to eat meat brought back to the den. When the pup is old enough, it starts hunting with the rest of the pack, copying what they do and learning all the skills that it will need to survive and raise its own family.
Habitats

Animals, plants, and all living things are adapted to life in their natural surroundings. These different environments are called habitats.

Every living species on Earth has its own favored habitat, which it shares with others. These different species interact with each other and with their natural environment—be it hot or cold, wet or dry—to create a web of life called an ecosystem. Some ecosystems are very small, but others such as rainforests or deserts cover huge areas. These vast wild habitats are called biomes.

Ecosystems

All animals, plants, fungi, and microbes depend on other forms of life for their survival. These communities of living things provide each other with shelter, food, plant nutrients, and even vital oxygen. All ecosystems are shaped by the climate, which influences the plants that grow. The cacti that grow in deserts, for example, are unlike the trees of a tropical rainforest, and they support different types of animals. The rock type is also important, because this affects the minerals in the soil, and in the water of streams, lakes, and other freshwater habitats. Mineral-rich water is very fertile, so it supports a lot of microscopic algae and water plants. These are eaten by small creatures that feed fish and other animals.

Freshwater ecosystem

A pond is a miniature ecosystem. The plants in the water support the animals, and they, in turn, provide nutrients for the plants to grow.

The Everglades in southern Florida is the biggest freshwater habitat in the world.
Habitat loss
The greatest threat to the world’s wildlife is the loss of their natural habitats. Most living things have evolved to live in a particular ecosystem, and they cannot survive if this is destroyed. Habitat loss is the main reason why many wild species are becoming rare.

Deforestation
Every day, a vast area of wild forest is felled for its lumber, or to clear the land for agriculture.
The cactus deserts of the southwestern United States and Mexico are home to a rich variety of plants and animals, all specially adapted to survive the hot, dry climate.

Deserts are the world's driest places. Many are hot while others are bitterly cold. Some may get no rain at all for many years, making them almost lifeless. The climate of the North American deserts, however, is not quite so extreme. The Sonoran Desert, for example, gets regular rain, even if there is not much of it. The rainwater is soaked up by cacti and other plants, which support plant-eating animals such as kangaroo rats, ground squirrels, and jackrabbits. These in turn provide prey for hunting rattlesnakes, owls, and coyotes.

Many desert predators are highly venomous, which helps them capture scarce prey.
Desert life

In the cool of early morning, the Sonoran Desert is alive with activity as animals forage for edible plants and seeds, or search for prey. Many are active throughout the night, relying on their acute senses to guide them in the dark, but as the temperature soars, most of them retreat to underground refuges for shelter from the scorching heat.

Kangaroo rats get all the water they need from their food, so they can survive without drinking at all.

Major deserts of the world

Most of the world’s hot deserts lie just north and south of the equator. They are created in zones where sinking dry air stops clouds from forming, so there is very little rain. Cooler deserts lie in the center of Asia, far from any ocean, while the coldest desert of all forms the heart of Antarctica.

Desert life

Coyote

The versatile coyote will eat fruit and insects as well as taking larger prey.

Brittlebush

Named for its brittle twigs, this low-growing shrub has hairy leaves that trap vital moisture in the air.

Great horned owl

The powerful horned owl usually preys on small mammals, and is big enough to kill and eat a jackrabbit.

Great horned owl nest

A spiny saguaro cactus makes an excellent nest site, since the spines deter many animals that might steal the eggs or the helpless young owls.

Miller’s pincushion

The barrel-shaped Miller’s pincushion has dark spines with curved points like fish hooks. Its bright pink flowers are followed by vivid red fruit.

Giant desert centipede

About 8 in (20 cm) long, this venomous multilegged predator is big enough to kill lizards and small mammals.

Globemallow

The orange flowers of this tough desert shrub appear in spring, and it often stays in bloom for several months.

Collared lizard

Fast-moving collared lizards chase insects and other small animals, sometimes running on their hind legs.

Tarantula hawk wasp

This giant wasp feeds its young on spiders, including tarantulas. The wasp lures a spider from its hideaway and paralyzes it with its venomous sting. It then drags the helpless spider back to its burrow and lays an egg on it. When the wasp grub hatches, it has a ready supply of food.
Amazon rainforest

Hot, wet, and teeming with an amazing diversity of plant and animal life, the Amazon rainforest is one of the richest habitats on the planet.

Named after the mighty Amazon River that flows through it, the Amazon rainforest is a vast tract of tropical forest covering an area almost as big as Australia. Its warm, wet climate is ideal for plants, which never have to cope with cold or dry seasons, so they grow fast all year round. Huge evergreen trees soar high above the forest floor, creating an almost continuous canopy of lush green foliage that is alive with insects, tree frogs, snakes, birds, and monkeys.

Blue morpho butterfly
The wings of this dazzling insect flash with iridescent blue as it dances in the dappled light of the forest.

Black caiman
This deadly predator lives in rivers, where it preys mainly on fish but also seizes animals that wade into the water to drink.

Paca
Expert swimmers, pacas live in burrows that may be 10 ft (3 m) deep, emerging to feed at night.

Toco toucan
This bird uses its huge bill to pick fruit, but it also eats a few small animals.

Giant otter
Around 5 ft (1.7 m) long, this giant otter lives up to its name. It hunts in the water for fish, including the notorious piranhas.

Leafcutter ants
The tiny leafcutter ants live in huge underground nests in colonies of up to 8 million insects. They feed on a special fungus, which grows inside the nest on a compost made from pieces of leaf. The worker ants gather these from the forest, scissoring them out with their sharp jaws and following scent trails to carry them back to the nest.

High life
Most of the animals that live in a tropical rainforest spend their lives high above the ground, up in the trees. They feed on leaves, fruit, and flowers, which grow all year round, and prey on the swarming insects and other creatures. Far fewer animals live on the shady forest floor, but those that do include all the biggest predators.

Weightlifters
Amazingly strong leafcutter ants can carry pieces of leaf that weigh 20 times their own body weight.

Scarlet macaw

Giant water lily
The floating leaves of this magnificent plant can be over 8 ft (2.5 m) across, with 16 in (40 cm) flowers.

Capybara
The biggest of all rodents, the capybara lives in forest swamps and rivers.

Piranha

Toco toucan

Leafcutter ants

Blue morpho butterfly

Black caiman

Paca
Jaguar
A powerful predator, the jaguar prowls the forest floor at night in search of prey. It can kill a caiman with a single bite.

Green iguana
Unlike most lizards, iguanas are herbivores, climbing high into the tree canopy to eat leaves, fruit, and flowers.

Kapok tree
Supported by its massive buttress roots, the kapok can grow to 200 ft (60 m), rising well above the main canopy.

Three-toed sloth
Suspended by their long, stout claws, leaf-eating sloths hang upside down from the branches. They are famously slow-moving.

Emerald tree boa
In the rainforest, even snakes live in the trees. This climbing boa seizes prey in its teeth before squeezing it to death.

Jaguar
A powerful predator, the jaguar prowls the forest floor at night in search of prey. It can kill a caiman with a single bite.

Lianas
Many soft-stemmed plants climb toward the light by scrambling up the trunks of tall forest trees.

AT LEAST HALF OF ALL PLANT AND ANIMAL SPECIES ON EARTH LIVE IN TROPICAL RAINFORESTS.
The African savanna is home to both the largest land animal—the elephant—as well as the tallest animal—the giraffe.

The African savanna

The tropical grasslands of Africa are open landscapes of dramatic seasonal extremes. They provide one of the most amazing wildlife spectacles on the planet.

Throughout the tropics, regions that do not get enough rain to support dense forest develop into grasslands. In Africa, these grassy, tree-dotted plains are called savannas. For half the year they are hot, dry, and swept by wildfires, but then the drought gives way to a rainy season that revives the grass. This provides food for the herds of grazing animals that roam the plains, hunted by fearsome predators such as lions and hyenas.

Lions
Powerful hunters, lions rely on stealth, creeping up on their prey before launching a group attack. They spend the heat of the day resting in the shade.

Umbrella acacia
The grasslands are dotted with tall, thorny, broad-topped acacia trees. They can survive many months without rain, and recover quickly from fire.

Wildebeest
Tireless trekkers, wildebeests gather in huge numbers to migrate in search of food. They are prime targets for lions.

African elephants
These giants feed on a wide variety of plants, even pushing trees over to get at their leaves.

White-backed vultures
The remains of a hunter’s kill attract keen-eyed vultures that settle to pick the bones clean.

Browsers, grazers, and hunters
At the start of the rainy season a storm fills a dried out pool with rainwater, attracting thirsty animals from a wide area. They include leaf-browsing giraffes that eat the foliage of tall trees, and grazers such as wildebeests and gazelles. Hunters lie in ambush, hoping for an easy kill.

Aardvark
Ant-eating aardvarks hunt at night and hide in burrows by day.

Termite mound
The savanna swarms with termites that live in big colonies. Many build towering nests of sun-baked clay.

Umbrella acacia

African savanna

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The number of migrating wildebeests in the largest herds.

**Savannas**
The world's tropical grasslands lie close to the equator, mainly north and south of the tropical rainforests, in hot regions with distinct wet and dry seasons. There are tropical grasslands in South America, Australia, and India. But the African savannas are the largest, and have the richest wildlife.

**Giraffes**
At up to 20 ft (6 m) tall, giraffes are well equipped for browsing on high-level foliage. Their lips and tongues have extra tough skins to cope with the long, sharp acacia thorns.

**Whistling thorn acacia**
Hungry giraffes avoid the whistling thorn acacia because it is defended by an army of stinging ants. The ants live inside the tree's long, swollen thorns, getting in and out through holes that whistle in the breeze. If a leaf-eater comes too close, they swarm out to attack it with their stings.

**Dwarf mongoose**
This mongoose family has adopted an old termite mound as a den. They hunt by day for small animals.

**African rock python**
Reaching lengths of up to 23 ft (7 m), the rock python is Africa's biggest snake. The python can easily kill and eat an animal the size of a gazelle by coiling itself around its victim and suffocating it before swallowing it whole.

**Dung beetles**
All the dung produced by the animals grazing the savanna contains a lot of half-digested grass. This is recycled by busy dung beetles that roll the dung into balls, burying them for use as food reserves for themselves or their young.

**Plains zebra**
The beautifully striped plains zebra live in groups that roam the savanna looking for fresh grass and watering holes. Each zebra has its own unique coat pattern.

**Grant's gazelles**
These gazelles are the main prey of many hunters, but their speed and agility often saves them.

**Savannahs are plagued by plant-eating locusts**
In swarms the size of cities.

**62 mph (100 kph) — the speed a cheetah accelerates to in the space of five seconds.**
**Tropical coral reefs**
Coral reefs grow in clear, shallow water on tropical coasts where the water temperature is higher than 64°F (18°C). They are most extensive in the southwest Pacific and nearby Indian Ocean.

**Natural wonder of the world**
The Great Barrier Reef off the coast of northeastern Australia is the biggest coral reef in the world, covering an amazing 131,000 sq miles (340,000 sq km)—the size of a small country such as Japan. It comprises more than 2,900 individual reefs, which are home to an extraordinary variety of sea life.

**Dolphins**
Thirty species of dolphins and whales live in the deeper waters.

**Fish**
More than 1,500 species of fish live among the coral.

**Coral**
The reef consists of about 400 different species of coral, all living together in colorful profusion.

**Mollusks**
As many as 4,000 types of mollusks have been found on the reef, including giant clams.

**Turtles**
Six of the seven sea turtle species found in the world’s oceans breed on the reef.

**Starfish**
The coral supports about 600 species of echinoderms, including starfish and sea urchins.

**The Great Barrier Reef**

The Great Barrier Reef is the largest single structure made by living organisms, and is visible from space.

**Some of the coral reefs we see today are thousands of years old—the Great Barrier Reef started forming 500,000 years ago.**

**Blue starfish**
This starfish creeps over the reef, grazing on seaweed and organic debris.

**Banded sea krait**
A type of sea snake, the banded krait has a flattened tail that it uses to drive itself through the water in pursuit of fish.

**Cloth of gold cone shell**
The cone shell spears its prey with a venomous dart powerful enough to an adult.

**Sea grass**
This is one of the few true plants able to grow in saltwater. It forms broad underwater meadows in shallow reef lagoons.

**Peacock mantis shrimp**
A ferocious hunter, the mantis shrimp uses its armored claws to smash the shells of snails and clams so that it can get at the soft flesh inside.

**Staghorn coral**
This quick-growing type of coral is very common on the reef, but is fragile and easily damaged by storms. It can be many different colors.

**Sting coral**
Sponges are very simple animals that live by pumping water through their bodies, filtering edible particles.

**Sea anemones and clownfish**
Anemones snare their prey with stinging tentacles, and many can kill fish. Despite this, the clownfish is able to live among the tentacles of certain anemones without being harmed, probably because it has a protective coating on its skin. The stinging tentacles defend the clownfish from bigger fish that might want to attack and eat it.
Reef life

The corals that build reefs are simple animals resembling sea anemones. The individual coral polyps are linked together in colonies that grow in warm, shallow seas. They are supported by limestone skeletons made of minerals absorbed from seawater. When the corals die, their stony skeletons survive, and new corals grow on top. Over centuries, they build up to form a rocky, living reef.

Reef life

Reef corals have microscopic algae in their cells that make food using solar energy. The corals share some of this food, allowing them to live in clear, tropical water that contains very little food of any other kind—although the corals also trap small drifting animals. The reefs that they build support a dazzling diversity of fish and other creatures.

Dazzling coral reef fish

Schools of small, brightly colored fish dart around the reef. Food is in short supply, so to avoid direct competition for the same types of food each species has developed a slightly different way of life. This has led to the evolution of many different species, each with its own special adaptations.

Weedy scorpionfish

The weedy scorpionfish lurks in ambush, waiting for smaller fish to swim within range. Venomous spines on its back protect it from bigger predators.

Sea slug

Colorful sea slugs eat stinging animals such as anemones, but recycle their stinging cells to form their own system of defense.

Table coral

Some of the biggest corals are these broad table corals. Each head of coral is a colony of hundreds of small coral polyps that soak up the sunlight they need to make food.

Red sea fan

Like corals but with tough, flexible skeletons, sea fans have spreading branches occupied by tiny polyps that feed by catching edible particles in their tentacles.

Box jellyfish

One of the most deadly animals in the ocean, the box jellyfish has four bunches of long, trailing tentacles, each armed with millions of highly venomous stinging cells.

Brain coral

Like all reef corals this is a colony of animals. They are linked in rows and divided by narrow grooves, giving the coral its amazing brainlike appearance. Each individual coral polyp has tentacles that it uses to snatch tiny drifting animals. These supply vital types of food that the algae in the coral cannot make.

Coral reef

Tropical coral reefs are the most spectacular of all oceanic habitats, providing homes for an astonishing variety of colorful marine life.

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Animal architects

Some animals have amazing architectural skills. They use them to build their homes, make temporary nests, or in some cases to create ingenious traps for catching prey.

Many animals dig burrows or make nests, but a few have refined their building skills to create marvels of engineering. Some of the most astounding constructions, such as the monumental fortresses of termites, are built by the simplest of creatures. Over millions of years, they have evolved the ability to create complex structures entirely by instinct. Other animals such as beavers and birds also work mainly on instinct, but they may perfect their skills by trial and error, and by learning from others.

Termite city
Tiny insects called termites live in huge colonies centered on a single breeding queen. Some of these colonies create astonishing nests that contain royal chambers for the queen, nurseries for her young, and indoor gardens for growing food. They are built by millions of blind worker termites sharing an instinctive master plan that is passed on from generation to generation.

Fungus garden
These particular termites cannot digest plant material. Instead, they chew it up to turn it into compost for growing a special fungus inside their nest, then they eat the fungus.

Queen termite
The queen is far bigger than the tiny blind workers. She lives in a special chamber of the nest, attended by the smaller king termite. She produces thousands of eggs a day, which are taken away and cared for by the workers.
Beaver lodge
The beavers of northern forests make their nest inside a pile of sticks called a lodge. They protect this from enemies such as wolves by building a dam across a nearby stream so that it forms a lake around the lodge. In winter, the lake freezes over, but since the lodge entrance lies below the ice, the beavers stay safe from hungry hunters.

Web spinners
Spiders are experts at using silk to trap their prey. The most spectacular traps are those of orb web spinners. Even tiny newborn spiders can make perfect webs, showing that they work entirely by instinct. Each spider starts by producing a thread of strong silk from its tail end, and letting it stream out on the breeze until the far end catches on something. Once it has bridged a gap with silk, the spider can get on with building its spiral insect trap.

Nest weavers
The male juba weaver bird of East Africa makes his nest by using his bill to weave grass blades together. He starts by attaching a woven ring of grass to a branch, then keeps weaving more and more grass onto the ring until it becomes a hollow ball. He leaves a hole near the bottom to use as an entrance.
Predators and prey

Many animals survive by hunting and eating other animals. These predators have special adaptations for finding, catching, and killing their prey, while their victims have evolved defenses that help them escape.

Hunting is difficult and sometimes dangerous, but predators have evolved many ways of improving their chances of success. They have acute senses for detecting their prey, and have ways of ambushing or creeping up on their victims without being detected. Speed, fast reactions, and sheer strength help them catch their meal, and weapons such as sharp teeth, claws, and even venomous fangs help them kill it. But the animals they hunt are not helpless victims. They can avoid detection, run away, confuse their enemies, or even fight back. So predators and prey are often evenly matched in this battle for survival.

Traps and tricks

Stalking and chasing prey is hard work, and it can use a lot of energy. Some venomous snakes avoid it by using lures to tempt animals within range. Other predators rely on traps, such as the spiders that spin webs to snare their prey. Some insects also build elaborate traps and wait for their victims to fall into them.

Sandy trap

Antlions are the larvae (young) of winged insects that live in warm countries. They dig steep-sided pits in sandy ground and make passing insects tumble in by flicking sand grains at them. The steep, sandy slope gives no foothold for prey trying to climb out of the trap. The victim falls into the sharp jaws of the antlion.

Hunting together

Most predators hunt alone. A few, however, have found ways of working together as a group to outwit their prey or kill animals much bigger than they could bring down alone. These cooperative hunters range from army ants to wolves, hyenas, dolphins, and humpback whales. Recently, scientists have discovered that chimpanzees sometimes band together to hunt small monkeys through the treetops.

Chimpanzee ambush

Troops of chimpanzees hunt colobus monkeys in the forests of tropical Africa. They climb up into the trees, spread out, and hide among the branches and leaves. Then one chimpanzee scares a monkey into trying to escape, and the others herd it toward an ambush.
Solitary hunters
Lone predators that hunt in the open rely on stealth, speed, and power to catch prey. Hunting uses a lot of energy, so predators must make the chase as brief as possible. If they can, they creep up close before launching a high-speed attack. These lone hunters usually target smaller animals that they can overpower easily.

Super-fast hunters
All these predators use their speed to take their prey by surprise, giving it less chance to escape.

Defense tactics
Some prey animals have armor or spines that make them difficult to attack. Armored animals include armadillos, tortoises, and crabs, while hedgehogs, porcupines, and sea urchins are covered with spines. Amphibians have poison glands in their skin, making them unpleasant or even lethal to eat, and many insects build up poisons in their bodies. Skunks spray their enemies with vile smelling chemicals.

Armored ball
The body and head of an armadillo are protected by plate armor. When attacked, this three-banded armadillo rolls itself into an armored ball that few predators can penetrate.

Southern three-banded armadillos are the only animals in the world that can roll their armored bodies into a tight, impenetrable ball.

Cunning camouflage
Both predators and their prey use camouflage to avoid being seen. By blending in with its background, a hunter can lay a deadly ambush for creatures that wander too close. Other animals rely on near invisibility to protect themselves from predators that hunt by sight, such as birds. Most camouflaged animals have patterns that resemble plants or sand, but some insects even have body shapes that match their habitats.

Sand viper
This venomous snake buries itself in the dry sand of Africa’s Namib Desert. It waits for small animals to come within striking distance.

Orchid mantis
The body of this tropical predator is shaped and colored like a flower. Insects approaching for a sip of sugary flower nectar are snatched.

Leaf-tailed gecko
The night-hunting gecko spends the day crouched on a tree, disguised by its amazing camouflage. Even its eyes are patterned to match the tree bark.

Leaf insect
Few animals are quite as hard to spot as this Malaysian leaf mimic. When it moves, it even sways from side to side like a leaf blowing in the breeze.
The human body is a fantastically complex machine containing 206 bones, 650 muscles, and 75 trillion parts called cells. Scientists have studied the body in greater detail than any object in history, yet many mysteries remain.
BODY BASICS

The human body is a fantastically complicated machine made from millions of different parts, all packed tightly together beneath the skin. To understand how the body works, we need to look inside and see how the parts fit and work together to make us living, breathing, thinking human beings.

BUILDING A BODY

Just as a building is made from thousands of bricks stacked carefully together, the human body is constructed from simple parts that fit together in an organized way. Small, living units called cells are joined together much like bricks to form larger structures called tissues, which are used in turn to build organs and organ systems.

BODY SYSTEMS

The organs and tissues that make up your body are organized into groups that doctors call systems. Each system does a particular job. Your digestive system, for example, breaks down food into nutrients that your body can absorb. Your circulatory system transports these nutrients and other vital chemicals around the body. Some of the main body systems are shown below.

Nervous system
This system allows your body to react with speed. Thousands of nerves run through the body, carrying electric signals to and from the brain. Some nerves bring signals from sense organs to the brain. Others send signals to muscles to make the body react.

Respiratory system
All your body’s cells need a supply of life-giving oxygen, which comes from air. Your respiratory system’s job is to take in oxygen and pass it to the blood. The main organs in this system are the lungs, which suck in air when you breathe.

Circulatory system
The heart, blood, and a network of blood vessels make up the circulatory system. Its job is to transport vital supplies such as oxygen and food molecules around the body. Blood also carries away waste chemicals for disposal.

Digestive system
Everything you eat passes through your digestive system—a long, complicated tube that runs from your mouth to your anus. The organs of the digestive system break down the large molecules in food into smaller molecules your blood can absorb.

Reproductive system
This body system works only during adulthood and is different in men and women. Its job is to produce babies. Male sex cells from a man’s reproductive system join with female sex cells inside a woman’s reproductive system and grow into a baby.

Muscular system
Muscles are what make you move. Your largest muscles work by pulling on bones to move your skeleton, allowing you to run, jump, tie your shoelaces, or kick a ball. Muscles also keep your heart beating and churn the food inside your stomach.

Immune system
The immune system’s job is to keep you healthy by fighting off germs—microscopic organisms that can cause disease. Any germs that get inside your body are attacked by white blood cells, which patrol the blood and other tissues for invaders.

Skeletal system
The skeleton is a tough, living framework of bones that supports the weight of your body and protects delicate internal organs, such as the brain and heart. The skeletal and muscular systems work together to move your body.

Organs join together to form organs, such as the heart, stomach, or brain. Organs perform a specific job. The heart’s job is to pump blood around the body.
Ancient Egyptians

When preparing bodies for mummification, the Ancient Egyptians pulled out organs to preserve them separately. They discovered that the heart is a kind of pump that pushes blood around the body.

Father of medicine

The Ancient Greek doctor Hippocrates is known as the father of medicine. He was one of the first people to realize that diseases have natural causes, rather than being punishments inflicted by the gods.

Dissecting bodies

Flemish professor Andreas Vesalius dissected (cut up) corpses in the 1500s and made detailed drawings of the bones, muscles, and organs. His pioneering work, which he published in a textbook, turned the study of the body into the science of anatomy.

DNA

In 1953, English scientist Francis Crick and his US colleague James Watson figured out the structure of DNA (deoxyribonucleic acid), the molecule that carries the instructions for life as a simple four-letter code.

Understanding the body

For most of history, the workings of the human body were a mystery, and people relied on supernatural theories to explain disease. The earliest recorded attempts to study the body scientifically date back to Ancient Egypt, but it took many centuries before people discovered how the living body truly works and why illness occurs.

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Building blocks

The human body is a jigsaw made up of around 75 trillion microscopic pieces called cells. Every part of your body is constructed from these tiny building blocks, from your eyelashes to your toenails.

Individual cells are too small to see with the naked eye. The average cell is less than half as wide as a human hair, but some are so tiny that 30,000 could fit inside a period. Cells work as independent units, absorbing food, oxygen, and other basic chemicals from their surroundings, and manufacturing the complex organic compounds they need to grow and function. Some cells, such as blood cells, travel around the body singly. Others are fixed together in sheets to form tissues such as skin or muscle.

Inside a cell

Despite their tiny size, cells are immensely complicated inside. Each one is like a factory, packed with machines that carry out particular jobs. The machines inside a cell are called organelles, which means “tiny organs.” The most important of these is the nucleus, which controls the rest of the organelles by sending out chemical instructions. Other organelles release energy, manufacture chemicals, and transport substances through the cell.
Lysosome
This organelle makes powerful chemicals that attack and break down unwanted substances and worn-out cell parts.

Ribosomes
These tiny molecular machines construct large protein molecules by joining small units called amino acids into chains. They use genes as templates to get the order of amino acids correct.

Endoplasmic reticulum
Folded membranes form a network of separate compartments in which various chemicals are manufactured, broken down, or stored.

Mitochondria
Cells get their power from mitochondria, which break down sugar molecules to release stored chemical energy.

Cytoplasm
A jellylike fluid made mostly of water fills the space between the cell’s organelles.

Cytoskeleton
Fine strands of protein form the cell’s inner framework.

Types of cell
There are more than 200 different types of cells in the human body, each type specialized to do a particular job. Some, such as skin cells and blood cells, last just a few weeks before dying and are continually replaced. Others, such as brain cells, can last a lifetime.

Red blood cell
These disc-shaped cells carry oxygen around the body. They are packed with a red pigment called hemoglobin.

Epithelial cell
The inside of the mouth and intestines are lined with these cells. Special toughened epithelial cells form the skin.

Fat cell
Body fat is stored in fat cells, which expand like balloons. As well as storing energy, fat cells help keep you warm.

Egg cell
The largest cells in the human body are egg cells. These develop into babies if they are fertilized by sperm cells.

THE LONGEST CELLS ARE THE NERVE CELLS THAT RUN FROM YOUR SPINE TO YOUR TOES.

Genes and DNA
The nucleus of most cells contains a complete set of your genes, stored as a chemical code in DNA. A single cell contains about 8 ft (2 m) of DNA. When not in use, this DNA is wound up tightly in packages called chromosomes. There are 46 of these in every nucleus.

Making new cells
The human body starts out as a single cell. By dividing in two again and again, it multiplies until there are billions of cells. The most common form of cell division is called mitosis. First, the chromosomes are copied, forming double strands. Next, the chromosome strands are pulled apart, and finally, the rest of the cell divides.

1. Chromosomes form double strands.
2. Chromosomes are pulled apart.
3. Two nuclei form.
The skeleton

Without a framework of bones, your body would collapse into a heap of shapeless flesh. Your skeleton not only holds you up—it also gives your muscles something to pull on, allowing you to move.

Bones are made of living tissue: they can feel pain, they bleed when cut, and they repair themselves if they break. We tend to think of bones as dry and brittle, but living bones are moist and slightly flexible to make them springy. Although smooth and solid on the surface, their insides are riddled with hollows to make them lighter. By weight, about 50 percent of a bone is a white calcium-rich mineral called hydroxyapatite, which is also found in teeth. This hard, crystalline material gives bone the great strength it needs to support the body’s weight.

Broken bones

If bones break, the healing process begins immediately. First, a blood clot forms inside the break. Next, tough fibrous tissue grows across it to strengthen the damaged area. New bone cells then replace the blood and fibrous tissue, knitting the broken ends back together. Some broken bones need to be realigned and held in a cast so that they don’t heal in a crooked shape.
Thigh bone
The longest, heaviest, and strongest bone in the body, the thigh bone (femur) makes up one-quarter of a person's height.

Kneecap
Like a shield, the flat kneecap bone (patella) protects the knee joint.

Fibula
This long, slender bone lies alongside the bigger shinbone.

Shinbone
Also called the tibia, this is the main bone in the lower leg.

Knee joint
The largest joint in the body, the knee works like a hinge but also permits a certain amount of twisting.

Ankle
Seven bones called tarsals make up the ankle, which also contains three joints.

Toes
There are three toe bones (phalanges) in most toes but only two in the big toe.

Metacarpals
Phalanges

Fibrous outer lining
Compact bone
Bone marrow
Spongy bone

Inside a bone
To save weight, the inside of a bone is a honeycomb of spaces, forming a material called spongy bone. The solid, outer layer is called compact bone. Large bones also have a hollow center filled with bone marrow tissue, where blood cells are made.

Joints
Bones meet other bones at joints. In some joints, such as those in your skull, the neighboring bones are glued together rigidly. In most, however, the bones don't touch each other but are tied loosely together by tough straps of tissue that allow the bones to move. Joints give your skeleton incredible flexibility.

Inside a joint
To help the two bones in this joint to move, their ends are coated with slippery cartilage and surrounded by a pool of fluid. Tough ligaments tie the bones together.

Flexible joints
There are six main types of free-moving joints in your body. Each type allows a restricted range of movement, depending on how the bones fit together.
Muscle power

Muscles allow us to walk, run, jump, and wiggle our fingers. They also move blood around the body and food through our intestines and allow us to speak.

Muscles make the body move. All muscles are made up of tiny fibers that can contract, making a muscle shorter so that it pulls on a part of the body. The largest muscles in the body are connected to the bones. Most of these skeletal muscles are under voluntary control, which means we can move them at will. Other muscles, such as those in the heart and stomach, are involuntary—they work without our having to think. Altogether, there are billions of muscles in the human body, including microscopic muscles on every hair and blood capillary.
Working in pairs
Skeletal muscles often work in pairs that pull bones in opposite directions. For example, in the upper arm there are two large muscles: the biceps at the front and the triceps at the back. When the biceps contracts, it bends your arm. When the triceps contracts, it straightens the arm.

Muscle shapes
Muscles come in a wide variety of shapes, depending on their location and role in the body. Some taper to a point at one or both ends to produce maximum pulling force, while others have simple strap shapes. Circular muscles close body openings, such as the mouth and bladder exits.

Tendons
Tough bands of fibrous tissue called tendons anchor muscles to bones.

Foot tendons
Long, thin tendons run from your leg muscles to your toes. You use leg muscles to move your toes, and arm muscles to move fingers.

Fibers in fibers in fibers
Skeletal muscles, such as those in your legs, consist of bundles of muscle cells, called muscle fibers. Each cell consists, in turn, of a bundle of smaller, rod-shaped fibers called myofibrils, and these are made of even thinner fibers called filaments. The filaments are the parts that create movement. When triggered by a nerve signal, they slide across each other, interweaving to make the cell shorter. All the cells in the muscle contract at once to make the whole muscle shorter.

Biceps bends the arm

Triceps straightens the arm

Myofibril

Filaments

Skeletal muscle

Muscle cell

Bundle of muscle cells

Inner thigh muscle
Also called the sartorius, this long, strap-shaped muscle in the inner thigh is the body’s longest muscle.

Calf muscle
The muscles in the back of your lower leg let you stand on tiptoe.

Thigh muscle
A four-part muscle called the quadriceps forms the front of the thigh. One of the largest and most powerful muscles in the body, the quadriceps extend your leg when you walk, run, and jump.

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The skin

Wrapped around your body like a protective overcoat, your skin forms a barrier between the inside of your body and the outside world.

Skin is waterproof, keeps out germs, and repairs itself. It filters out harmful rays in sunlight, gives you the sense of touch, and helps to control your body temperature. Your skin is just millimeters thick, yet it makes up the largest organ in the body, accounting for about 16 percent of your weight. Its tough outer surface is designed to wear away, so it continually renews itself from below. Skin also produces hair and nails. Like the outer surface of skin, these protective tissues are made of dead cells hardened by a tough protein called keratin.
Nerves

Nerves carry electrical signals from touch and pain receptors to the brain.

Papillae

The top of the dermis is shaped into bumps called papillae. These help bind the epidermis and dermis together.

Meissner’s corpuscles

These receptors sense light touch, but will switch off if stimulated for a long time. That’s why we stop feeling our clothes against the skin a few minutes after getting dressed.

Papillae

The top of the dermis is shaped into bumps called papillae. These help bind the epidermis and dermis together.

Skin color

Human skin varies from pale to dark brown. The color comes from an inky pigment called melanin, which is made by cells in the base of the epidermis. Called melanocytes, these cells spread packets of melanin into the epidermis, where they burst and release melanin granules. The pigment shields the body from strong sunlight.

Skin flakes

Dead cells fall off the skin as flakes.

Basal layer

The base of the epidermis makes new skin cells.

Skin flakes

Dead cells fall off the skin as flakes.

Nerves

Nerves carry electrical signals from touch and pain receptors to the brain.

Blood vessels

Nutrients and oxygen are brought to the skin by a network of fine blood vessels.

Fingernails

Fingernails improve the delicate sense of touch in our fingertips by creating counter pressure when we touch or hold something. They also help us pry and grip very tiny objects. The top part of a nail—the plate—is made of dead cells packed solid with the tough protein keratin. Underneath the plate is the living nail bed—a special type of skin that produces nail cells rather than ordinary epidermis cells. The nail bed contains the most rapidly dividing cells in the human body.

Fingernails grow about three times faster than toenails.

Fingernails

Fingernail growth chart:
- Fingernails grow about three times faster than toenails.
- 0.12 in (3 mm) — the average length nails grow in a month.
- 18½ ft (5.6 m) — the world record for the longest human hair.

Fingerprints

Look closely at your fingertips and you’ll see tiny ridges in swirling patterns. These exist to improve your grip, like the tread on tires. No two people have the same pattern of ridges, which is why police use fingerprints to identify suspects. Fingerprint experts look for distinctive features like whorls (spirals), arches, and loops when they compare prints.

How hair grows

Like nails, hairs are made of dead cells packed with keratin. They grow from living roots in the base of pits called follicles. A typical hair grows for 2–3 years, after which its blood supply is cut off and the root dies. A new hair then starts growing and pushes the old one out. We shed 50–100 old hairs every day.

How hair grows

- Old hair is pushed out by new hair
- Cells divide here to make hair grow
- New hair
- Hair follicle
- Muscle
- Old hair

Straight, wavy, or curly

The shape of your hairs affects the style in which they grow. Hairs that are round in cross section (cylindrical) tend to grow straight. Hairs that are oval in cross section tend to grow in a wavy style, and hairs that are flat tend to grow curly. Curly hair can also be caused by hairs emerging from the skin at a slanted angle.
FUELING THE BODY

Every cell in the human body needs a continual supply of fuel and oxygen in order to stay alive. The fuel comes from the food we eat, while oxygen comes from the air. Inside each cell, food molecules and oxygen are chemically combined to release the energy needed to power the cell's activities. Several body systems work together to supply cells with fuel and oxygen and carry away waste. These include the digestive system, the respiratory system, the circulatory system, and the urinary system.

DIGESTION

Food is a mixture of many different organic compounds, including carbohydrates, fats, and proteins. These compounds are made of long, chainlike molecules that are too big to pass into the blood and enter body tissues. The process of digestion breaks down these large molecules into smaller units that are easy to absorb. Digestion turns carbohydrates into sugars, proteins into amino acids, and fats into fatty acids.

Digestive system

The parts of the body that break down food make up the digestive system. Digestion begins in the mouth, which breaks down food physically. Swallowed food then passes to the stomach and intestines, where it is broken down chemically. The intestines also absorb the products of digestion and expel the undigested remains.

Enzymes

Digestive organs produce chemicals called enzymes, which break the bonds in food molecules to turn the long chain molecules into smaller units. There are many different enzymes, each one specialized to break down a particular type of food molecule. The enzyme sucrase, for example, breaks down sucrose (table sugar) in the intestines.

Healthy diet

The main nutrients in food are proteins, which help the body build and repair tissues; carbohydrates, which provide energy; and fats, which are used for storing energy. A healthy diet should also include plant fiber, which is indigestible but helps the intestines work, as well as essential chemicals called vitamins and minerals, which are needed in small amounts. A varied mixture of different types of food, as shown in the wheel below, helps ensure a balanced diet.

Energy from food

Scientists measure the energy in food in calories. The amount of energy you need depends on how active and how old you are. If you eat more calories than you need, the extra energy is stored in your body as fat. Regularly eating too much can make you overweight, which can lead to health problems, especially in later life.

RESPIRATION

The human body is powered by the same chemical process that powers a car. Inside a car engine, fuel reacts with oxygen to release energy, which turns the wheels. In the human body, food molecules react with oxygen inside cells. The process of obtaining oxygen from the air and then using it in cells is called respiration. The organs that bring oxygen into the body make up the respiratory system.

Respiratory system

The main organs of the respiratory system are the lungs (soft, spongy organs that fill most of the space in the chest) and the airways that lead to the lungs, such as the trachea (windpipe). Inflated by the muscles surrounding them, the lungs suck in air and allow oxygen to pass into the blood, while waste carbon dioxide gas passes in the other direction.
**Cellular respiration**

Food molecules contain trapped chemical energy, just as gasoline put into a car contains trapped energy. Living cells release this energy through a process called cellular respiration. Molecules such as sugars are made to react with oxygen molecules.

\[
\text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \rightarrow 6\text{CO}_2 + 6\text{H}_2\text{O} + \text{energy}
\]

**Mitochondria**

Cellular respiration takes place in microscopic power plants called mitochondria, which are found in every cell. Some cells have only one or two mitochondria, but a cell that uses a lot of energy—such as a muscle cell—may have hundreds. Each mitochondrion is enclosed by two membranes: a flat outer membrane and a deeply folded inner membrane. The chemical reactions of respiration happen on the inner membrane.

**TRANSPORT**

The human body contains thousands of miles of blood vessels, from arteries as thick as your thumb to capillary vessels finer than hairs. Like a network of roads that reach every house in a country, blood vessels deliver vital supplies to every living cell in the body, as well as carrying away waste.

**Circulatory system**

The heart and blood vessels make up the body’s circulatory system. With each beat, the heart pumps blood out through thick-walled vessels called arteries. Blood returns to the heart in veins. Between the arteries and veins is a vast network of tiny vessels called capillaries, which have thin walls that let oxygen, food molecules, and other chemicals pass freely across.

**How blood works**

Blood is a liquid tissue, made up of billions of cells suspended in a watery liquid called plasma. By volume, blood is about 54 percent liquid and 46 percent cells. Oxygen is carried by a protein called hemoglobin in red blood cells. Food molecules, hormones, salt, wastes, and various other chemicals are carried dissolved in plasma.

**WASTE DISPOSAL**

The chemical reactions that happen inside cells produce wastes that would poison the body if allowed to build up. These chemicals are carried by the blood to various organs that destroy or get rid of them, including the kidneys, liver, skin, and the lungs, which breathe out waste carbon dioxide.

**Urinary system**

Many of the wastes in the blood are removed by two bean-shaped organs called kidneys. These filter blood continually, removing excess water and various chemicals, which form a fluid called urine. The urine drains to a storage organ called the bladder, ready to be expelled from the body. The kidneys, bladder, and urine-carrying vessels make up the body’s urinary system.

**Urine contents**

Urine consists mostly of water and a compound called urea, which is produced in the liver when excess proteins are broken down. The other compounds in urine are mostly salts. The amount of water in urine rises if you drink lots of fluid and falls when you’re thirsty.

- **94%** water
- **3.5%** urea
- **1%** sodium
- **0.5%** chloride
- **0.25%** potassium
- **0.25%** phosphate
- **0.25%** sulfate
- **0.15%** creatinine
- **0.1%** uric acid
From mouth to stomach

Just the thought or smell of food is enough to get digestive juices flowing in the mouth and stomach. As soon as food enters the body, it’s mashed to a pulp and attacked by chemicals that begin to break it down.

Most of the nutrients in food are long, chainlike molecules that are too big to dissolve in water and be absorbed by the blood. The process of digestion turns these giant molecules into tiny units the body can absorb. The first stage of the process is physical: we tear, crush, and mash food as we chew it with our teeth. This physical action helps digestive juices penetrate the food to break it down chemically.

Inside the mouth

Unlike cats and dogs, which can wolf down large chunks of food, human beings have to chew food before swallowing it. Inside the mouth, food is mashed by the teeth and mixed with a watery fluid called saliva (spit). Saliva moistens food to make it slippery and easier to swallow. It also contains chemicals called digestive enzymes, which break large food molecules into fragments. The enzyme amylase breaks down starch molecules from foods like bread and rice, turning them into sugar. The enzyme lipase breaks down fat molecules.

Swallowing

Food doesn’t simply fall to the stomach when you swallow it. Instead, it’s pushed through a tube called the esophagus by muscle action. The wall of the esophagus contracts behind the food to squeeze it along. A wave of contraction shoots all the way down the esophagus, pushing food to the stomach in 7–8 seconds.
How teeth work

Our teeth are the first line of attack in the digestive process, chomping and grinding food into smaller pieces. We have two sets of teeth during our lifetime: 20 milk teeth that last 6–10 years, followed by 32 permanent teeth. There are several different types of teeth. The front teeth (incisors) have thin edges that make them good for snipping and biting into things. The rear teeth (molars and premolars) are broader, with bumpy tops suited to grinding and crushing food. Canines are pointed teeth used for piercing and gripping. Human canines are small, but other mammals have long, sharp canines called fangs.

In the stomach

Like a food processor, the stomach churns and mixes food until it turns into a thick liquid. Glands in the stomach wall secrete acid and enzymes that work together to break down protein molecules in food such as meat and fish. The stomach’s wall can’t absorb nutrients from food, but it can absorb water and medicines such as aspirin.

Filling and emptying

The stomach expands like a balloon as it fills. It can comfortably hold about 2 pints (1 liter) of food and drink when full but can expand to three times larger than this. Food spends from 40 minutes to 5 hours in the stomach, depending on how large and rich a meal is.

1 Filling up

The stomach expands and secretes gastric acid as you eat. The food and gastric acid collect in a pool at the bottom of the stomach.

2 Churning

Muscles in the stomach wall contract rhythmically to stir the food and digestive juices together. Enzymes in the gastric acid chemically break down proteins.

3 Emptying

A ring of muscle (the pyloric sphincter) opens up to let food pass into the intestine. The wall of the stomach contracts to squirt the liquefied food out.

Loud rumbling sounds happen when the stomach is empty and its muscles contract to push unused digestive juices into the intestine.
The intestines

Coiled up in your abdomen, your small and large intestines form a single tube some 28 ft (8 m) long. As food travels through, a collection of chemicals breaks it down into molecules the body can absorb.

The intestines make up the most important part of the digestive system. Here, the process of chemical digestion is completed, and the nutrients released are absorbed into the bloodstream to be carried to other parts of the body. Like the stomach, the intestines have muscular walls that contract to squeeze food along. It takes only a few hours for a meal to pass through the small intestine, by which time nearly all the nutrients are absorbed. The remains then spend up to a day traveling slowly through the large intestine, where water is absorbed and bacteria help digest tough fibrous matter. The journey ends at the anus, where the undigested remains leave the body as feces.

Chemical attack
As soon as food leaves the stomach and enters the small intestine, it is mixed with powerful digestive chemicals from two nearby organs: the gall bladder and the pancreas. The gall bladder secretes a green liquid called bile, which neutralizes stomach acid and turns fats into tiny droplets that are easier to digest. The pancreas secretes at least seven digestive enzymes. These attack carbohydrate, protein, and fat molecules, breaking them down into smaller units.

Absorbing food
Lining the inside wall of the small intestine are millions of tiny, fingerlike growths called villi, each about 0.04 in (1 mm) long. Villi absorb the small food molecules produced by digestion, such as sugars and amino acids. These molecules pass into blood vessels in the villi to be carried away. Together, all the villi provide a huge surface area for absorption to take place. If all your villi were stretched out flat, they would cover the same area as a tennis court.
Small and large intestines
The intestines run all the way from the stomach to the anus. There are two main sections. The first, longer section is the small intestine and does most of the work of digesting and absorbing food. The second section, called the large intestine, is twice the width of the small intestine and a quarter of its length. It receives watery leftovers from the small intestine and turns them into feces.

Stomach
Food stays inside the stomach until it has turned into a creamy liquid.

Pancreas
This organ produces enzymes that break down proteins, fats, and carbohydrates.

How digestion works
The nutrients in food are locked up in giant molecules that our bodies can’t absorb directly. The process of digestion breaks these molecules into smaller molecules that can dissolve in body fluids and enter the blood. The digestive organs produce a range of chemicals called enzymes to break down food. Each enzyme attacks a particular type of food molecule.

Fats
Butter and oil are sources of fat. Enzymes in the small intestine break down fat into glycerol and fatty acid molecules.

Proteins
Meat and cheese are rich in protein. Enzymes in the stomach and small intestine break protein molecules into amino acids.

Carbohydrates
Foods rich in carbohydrates include pasta, rice, and bread. Enzymes in the mouth and small intestine split large carbohydrate molecules into sugars.

Taking time
Getting all the nutrients from food takes time. From eating a meal to passing out the undigested remains can take between 20 and 44 hours. The speed depends on what you’ve eaten. Fruit and vegetables pass through the body much more quickly than meat.

100 trillion bacteria live inside the intestines, outnumbering human cells in the body. These bacteria release extra nutrients from food rich in fiber.
Blood is the body's transport system. It carries food, oxygen, hormones, heat, and other vital resources to every living cell in the body, as well as taking away waste.

Blood circulates endlessly around the body, traveling through thousands of miles of tubes called blood vessels. The largest blood vessels are as thick as a garden hose. The tiniest are a tenth as wide as a hair and too small to see with the naked eye. As blood flows through the thinnest vessels, it releases oxygen and nutrients to keep the body's cells alive and functioning. It collects wastes from the same cells and carries them away to be removed from the body. Blood also contains cells that battle against germs and heal wounds. Other roles of blood include transporting chemical messengers called hormones and helping spread heat around the body.

**What's blood made of?**

Blood is a living tissue, consisting of about 20 trillion tiny, living cells floating in a yellowish liquid called plasma. Plasma is mainly water, but it also contains hundreds of vital substances that your body tissues need to stay alive, such as salt, sugar, fat, and protein. It also carries waste chemicals away. An average adult has about 10.6 pints (5 liters) of blood.

**Circulatory system**

The heart and blood vessels make up the body's circulatory system. Blood leaves the heart in vessels called arteries (shown in red), which divide into finer and finer branches. It then passes through tiny vessels called capillaries, where it releases nutrients and collects waste. Capillaries join to form larger vessels called veins (shown in blue), which take blood back to the heart.

**Vena cava**
The largest vein is called the vena cava. It carries blood back to the heart.

**Heart**
The heart is a muscular pump that pushes blood around the body.

**Aorta**
As thick as your thumb, the aorta is the body's largest artery.

**Jugular vein**
This large vein in the neck carries blood from the head to the heart.

**In the brain**
About 20 percent of your blood flow goes to your brain.

**54%**
plasma

**1%**
white blood cells and platelets

**45%**
red blood cells

**Red blood cells**
These cells carry oxygen. They make up a quarter of all your body's cells.

**Platelet cells**
If your skin is cut, these cells make the blood clot.

**Blood cells**
There are three main types of blood cells. By far the most numerous are red blood cells. These bright red, disc-shaped cells have the sole task of collecting oxygen in your lungs and releasing it everywhere else in your body. White blood cells roam through the body hunting for germs and destroying them. Platelet cells are tiny cell fragments that help blood to clot when the body is injured.
Bone marrow is found in the center of certain bones.

**Arteries**
These large blood vessels carry blood away from the heart. They have strong, muscular walls that stretch as blood surges past with each heartbeat. After stretching, arteries shrink back to normal size, which helps push the blood along.

**Veins**
Blood vessels that carry blood back to the heart are called veins. They have thinner walls than arteries. The force of the heartbeat is much weaker in veins, so veins use one-way valves to keep blood flowing.

**Capillaries**
Microscopic blood vessels called capillaries carry blood between arteries and veins. There are thousands of miles of capillaries running through almost every part of the body. Their very thin walls allow oxygen and nutrients to pass out of the blood into body tissues, as well as allowing waste to enter the blood.

**Making blood**
Every second, about 2 million of your red blood cells die and 2 million new ones are made. New blood cells are made in bone marrow—a soft, fat-rich tissue found inside hollow bones. White blood cells are also made in bone marrow.

**How blood clots**
When your skin is cut, a series of chemical reactions causes proteins in blood plasma to form a tangle of threads that trap blood cells. At the same time, the tiny platelet cells in blood change shape, becoming spiky, and then stick together in clumps. These two processes make blood turn solid—it clots. The clotted blood hardens and dries to form a protective scab.
The heart

People once thought the heart was the seat of thought and emotion, but now we know better: it is simply a muscular pump that beats tirelessly to keep blood flowing.

Unlike other muscles in the body, which need to rest and recover after heavy use, the heart is built to work nonstop. It beats 70 times a minute, 100,000 times a day, and 40 million times a year—pumping enough blood in the average lifetime to fill three supertankers. With each beat it squeezes out about a cupful of blood, using sufficient force to keep blood moving through the body’s 60,000 miles (100,000 km) of blood vessels. A continual supply of fresh blood is vital to the body’s cells because without it, they will die of oxygen starvation in minutes.

Beating heart

Hollow in the middle and with thick walls of powerful muscle, the heart is about the same size as a clenched fist—and just as strong. The top of the heart is connected to a maze of heavy-duty blood vessels. Blood pours in through vessels called veins, filling the heart’s inner chambers. When the heart beats, its muscular wall squeezes and forces the blood out through vessels called arteries.

Heart cells

The heart is made of a special type of muscle (cardiac muscle), seen here magnified thousands of times by a microscope. Heart muscle cells burn through energy at a rapid rate and need more fuel and oxygen than other cells. They are fueled by fat, and the energy is released by oval-shaped bodies called mitochondria. Like ordinary muscle cells, they are packed with microscopic protein fibers arranged in parallel. These fibers slide across each other to make the cells contract.
Heart valve
Inside the heart are four large valves that make sure the blood flows one way only. Heart valves have two or three flaps that are forced apart by a surge of blood when the heart pumps. When the blood tries to flow back, it fills the flaps and pulls them together, shutting the valve. The sound of your heartbeat is the sound of your heart valves snapping shut.

Nerves
Nerves carry signals from the brain to the heart, telling it when to beat faster or slower.

Pulmonary vein
After collecting fresh oxygen in the lungs, blood flows back to the heart along the pulmonary vein.

Coronary arteries
As well as pumping blood to the body, the heart pumps blood through its own muscular wall. Heart muscle works very hard and needs a generous supply of oxygen-rich blood.

Coronary vein
After delivering oxygen and fuel to the muscular wall of the heart, used blood flows back along veins (shown in blue).

Valves
One-way valves stop blood flowing backward.

Atria
The heart has two small top chambers called atria.

Left ventricle
This large, muscular chamber pumps blood to most parts of the body.

Right ventricle
The smaller right-hand chamber pumps blood to the lungs and back.

Heartbeat cycle
Each beat of the heart involves several carefully timed steps. The whole sequence is controlled by a wave of electricity that sweeps through the heart’s muscular wall, triggering the contraction of muscle cells.

1 Filling up
Between heartbeats, blood enters the heart through veins and collects in the top chambers (atria).

2 Atria contract
The top chambers contract, pushing the blood through valves into the two lower chambers (ventricles).

3 Ventricles contract
Finally, the ventricles contract with great force, pushing the blood out to every part of the body.

In one year, the heart pumps enough blood to fill an Olympic-size swimming pool.

Average heart rate: 70–80 beats per minute
Tears
With every blink, watery tears wash dirt and bacteria off the surface of your eyes. Tears also contain lysozyme, a chemical that destroys the cell walls of bacteria.

Saliva
Continually produced by glands in your cheeks and under your tongue, saliva flushes germs out of your mouth and into your stomach, where acid destroys them. Saliva also contains a range of antibacterial chemicals that attack germs.

Tonsils
These soft red areas at the back of the mouth are packed with white blood cells that destroy germs from food or the air. When you have a sore throat caused by viruses or bacteria, your tonsils swell up as they help fight the germs.

Skin
Your skin forms a thick, protective barrier that germs cannot cross, unless the skin gets cut. Glands in the skin secrete sweat and an oily fluid called sebum, both of which contain chemicals that repel germs.

Stomach acid
The lining of the stomach makes powerful hydrochloric acid, which destroys germs in food. It also kills the germs in mucus from the throat, which we swallow regularly to help keep the airways clean.

Lymph node
As body fluids flow through the vessels of the lymphatic system, they are filtered through swellings called lymph nodes, which vary from the size of a period to the size of a grape. They are packed with white blood cells that screen the passing fluid for germs and destroy them.
Fighting germs

Your body is under constant attack. Tiny organisms are continually trying to get inside you and multiply, which can make you sick. Fortunately, your body has a powerful immune system to repel the invaders.

The first line of defense against germs is your body’s surface, which acts as a barrier. The surface includes not only your skin but also the surface of your eyes and the soft tissues lining your mouth, nose, throat, and stomach. If germs find a break in any part of your body—such as a cut—the damaged tissue reacts immediately by becoming inflamed: it swells and fills with germ-destroying blood cells. Many parts of the immune system work to block all kinds of germs, but others are more specific. Your adaptive immune system identifies new germs and then targets them specifically. It also remembers them for the future, giving you immunity to the diseases they cause.

Filtering germs

Germs that break through the body’s barriers and invade internal tissues do not usually survive for long. The human body contains a network of tiny vessels that collect fluid from every organ and carefully filter it for germs, which are swiftly destroyed. This network of vessels is called the lymphatic system. Dotted along its vessels are small filtering units called lymph nodes, which are packed with germ-destroying cells.

An allergy occurs when the immune system attacks something harmless, like pollen or household dust.

How antibodies work

Antibodies are chemicals that stick to specific kinds of germs, flagging them for destruction. There are millions of different germs, but the human body can manufacture 10 billion different antibodies, ensuring there’s one for any germ you encounter. Once an antibody cell has been activated by meeting a matching germ, it makes copies of itself and makes the body immune.

1. Infect
   A new germ invades the body and multiplies. It gets carried by body fluids to a lymph node, where many different white blood cells examine it.

2. Detect
   Antibody cells touch the germ to see if it matches molecules on their surface. Eventually, an antibody cell with matching molecules sticks to the germ.

3. Activate
   Now activated, the matching cell makes an army of clones. It also makes memory cells, which will stay in the body for years in case the germ returns.

4. Seek
   The clones make antibodies and release them into the blood. When they find germs, they stick to them.

5. Destroy
   The antibodies act as guides to cells called macrophages, which swallow and destroy the germs.

A vaccine triggers your body into producing antibodies, making you immune to a disease without having to suffer it.
**Waterworks**
The bladder’s stretchy wall allows it to hold up to 1.48 pints (700 ml) of urine, but the urge to pass urine is triggered when it contains just a quarter of this.

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**Bladder full**
The bladder’s muscular wall stretches as it fills up. This activates nerve cells embedded in the bladder wall, which send signals to the brain and trigger the urge to urinate.

**Bladder empties**
Circular muscles called sphincters normally keep the bladder’s exit closed. When you urinate, the sphincters open and the bladder’s wall contracts to force urine out through the urethra.

**Why is it yellow?**
The yellow color of urine is due to a waste chemical produced when the body breaks down old red blood cells. Some foods change the color of urine—beets makes it pink and asparagus makes it green. The amount of water in urine also affects its color.

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**SHADES OF YELLOW**

- **ENOUGH WATER**
  Urine is pale when it contains lots of water and dark if it contains little water. If your urine looks dark yellow, you need to drink more water.

- **DEHYDRATED**

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**Urinary system**
The urinary system includes the two kidneys, the bladder, and various tubes for carrying urine. The kidneys are reddish-brown organs on either side of the spine, each about the size of a computer mouse. The urine they make trickles constantly down two long tubes called ureters to a stretchy storage organ—the bladder. When this is full, the urine leaves the body through a tube called the urethra.
Cleaning the blood

The body has its own internal cleaning service called the urinary system, which filters the blood. It removes toxic wastes and excess water from the body, turning them into urine, while keeping back useful substances.

As well as carrying substances like oxygen and food around the body, the blood picks up chemical waste products. These chemicals would poison us if they were left to build up, so they are removed by the urinary system.

Blood is filtered and cleaned in a pair of bean-shaped organs called kidneys, which are located next to the spine. Every day, all the blood in the body passes through the kidneys 300 times. Although we have two kidneys, just 75 percent of one kidney would be enough for us to survive without becoming ill. That’s why some people are able to donate one of their kidneys to someone whose own kidneys have been damaged by disease.

Water balance

As well as getting rid of waste chemicals, the urinary system helps us maintain a healthy level of water in the body. When there’s too much water in the blood, the kidneys allow a lot of water to pass into the urine. When the water level in the blood is low, the brain releases a hormone that tells the kidneys to reabsorb some of the water from urine. As a result, we produce a smaller volume of darker, more concentrated urine when we’re dehydrated.

In and out

Most of our water comes from food and drinks, but a small amount is “metabolic water”—water created by chemical reactions in our cells. We lose water mainly through urine and through breathing.

Inside the kidney

Each kidney contains about one million microscopic filtering units called nephrons. The first part of a nephron is a tiny, tangled knot of blood capillaries that allows fluid to leak out. The fluid then flows along a long, looping tube, from which useful substances and water are reabsorbed. The leftover fluid becomes urine and drains out of the kidney to be stored in the bladder.

Blood filter

In the filtering units of the kidneys, blood flows into knots of tiny blood vessels called capillaries (pink, above). Wrapped around these are cells called podocytes (beige, above). The podocytes act as sieves, allowing small molecules such as water to pass through but stopping cells and larger molecules from leaving the blood.

In medieval times, doctors attempted to diagnose disease by studying urine. They examined its color, smell, and cloudiness—and then tasted a sample.
Air supply

Every minute, without you thinking about it or even noticing, your lungs take in about 15 breaths of air. This vital process of breathing keeps all the cells in your body supplied with the life-giving gas oxygen.

Oxygen is essential for life. Without it, the cells in your body would not be able to release the hidden energy trapped in food molecules. With each gulp of air, fresh oxygen is drawn deep into your lungs. The air is channeled through hollow tubes that branch into finer and finer passages. Finally, it reaches a dead end, formed by millions of tiny, bubble-shaped pockets that swell up like balloons as they fill with air. Oxygen passes through the walls of these air pockets and into the microscopic blood vessels that surround them, to be carried away by red blood cells. The waste gas carbon dioxide travels the opposite direction, from the blood to the air pockets, to be breathed back out.

Inside the lungs

The lungs are spongy, lightweight organs that fill most of the space inside the chest. They are 10 percent solid and 90 percent air, making them so light that they could float on water. The combined surface area of all the tiny air pockets inside the lungs is huge: about 750 sq ft (70 square meters), which is 40 times the surface area of your skin. The surface area needs to be large so that as much oxygen as possible can be absorbed from the air with each breath.

Air pockets

The tiny air pockets in the lungs are called alveoli. Each single alveolus is just a fraction of a millimeter across and has a network of blood vessels wrapped around it. The walls of the alveoli and blood vessels are so thin that oxygen can pass freely across to enter the blood.
Blood vessels
Large blood vessels carry stale blood directly from the heart to the lungs and carry fresh, oxygen-rich blood back to the heart.

Heart
The heart fits snugly in a hollow between the lungs, slightly to the left side of the body.

Cleaning the lungs
Air contains tiny flecks of dust and germs that could damage our lungs. To get rid of this dirt, the airways make a sticky liquid called mucus, which traps particles. Microscopic hairs lining the surface of the airways beat back and forth to push the mucus upward to the throat, so it can be coughed or sneezed out or swallowed.

How breathing works
The lungs have no muscles. To suck in air and push it out again, they rely on the muscles around them. The diaphragm muscle does most of the work, but the rib muscles also help, especially when you breathe deeply.

Breathing in
The diaphragm contracts and pulls flat, and the rib muscles lift up the ribcage. The chest gets larger, making the lungs expand and suck in air.

Breathing out
The diaphragm relaxes and springs upward, and the ribcage falls back down. The chest gets smaller, squeezing the lungs and pushing out air.

Gas exchange
Because the lungs take oxygen from the air and release waste carbon dioxide, the air you breathe in is different from the air you breathe out. There is also a lot more water vapor in exhaled breath, from moisture in the airways. On a cold day you can see this moisture turn into mist when you breathe out.

You breathe in about 21,000 pints (10,000 liters) of air every day. That’s enough to fill 1,000 balloons.

Lungs and lobes
Your right lung is slightly bigger than your left lung. It has three parts, or lobes, while the left lung has only two. Like many parts of the body, lungs come in pairs. If one becomes damaged by injury or disease, the other acts as a backup, keeping you alive on its own.
CONTROL CENTER
The brain and spinal cord make up the central nervous system, which serves as the nervous system’s control center. In very simple animals, brains do little more than coordinate basic reflexes, a task carried out in humans by the spinal cord. The human brain, however, has evolved into something far more complex, able to generate an inner world and a conscious self that can reflect, plan, and make decisions. How these higher functions work remains a mystery to science.

The human brain
Filling the space inside the skull, the human brain is dominated by a large, folded structure called the cerebrum. Far larger in humans than in other animals, the cerebrum is responsible for conscious thought, planning, social judgment, and language. Beneath the cerebrum is the limbic system, which generates emotions, and the cerebellum, which coordinates movement.

Brain evolution
The human brain shares many features with the brains of other vertebrates (animals with backbones)—a sign of our shared evolutionary history. Our closest vertebrate relatives are other mammals, which, like us, have a large cerebrum. The thinking part of the brain, the cerebrum allows mammals to learn complex behaviors. The mammal brain also includes a limbic system, which produces emotions such as rage and fear.

Brain in action
Until recently, scientists could only guess at how the brain creates thoughts. The invention of brain scanners has provided a window on its workings. Functional brain scans reveal that different brain areas specialize in specific tasks, yet mental processes often involve many brain areas working together.

Brain scan
This MRI scan shows the right side of the brain light up as a person moves their left hand.

NERVOUS SYSTEM
The brain, nerves, and sense organs make up the body’s nervous system. The nervous system carries information around the body in the form of electrical signals. The various parts of the system are in constant communication and continually active. Messages stream into the brain from the senses every split second. At the same time, the brain coordinates the exact tension of hundreds of muscles around the body, from the tiny muscles that move the eyes to the large muscles needed for running.

Sensing and reacting
The nervous system has three main parts. The first part collects information from sense organs that monitor the outside world and the inner state of the body. The second part—the central nervous system—processes the information and creates a sense of awareness. The third part makes the body react. These three parts work together very quickly, allowing the body to react to a stimulus in a split second.

Voluntary and involuntary actions
Some of the responses made by our nervous system are under voluntary control, while others are involuntary—they happen without our choice. The voluntary division is called the somatic nervous system, while the involuntary division is called the autonomic nervous system.

IN CONTROL
Just as an orchestra needs a conductor, so the many organs in the human body need to be coordinated to work together well. The nervous system is the body’s main control network. Using high-speed electrical signals, it sends messages along cables called nerves, controlling muscles, glands, and organs. The body also uses chemicals called hormones to send messages via the blood. These act more slowly than nerves.

Control network
Many of the body’s nerve cells are bundled together to form cables called nerves. Nerves run to every part of your body, carrying signals to and fro at up to 250 mph (400 kph). Most nerves communicate with the brain via the spinal cord—a column of nervous tissue inside the spine.

Central and peripheral systems
The brain and spinal cord make up the central nervous system (green, above), while the rest of the body’s nervous tissue makes up the peripheral nervous system.

Somatic nervous system
This branch of the nervous system controls parts of the body that you control at will, such as the muscles you use to hold this book or kick a ball.

Autonomic nervous system
This part of the nervous system controls organs without you having to think. It makes your heart speed up and slow down, pushes food through your intestines, and controls how wide the pupils in your eyes are.
**Nerve cells**
The cells that make up the nervous system are called nerve cells, or neurons. Neurons transmit electric signals along long fibers called axons, which are sheathed by a fatty material called myelin to help the signal travel faster. There are three main types of neurons.

**Unipolar neurons**
These neurons typically carry incoming sensory signals. The cell body has a single extension.

**Bipolar neurons**
These neurons are found in the eyes and in muscles. The cell body of a bipolar neuron has two extensions.

**Multipolar neurons**
Found in the brain, these are the most common neurons. The cell body has multiple extensions.

**Hormones**
The electric signals that shoot down nerves are not the only messages traveling around the body. Hormones are chemicals that carry messages. They are released into the blood by glands and have powerful effects elsewhere in the body, acting more slowly than nerve signals. Hormones affect only certain target cells, changing the way they work. There are two main ways that hormones can activate their target cells.

**Water-soluble hormones**
These hormones can dissolve in water but not fat. They are unable to pass through the cell membrane of target cells, which have fatty layers. Instead, they bind to receptors on the cell surface and trigger chemical changes inside the cell.

**Fat-soluble hormones**
These hormones can dissolve in fat. They pass through the membrane of target cells and bind to receptor molecules inside the cell. The hormone then enters the cell nucleus and switches certain genes on or off. Fat-soluble hormones include sex hormones, such as testosterone.

**Senses**
Sense organs gather information about the world and send it to the brain as a stream of electric signals. The brain then decodes this information and uses it to create a feeling of conscious awareness.

**Main senses**
Five main senses dominate our inner world, with vision being by far the most important. Most of our main senses are created by specialized organs, such as eyes and ears. Large areas of the brain are devoted to processing the incoming signals from these organs.

**Vision**
This sense comes from neurons that detect light. Like cameras, eyes focus light to create an image.

**Hearing**
Sound consists of invisible waves traveling through air at high speed. Our ears capture and amplify these waves.

**Smell**
Neurons in the roof of the nose create this sense by detecting thousands of different chemicals in the air we breathe.

**Taste**
Chemical sensors in the mouth detect five tastes: salty, sweet, sour, bitter, and savory (umami).

**Touch**
Skin contains a range of different sensory receptors sensitive to different types of touch.

**Gravity**
The inner ear contains tiny gravity sensors that tell the brain which way is up, helping us balance.

**Time**
A clusters of neurons in the heart of the brain works as an inner clock, helping us sense time.

**Additional senses**
The human body has far more than five senses. Our additional senses help us to move, balance, and detect heat, pain, and the passage of time.

**Bladder and rectum**
Stretch sensors in the bladder and rectum walls trigger the urge to go to the bathroom.

**Heat**
Heat sensors all over the skin, lips, and mouth can feel warmth or cold, even from a distance.

**Muscle sense**
Muscles contain stretch sensors that tell the brain about the body’s posture, position, and movement.

**Hormone binds to cell**
Hormone
Receptor
Chemical reaction triggered
Nucleus
Cell reacts
Hormone binds to receptor
Hormone enters nucleus
Cell reacts
Gene switched on

THE HUMAN BRAIN CONTAINS ABOUT 100,000 MILES (165,000 KM) OF AXONS.
Nervous system

The human body is controlled by a network of living wires called the nervous system. While man-made wires carry power, the cells that make up the nervous system carry information.

Your nervous system makes it possible for you to react to the world with lightning speed. Every moment, electrical signals from your senses shoot along your nerves, racing toward your brain at up to 250 mph (400 kph). Your brain analyzes the flood of incoming information, decides how to respond, and sends outgoing signals to muscles and other organs, telling them what to do. Much of your nervous system is under voluntary control, which means you can choose how to react. However, many parts of the nervous system work automatically, controlling your internal organs and reflexes without your conscious awareness.

Parts of the nervous system

The nervous system has two main parts. The central nervous system (below, green) consists of the brain and spinal cord. Together, these process incoming signals and decide how the body should react. The peripheral nervous system (yellow) carries signals around the rest of the body, linking the central nervous system to sense organs, muscles, and other parts of the body.

Nerve cells

The nervous system is made up of billions of cells called neurons (nerve cells). These odd-looking cells have many finely branched fibers extending from the main cell body. A typical neuron has one large fiber (an axon) that carries outgoing electrical signals, and a large number of smaller fibers (dendrites) that carry incoming signals. Neurons connect to other neurons at junctions called synapses.
Longest nerve
The sciatic nerve is the longest nerve in the body, running from the spine to the foot.

The number of pain receptors in your brain.

0 The minimum number of synapses in your brain.

2 billion—the approximate number of nerve endings in your skin.

100 trillion—the minimum number of synapses in your brain.

0 The number of pain receptors in your brain.

Inside a nerve
Nerve cells have long extensions called axons that can stretch to 3 ft (1 m) in length. Axons running through the body are bundled together to form nerves, much as electric wires are bundled to form cables. Each axon inside a nerve carries a separate electric signal.

Finger nerves
Nerves in your hands carry signals from touch receptors in your fingers to your brain.

Reflex actions
Most of the signals from your sense organs are processed by your brain before your body reacts. A reflex action, however, happens more quickly by taking a shortcut through your spinal cord. For example, if you touch something painful, a reflex action pulls your hand away before your brain even has time to feel pain.

1 Touching a needle triggers pain receptors in the skin.

2 The pain receptor sends a nerve signal to the spinal cord.

3 The signal passes through the spinal cord.

4 A motor neuron sends a signal to an arm muscle, which contracts.

5 The hand pulls away from the source of pain.

Synapses
Signals travel along nerve cell fibers as a wave of electrical charge. When the charge reaches the end of a neuron, a tiny gap called a synapse prevents it from jumping across. Instead, chemicals called neurotransmitters flood into the gap and trigger a new signal in the next neuron.

Tibial nerve
This nerve makes the calf muscle contract, flexing your foot and providing the push that allows you to walk.

If all the nerve cells in your body were laid end to end, they could wrap around Earth two and a half times.
Brainpower

Locked safely inside your skull is your brain—the headquarters of your nervous system and your body’s control center.

More complex and powerful than the brain of any other animal, the human brain is the most poorly understood organ in the body. Somehow this cauliflower-shaped mass of nerve cells creates a whole inner world of experience and a sense of self. Everything you see, touch, think, dream, and remember is generated within it. In some respects the brain works like a computer, but one that is continually rewiring itself as it learns and adapts. Its basic component is the nerve cell, or neuron—a wirelike cell that sends electrical signals to other neurons, forming complex circuits of activity. Every second, trillions of electrical impulses dart among your brain cells, weaving infinitely tangled paths among an ever-changing maze of connections.
Basic instinct
While the outer part of the brain deals with higher mental processes such as thought, a set of structures deep inside the brain controls basic drives and emotions, such as pleasure, fear, and anger. These structures form what is known as the limbic system.

Brain size
Most of the complex processing happens in the brain's surface—the cerebral cortex, which is packed with synapses. Humans have a far larger cortical area than other animals, giving our brains more processing power.

Sense of touch
The top of the cerebral cortex processes the sense of touch, but some parts of the body have more cortex devoted to them than others. This figure shows how much of the brain receives touch signals from different places, making some parts of the body more sensitive than others.

How memory works
The brain stores memories as networks of connections between neurons. Every new experience or new piece of information makes your neurons fire in a particular pattern. When you recall the event or fact, you make the neurons fire in the same pattern again, strengthening the memory.

1. Experience
   A new experience makes neurons send signals in a particular pattern. In reality, hundreds of neurons are involved in the network.

2. Repeating
   Repeating the experience or recalling the fact causes new links to form, making the network larger and easier to trigger.

3. Strengthening
   Further repetition strengthens the network further, consolidating the memory. Links that are not refreshed tend to fade and are lost.

The thinking brain
The largest and cleverest part of the brain is its outermost layer, the cerebral cortex. Deep folds divide the cortex into distinct areas called lobes, which tend to specialize in different processes, such as speech or vision. However, scans of active brains reveal widespread activity across the cortex during mental tasks, showing that the various areas work together in complex ways.
How vision works

Vision is the most important sense in humans. We gather more information through our eyes than through all our other senses combined.

It takes a fraction of a second for our eyes to take in a scene. They don’t simply take a snapshot. Instead, our eyes dart about quickly and instinctively, resting briefly on details that the brain considers important, such as faces, moving objects, and anything that interests us.

The human eye works much like a camera, capturing light rays and focusing them with a lens to form a pinpoint image. Unlike a photograph, the image in our eyes is highly detailed and brightly colored only in the very center. This small, sharp spot in our visual field is created by a tiny pit in the back of the eye called the fovea. Your fovea forms high-definition images of the words in this sentence as you read it.

Inside the eye

The human eye is a hollow ball filled mostly with clear, jellylike fluid that lets light pass through. The light rays are focused partly by the curved front part of the eye—the cornea—and partly by an adjustable lens. A camera autofocuses by moving its lens, but the human eye focuses by changing the shape of the lens. The image is captured by a layer of light-sensitive cells lining the inside of the eyeball—the retina. The retina then sends the image to the brain as electrical code.

The iris

The colored part of the eye is called the iris. The iris is a ring of muscle fibers that controls how much light enters the pupil. In bright light, the pupil shrinks to 0.08 in (2 mm) wide. In the dark, it widens to 0.5 in (9 mm). The iris reacts not just to light but also to emotion: if you look at something or someone you like, your pupils widen. The iris’s color comes from melanin—the same pigment molecule that gives hair and skin their color.

Aqueous humor

A watery liquid called the aqueous humor fills the front part of the eye.

Ciliary muscle

Surrounding the lens is a ring of muscle that pulls on the lens to change its shape.

Muscle

Each eyeball is attached to six muscles. Working together, they can move the eye in any direction.

Sclera

The white of the eye is the sclera—a tough, protective coat around the eyeball.

Pupil

Light passes through a black hole in the iris, called the pupil.

Cornea

The curved front part of the eye does the bulk of the focusing. Unlike the lens, it cannot change shape.

Lens

Behind the pupil is the adjustable lens. It changes shape to autofocus.

Aqueous humor

A watery liquid called the aqueous humor fills the front part of the eye.

When the pupil opens from its smallest to its fullest size, 20 times more light enters the eye.
**Optic nerve**
Images captured by the retina are carried to the brain by the optic nerve.

**Blind spot**
Blood vessels and nerves enter and leave the eye here. This part of the retina is called the blind spot because it has no light-sensitive cells.

**Retina**
Images are captured by the retina, a layer of light-sensitive cells lining the inside of the eyeball.

**Jelly**
The main part of the eyeball is filled with a jellylike fluid similar to egg white. If you close your eyes, you can see tiny particles floating in this fluid.

**Fovea**
In the middle of the retina is a small pit about 0.04 in (1 mm) wide—the fovea. The fovea is very densely packed with cone cells, giving much more detailed vision than the rest of the retina. Half the nerve signals traveling from the retina to the brain come from here.

**Rods and cones**
The light-capturing cells in the retina come in two types: rods and cones. Cones can see color and fine detail, but they need bright light to work. Rods work in dim light, but they see in black and white and pick up less detail. When it’s very dark, only your rods work, so the world becomes colorless and blurry. Switch on a light and your cones switch on too, giving you high-definition color vision.

**Focusing images**
When light rays leave an object, they diverge (spread out). To create a sharp image, the eye must bend the diverging rays so they come back to a point, a process called focusing. The cornea and the lens work together to focus light on the retina. The image this creates is upside down, but the brain turns it upright.

**Near and far**
When you look at nearby objects, the muscles around the lens in each eye make the lens rounder, increasing its focusing power. When you look at distant objects, the muscles relax and the lens gets flatter. In some people, the focusing power of the lens is too strong or weak. Wearing glasses corrects this.

**Seeing in 3-D**
Our two eyes see the world from slightly different points of view, creating different images. These two images are combined in the brain to create a single, 3-D picture. Seeing in 3-D allows us to judge distance.

| 10,000 | The number of times we blink in a day. |
| 130 | million—the number of rod cells in the eye. |
| 5 | months—the average lifespan of an eyelash. |

8% of males and 0.04% of females are red–green color blind, which means their eyes cannot easily distinguish red from green.
Inside the ear

Sound is caused by invisible waves rushing through air at hundreds of miles an hour. Our ears capture and analyze these fast but faint vibrations to create the sense of hearing.

Throw a pebble into a pond and it will make waves that spread out in circles. Sound works in a similar way, spreading through air as spherical ripples that our eyes cannot see. Unlike a wave in the surface of water, a sound wave is a region of higher pressure where air molecules are briefly squashed together. These pressure waves arrive at our ears at a rate of 20 to 20,000 a second. Deep inside each ear is a delicate membrane—the eardrum—that flutters in response to the incoming waves. This incredibly sensitive device can pick up the faintest sound, and it vibrates at the same frequency as the waves, allowing our ears to gauge pitch.

As well as giving us hearing, our ears contain a number of tiny sensory structures that swing back and forth in response to movement and gravity, giving us a sense of posture and balance.

**Parts of the ear**

The human ear has three different areas: the outer ear, middle ear, and inner ear. The part we can see is the pinna—a flap of rubbery tissue and skin that funnels sound into the ear canal. Its odd shape helps us sense the direction that sound comes from. The ear canal is a hollow tube that runs deep into the skull, carrying sound to the eardrum. Tiny, hinged bones connected to the eardrum transmit the vibrations across the air-filled middle ear to the fluid-filled inner ear.

**Sensing sound**

Vibrations of the eardrum are passed on to and magnified by a chain of three tiny bones (hammer, anvil, and stirrup) in the air-filled middle ear. The final bone in the chain—the stirrup—relays the sound vibrations into the inner ear. The vibrations now travel through fluid into a spiral-shaped organ called the cochlea, which is the size of a pea. Inside the cochlea, the fluid vibrations trigger nerve signals that are sent to the brain.

**Ear bones**

Three tiny bones transmit sound from the eardrum to the inner ear. They work as levers, magnifying the force of the vibrations.

**Smallest bone**

The stirrup bone is only 0.13 in (3 mm) long, making it the smallest bone in the body.

**Air passage**

This air passage between the middle ear and throat keeps air pressure the same on either side of the eardrum.

**Balance organs**

Our ears don’t just detect sound—they also give us a sense of balance. Inside each inner ear is a complicated set of fluid-filled chambers and tubes, and within these are loose structures designed to swing back and forth. Some swing when you turn your head and make the fluid swirl. Others respond to gravity. All these structures send signals to the brain to keep it updated about your body’s position and movement.
How pitch works
Our ears detect sounds with wavelengths from about 0.7 in (1.7 cm) long to 56 ft (17 m) long. Sounds with short wavelengths have a high frequency (thousands of waves per second) and sound high-pitched. Long wavelengths have a low frequency (dozens of waves per second) and sound low-pitched.

Spiraling in
Sound waves enter the outer part of the cochlea first and work their way around toward the center. High-pitched sounds are detected at the beginning, while deeper sounds are detected farther in.

1 High pitch
The outer cochlea detects high-pitched sounds, such as birdsong. A typical song might include sounds with a frequency of about 3,000 waves per second and a wavelength of about 3 in (8 cm). Sounds higher than 20,000 waves per second are too high for most human ears.

2 Medium pitch
Speech contains a complex mixture of different sounds, with frequencies between 100 and 1,000 waves per second and wavelengths between 1 ft (30 cm) and 10 ft (3 m). These are detected in a wide stretch of the cochlea.

3 Low pitch
The deep rumbling of a large truck passing by includes frequencies of 100–200 waves per second, which are detected near the center of the cochlea. Human ears can’t hear sounds deeper than 20 waves a second, though we can sometimes feel these vibrations in our bones.

BATS CAN DETECT SOUNDS 10 TIMES HIGHER THAN HUMAN EARS CAN, BUT THE HUMAN VOICE IS TOO DEEP FOR THEM TO HEAR.
**The human tongue has around 10,000 taste buds, each containing up to 100 taste receptor cells.**

**Smell cells**
High up inside the nose is a small patch of tissue, no bigger than a postage stamp, called the olfactory epithelium. This is where the sensation of smell begins. Odor molecules from air dissolve in the sticky fluid that covers the epithelium and activate tiny hairs (shown in pink above) on smell-detecting cells. The cells then send smell signals to the brain.

**Surface of the tongue**
The surface of your tongue feels rough because it’s covered with hundreds of tiny, fingerlike bumps called papillae, which help the tongue grip food. The largest of these papillae also help create the sense of taste. Embedded in the surface of each one are dozens of microscopic pits called taste buds. These contain sensory cells that detect chemicals like salt and sugar.

**Taste and smell**
The human nose can detect around 10,000 odors, but our mouths react to only five different tastes. These two senses combine in the brain to give the food we eat an infinite variety of flavors.

Taste and smell work in similar ways. Both are “chemosenses,” which means they work by detecting particular chemicals. The distinctive taste of our favorite foods, from pizza to fresh orange juice, is created by both senses working together. In fact, up to 75 percent of what we experience as taste is actually smell—which is why food tastes bland when your nose is blocked. Our senses of taste and smell conjure up pleasurable sensations that tell us when food is rich in energy and safe to eat. They also warn us when something is dangerous by triggering an intense feeling of disgust.

**Nose and mouth**
The sense of taste comes mainly from your tongue, but there are also taste buds in the roof of the mouth, the throat, and even the lungs. The sense of smell comes only from the nose. When food is in the mouth, smell molecules travel around the back of your mouth and into your nose, giving the food its complex flavor.
The tongue
A complicated bundle of eight different muscles, the tongue is an amazingly strong and agile organ. It can reach and manipulate food anywhere in the mouth, and its rough surface keeps the mouth clean. As well as being the main organ of taste, it is also vital for speech.

How taste buds work
Chemicals from food dissolve in the saliva that covers the tongue, and the saliva then enters taste buds through pores (holes) in the papillae. Inside the pores, tiny hairs on the tips of taste receptor cells detect any of the five basic tastes (see below), triggering signals. These signals travel at high speed to the brain, which creates the conscious experience of taste.

Five tastes
Taste buds respond to only five kinds of chemicals, giving us just five main tastes.

- **Salty**: Taste buds sensitive to salt trigger a very powerful, salty sensation.
- **Sweet**: Sweet foods trigger taste buds that detect sugars.
- **Sour**: A sour taste comes from taste buds that detect acids, such as lemon juice.
- **Bitter**: Poisonous or inedible foods trigger taste buds that create a bitter sensation.
- **Savory (umami)**: Some taste buds react to the deep, savory flavor of cooked foods.

Smell and memory
Smells sometimes unlock powerful memories—perhaps the smell of the ocean brings back vivid memories of a happy vacation. Scientists suspect this happens because the part of the brain that recognizes smells has strong links to an area called the amygdala, which plays a key role in emotion and memory.
The endocrine system
The endocrine system consists of a number of hormone-producing glands and tissues scattered throughout the body. The hormones they produce are secreted directly into the bloodstream. Along with the nervous system, the endocrine system keeps the body working in a coordinated way. It plays a vital role in a process known as homeostasis—the maintenance of a stable internal environment within the body.

Control chemicals
Every second of every day, powerful chemicals called hormones course through your bloodstream. Hormones are made in your body and target specific organs, controlling the way they work.

Hormones are complex chemical substances that regulate body functions such as growth, water balance, and sexual development. They are made and released into the blood by organs called endocrine glands. Hormones work more slowly than the electrical impulses that flash through nerves, but they usually have longer-lasting effects.

Hormones reach every part of the body via the blood, but they only affect specific target tissues and organs. When they reach their destination, they trigger major chemical changes inside cells, sometimes switching particular genes on or off to change the way a cell operates. Many hormones are controlled by other hormones, and some hormones work in pairs to keep levels of body chemicals such as sugar in balance.
Ovaries
In females, the two ovaries secrete estrogen and progesterone. These hormones trigger the development of adult sexual features in girls. In adults, they control the monthly reproductive cycle.

Liver converts glucose to glycogen
Pancreas releases insulin

High blood sugar
Pancreas releases glucagon

Liver turns glycogen to glucose

Blood sugar falls

NORMAL BLOOD SUGAR LEVEL

Blood sugar rises

Ovaries
Testes
Intestines

Milk production
The pituitary hormone prolactin triggers a woman's body to start making milk after giving birth.

Uterus
During birth, oxytocin triggers muscle contractions in the uterus, forcing the baby from the womb.

Kidney tubules
The hormone ADH tells the kidneys to reabsorb more water from urine, helping the body retain water.

Adrenalin
When you're scared or excited, your heart pounds and your breathing gets deeper. These are two of the effects of adrenalin, a fast-acting hormone released by the adrenal glands. Adrenalin is called the fight or flight hormone because it prepares the body for sudden action in emergencies. By making the heart and lungs work harder, it helps get extra oxygen and fuel to body muscles.

Adrenalin sports
In sports that involve high-speed action and risky maneuvers, such as wakeboarding, adrenalin increases in response to the excitement, risk, and stress of competition.
LIFE CYCLE

The human life cycle begins as a single cell barely visible to the eye. Programmed by the genes it has inherited, this speck of life divides and multiplies to form a mass of cells, and a new human body begins to grow. We continue growing and developing for around 20 years, by which time we are old enough to have babies ourselves. Like all living things, from the tiniest virus to the tallest trees, human beings strive to create offspring before growing old—a process known as reproduction.

SEXUAL REPRODUCTION

Like most other animals, human beings reproduce sexually, which means that two parents are needed to create offspring. Sexual reproduction mixes up the genes from both parents. Doing so combines characteristics from both parents and makes every child (except identical twins) unique. The parents produce special cells called sex cells. Male and female sex cells fuse inside the mother’s body to form an embryo. Over the following nine months, in the protective environment of the mother’s uterus, the embryo develops into a baby ready for life in the outside world.

Sperm and egg

Male sex cells are called sperm, and female sex cells are called eggs. Both carry a single set of genes, stored on structures called chromosomes. When sex cells join, the two sets of chromosomes combine, giving the new individual a full set of genes. Egg cells are far larger than sperm because they contain a supply of food.

Making sex cells

Sex cells are produced by a special kind of cell division called meiosis. During meiosis, genes are shuffled about between chromosomes, and the total number of chromosomes is halved.

1. Normal cells have two sets of chromosomes: one from the mother (shown in red) and one from the father (green). Before meiosis, each chromosome copies itself, forming an X shape.
2. The cell nucleus disappears. Maternal and paternal chromosomes pair up and swap sections randomly.
3. Fine threads called microtubules attach to the chromosomes and pull each pair apart. The cell starts to divide.
4. There are now two cells, each with half the original number of chromosomes.
5. The cells separate again. Each double chromosome is pulled apart to make two single chromosomes.
6. There are now four sex cells, each with a unique combination of genes and half the normal number of chromosomes. When two sex cells join, the full number of chromosomes is restored.

SPERM ARE THE SMALLEST CELLS IN THE HUMAN BODY, WHEREAS EGGS ARE THE LARGEST.

REPRODUCTIVE SYSTEM

The parts of the body dedicated to creating babies make up the reproductive system. The male and female reproductive systems are very different. Both produce sex cells, but the female reproductive system must also nourish and protect the growing baby.

Male reproduction system

Male sex cells (sperm) are made nonstop in a man’s body—at a rate of 50,000 a minute—inside organs called testes. These hang outside the body within a bag of loose skin called the scrotum. Sperm are delivered into a woman’s body in a liquid called semen after passing through the penis. Sperm cells make up about five percent of this liquid.

Female reproduction system

Female sex cells are made inside a girl’s body before she is born and stored in organs called ovaries. In a woman’s body, an egg cell is released from one of the ovaries every month and travels along a tube toward the uterus. If the egg cell meets a sperm cell, fertilization occurs and the resulting embryo implants itself in the uterus and grows into a baby.
GENES AND DNA

All living cells carry a set of instructions that control the chemical activity inside the cell. These instructions, called genes, are stored as a four-letter code by the molecule DNA (deoxyribonucleic acid). Human cells contain about 20,000 genes. These genes direct the process of development that turns a single-celled embryo into a fully functioning human body made of trillions of cells.

Genetic code

DNA is stored in structures called chromosomes. There are 46 chromosomes in the nucleus of ordinary body cells. Each one contains a single molecule of tightly coiled DNA. If you stretched out a DNA molecule, you’d see that it’s made of two strands twisted together, forming a shape called a double helix. The rungs holding the two strands together are made of chemicals called bases. There are four different bases in DNA, forming a four-letter code running along the molecule. The average gene is spelled out by a sequence of about 3,000 bases.

DNA molecule

DNA has the remarkable ability to make copies of itself by unzipping down the middle and then rebuilding each side. Every time a cell in the body divides, the DNA in the nucleus duplicates itself, making a new copy of every chromosome and every gene.

Sex chromosomes

A person’s sex is determined by two particular chromosomes, called X and Y after their shapes. Females have two X chromosomes, while males have an X and a Y chromosome. The Y chromosome is much smaller than the X and contains fewer genes—less than 100, compared to the 2,000 genes on the X chromosome. A mother’s egg cells always carry an X chromosome, while a father’s sperm can carry either an X or a Y chromosome.

Determining gender

As a mother always passes on an X chromosome to her children, it’s the father’s sperm that determines the sex of a baby. If a sperm carries an X chromosome the baby will be a girl. If it carries a Y chromosome, the baby will be a boy.

END OF LIFE

The human body is not made to last forever. In later life many organs go into decline, and the risk of diseases such as cancer rises. Thanks to advances in medicine, hygiene, and diet, however, average life expectancy is higher today than it has ever been and is still rising. How long you can expect to live depends largely on where you are in the world.

Life expectancy

Average life expectancy varies greatly around the world and is correlated with wealth. In wealthy regions, such as North America and Europe, two-thirds of people live into their 70s. In poor parts of the world, such as Africa, the average is much lower, partly because of a high rate of death during infancy. Children who survive the first few hazardous years of life can expect to live much longer than average.

THE LONGEST CONFIRMED HUMAN LIFESPAN IS THAT OF JEANNE CALMENT OF FRANCE. SHE WAS BORN IN 1875 AND DIED IN 1997 AT THE AGE OF 122 YEARS, 164 DAYS.

Cause of death

In developing countries, infectious diseases such as HIV/AIDS and malaria are among the main killers. Babies and young children are at particular risk of dying from malnutrition (poor diet) or from diarrhea, which is often spread by germs in unclean water. In wealthy countries, where health care, sanitation, and diet are all better, the main causes of death are diseases related to aging, such as heart disease and cancer. Lung diseases are a common cause of death worldwide. Many are linked to smoking. Scientists estimate that smoking causes about one in ten of all adult deaths.

Causes of death worldwide

- Infectious disease
- Heart disease
- Cancer
- Stroke
- Brain disease
- Accidental injury
- Digestive disease
- Deliberate injury
- Lung disease
- Other causes
A new life

A new life begins when two sex cells join and pool their genes together. Male sex cells (sperm) from the father and female sex cells (egg cells) from the mother join inside the mother’s body to form an embryo. In the first few days an embryo looks nothing like a human body, but by four weeks it has a head, the beginnings of eyes, arms, and legs, and its heart has started beating. The images on these pages show what happens in the first month of an embryo’s life. The following pages show what happens in the months leading up to birth.
Inside the uterus
The growing embryo bursts out of the thick coat that covered the egg cell. Doing this will help it stick to the wall of the uterus.

Muscular wall
The wall of the uterus is made of powerful muscles that contract to push the baby out during childbirth.

Cluster of cells
The embryo is 4 to 5 days old when it reaches the uterus. It is now a ball-shaped cluster of cells.

1 week old
A week later, the embryo has developed a yolk sac (yellow) and a fluid-filled space called an amnion (blue). Inside the amnion is a layer of cells—the embryonic disc—that will develop into a baby.

ACTUAL SIZE 🔗 •

2 weeks old
The embryonic disc grows rapidly and folds into a curved shape. Within a matter of days, it develops a head, tail, blood vessels, and the beginnings of major internal organs.

ACTUAL SIZE 🔗

3 weeks old
Now the size of a bean, the embryo has the beginnings of arms and legs, and its heart has started beating. Nerves and muscles develop, and eyes begin to form, at first without eyelids.

ACTUAL SIZE 🔗

4 weeks old
Like a seed planted in the ground, the embryo implants in the soft inner lining of the uterus and begins to get fed by the mother’s tissue.

ACTUAL SIZE 🔗

The uterus
Babies develop and grow in a protective organ inside the mother’s belly—the uterus. After first entering the uterus, an embryo embeds itself in the soft lining and grows fingerlike extensions that collect nutrients from the mother’s blood. The muscular wall of the uterus is very stretchy, allowing the organ to expand as the baby grows.
Life in the womb

Nourished by its mother’s blood and protected by her body, an unborn baby (fetus) develops rapidly inside the womb, doubling in weight every four to five weeks.

Although we can’t remember the period of life before birth, our brains and sense organs had already started working. In the late stages of pregnancy, an unborn baby can see the pinkish glow of light filtering through its mother’s skin and can hear her voice, her booming heartbeat, and the noisy sloshing of fluid in the uterus. Using its hands and feet, it explores the watery world around it and feels its own body. It can’t breathe while submerged in liquid, but it practices by sucking in the liquid and swallowing. For nine months, the womb provides a safe, warm, and comfortable environment, while the mother’s bloodstream supplies the growing baby with all the oxygen and nutrients it needs.

Ready for birth

Toward the end of pregnancy, the fetus positions itself head downward, ready for birth. Its digestive system is now capable of processing food, but it continues to draw nutrients from the mother’s blood via a bundle of blood vessels called the umbilical cord. A layer of fine hair grows all over the fetus’s body late in pregnancy but usually disappears before birth.

The eyes open when the fetus is six months old, but it can only see light and dark.

The growing fetus

All the major organs appear during the first nine weeks of life, when the developing baby is known as an embryo. From nine weeks onward, it is called a fetus. Over the next seven months, the fetus grows rapidly. Complex tissues and body systems form, strengthen, and begin to work. A skeleton comes together, made at first of rubbery cartilage tissue instead of bone. The brain develops and so do the senses—a fetus can see, hear, smell, taste, and feel long before it’s born.

4 weeks old

At four weeks old, the embryo is the shape of a shrimp and has a tail. Its arms and legs are little more than buds. Eyes and ears are forming, and the heart starts to pump blood, working at a rate of 150 beats a minute—twice the adult rate.

LENGTH: 0.4 IN (11 MM)

6 weeks old

The face is taking shape and the hands and feet are forming. They look like paddles at first because the fingers and toes are joined together by webs of skin. Parts of the fetus’s cartilage skeleton begin hardening into bone.

LENGTH: 0.6 IN (1.6 CM)

10 weeks old

The fetus has eyelids but they will remain fused shut for the next three months. It can swallow and begins to urinate into the amniotic fluid. Elbow and wrist joints have formed, allowing it to make simple arm and hand movements.

LENGTH: 2.1 IN (5.4 CM)
22 weeks old

Just over halfway through pregnancy, the baby can now move its fingers, which have developed fingerprints. It responds to sound and is easily startled by loud noises. The mother begins to feel the fetus kicking inside her.

Length: 12 in (30 cm)

34 weeks old

The fetus is nearly fully developed. It spends about 90 percent of the time sleeping and has dreams. It practices breathing by inhaling fluid about 40 times a minute. It can smell its mother’s meals and recognize her voice.

Length: 19 in (47 cm)

15 weeks old

The fetus is now the size of a hamster, with a huge head and tiny body. Facial features are well formed, and it practices making facial expressions, including smiles and frowns. It swallowed amniotic fluid and hiccups so strongly the mother can feel it.

Length: 5 in (13 cm)

Changing proportions

Because the brain and nervous system develop quickly in early pregnancy, the head grows faster than the rest of the body. By nine weeks it takes up half of the baby’s length and looks enormous. The rest of the body catches up in the later months of pregnancy.

Multiple births

Sometimes more than one baby grows in the uterus at the same time. About one in 80 pregnancies are twins and about one in 8,000 are triplets. Twins can form from two different eggs (fraternal twins, who look different) or a single egg that splits (identical twins, who look the same).

Amniotic fluid

The fetus floats submerged in a watery liquid that cushions it from bumps.

A baby’s heart starts beating when its body is the size of a lentil.

Uterus

The wall of the uterus stretches as the baby grows.

Skin

The skin is covered by a cheesy white substance called vernix, which provides waterproofing to stop the skin from absorbing amniotic fluid.

Birth canal

The baby must squeeze through a tight passage called the birth canal, or vagina, during birth.

9 weeks 12 weeks 16 weeks Birth

9 weeks

12 weeks

16 weeks

Birth

After the umbilical cord is cut, a baby takes its first breath. Fluid drains out of its lungs and they fill with air. The baby will now get its oxygen from the air in its lungs rather than from its mother’s blood via the placenta.

Length: 21 in (53 cm)

Triplets

This ultrasound scan shows triplets growing in the same uterus. Each fetus is surrounded by its own amniotic sac.
Growing up

Our bodies and brains are transformed as we grow up. The most dramatic changes happen in infancy and during the teenage years, but we continue changing throughout life.

A newborn baby weighs only 7 lb (3 kg) or so. Unable to walk, feed itself, or see further than a few inches, it is completely dependent on its parents. By the age of 20, we weigh perhaps 20 times as much and are capable of leading independent lives. The process of development that transforms a baby into an adult is continuous, but two major growth spurts occur during childhood. One takes place in the first six months, when a baby doubles in weight. The second is during puberty, when the release of sex hormones triggers the emergence of adult features. Growing up is not just a physical process. We also grow emotionally and intellectually, our brains changing as we slowly acquire complex knowledge and social skills needed to navigate the adult world.

The changing body

The human body changes continuously throughout life. In the first 18 years, a person develops from a helpless baby needing its parents for survival to an independent adult, capable of raising his or her own children. In their 20s and 30s, men and woman are in their physical prime. From the mid-30s onward, however, the body slowly begins to decline. The rate of deterioration varies widely from person to person and depends on lifestyle factors such as diet and exercise, as well as genes.

Infancy

Babies have a large head in proportion to the body and short limbs. By 12–18 months, they develop the strength and balance needed to take their first steps.

Early childhood

The growth of the limbs begins to catch up with that of the head. Young children learn to walk and run, and become skilled at using their hands to manipulate objects precisely.

Childhood

Steady growth continues and height increases by about 2½ in (6 cm) each year. During these years, children master physical skills such as cycling, swimming, climbing, and playing sports.

Puberty

Height increases significantly and adult features begin to appear in response to sex hormones. Emotional changes such as mood swings are common during puberty.

Early adulthood

Adult height has been reached and the body is near peak fitness. Men and women are now capable of having their own children, but still need a few years to mature emotionally.

Adulthood

The human body is in its prime between the ages of 20 and 35. Bones are at their strongest and all body systems run smoothly. This is the ideal age to have and raise children.
Brain development
At birth, a baby’s brain is about a quarter the size of an adult’s, but it has almost the same number of cells (about 100 billion). The brain grows rapidly until about age 6, when it reaches 90 percent of adult size. In early childhood, brain cells form a dense web of connections to each other, giving the brain great potential to learn new skills. Later, connections that haven’t been used are pruned away, and the remaining ones are strengthened.

Child’s brain
At around three years of age, a part of the brain called the hippocampus matures, allowing vivid memories to form. Changes in an area called the reticular formation allow a child to pay attention for longer. Language skills improve and social skills develop as the brain’s parietal cortex and prefrontal cortex begin to mature.

The teenage brain
The part of the brain that generates emotions (the amygdala) is mature by the teenage years, but the area involved with thinking and planning (the prefrontal cortex) is not. As a result, teenagers are prone to act on sudden impulses without thinking. Neural circuits that aren’t used much are pruned away in the teenage years.

The adult brain
In adulthood, the prefrontal cortex matures, allowing more thoughtful perceptions and dampening the influence of the amygdala. Unused circuits have been pruned away, making the brain less able to acquire new skills. Apart from an area called the hippocampus, most parts of the brain cannot generate new brain cells.

Puberty
Around the age of 10 to 14 in girls and 11 to 15 in boys, the body goes through a period of rapid growth and sexual development known as puberty. Sex hormones are released by the testes in boys and by the ovaries in girls. These cause many physical changes, such as growth of body hair and facial hair, development of breasts and the menstrual cycle, and changes in height and body shape. The physical changes are accompanied by emotional and behavioral changes as the brain matures—a slow process that lasts well into the 20s.

Growth spurts
Bones grow more quickly in puberty, causing a sudden increase in height. Girls reach puberty earlier than boys and overtake them in height at about age 11. Boys catch up by about age 14 and reach a greater average adult height than girls.
Genes and DNA

Packaged inside every cell nucleus in your body is a set of instructions that controls the way your body works and develops. These instructions, known as genes, are stored as a four-letter code by the molecule DNA.

Unless you’re an identical twin, you have a unique set of genes that makes you different from anyone else. Half your genes came from your father and half came from your mother. These two sets joined to form a complete set, or genome, with a maternal and a paternal version of every gene. Your genome controls most of your physical characteristics, from the color of your eyes to the shape of your body. It also influences your abilities and personality, though your experiences in life affect these too.

DNA

DNA is an amazingly long but slender molecule. It is shaped like a twisted ladder, the rungs of which spell out a code made up of four letters. The letters stand for chemicals in the rungs: A (adenine), T (thymine), C (cytosine), and G (guanine). A gene is a segment of DNA with a particular sequence of letters, like a paragraph in a book. The shortest genes are only a few hundred letters long and the longest contain millions.

The four bases

- Guanine
- Cytosine
- Thymine
- Adenine

Making proteins

In most genes, the sequence of letters is a code for the sequence of amino acid units needed to build a molecule called a protein. Proteins make up your body tissues and control the chemical activity inside cells. Each type of amino acid is spelled out by a sequence of three letters in DNA. To make a protein, a cell copies the code from a gene onto a molecule called messenger RNA, which is similar to DNA. The messenger RNA then serves as a template for small molecules called transfer RNA, which carry the amino acids into place.
1.7 in (44 mm)—the average length of the DNA molecule in a chromosome.

2.2 million—the number of letters in the longest known gene.

25 percent—the amount of DNA that humans share with daffodils.

Packaging DNA
Your DNA has to fit into a tiny space, so it is packed up in an ingenious way. Each molecule is wound like a thread around balls of protein (nucleosomes), which are arranged to form a thick cord. This cord is coiled around to form a thicker cord, and then coiled up again. The end result is a chunky, X-shaped structure called a chromosome, containing a single molecule of DNA about 1½ in (4 cm) long. Chromosomes are too small to see with the naked eye—you'd need about 10,000 of them just to fill this period.

Chromosomes
Each cell in your body contains a set of 46 chromosomes squashed into the cell nucleus (except red blood cells, which have no nuclei). Two special chromosomes—the X and Y chromosomes—determine whether a baby is a boy or a girl.

Inheriting genes
Your genome includes two versions (alleles) of every gene—one from your mother and one from your father. Some gene versions are dominant, which means they always have an effect on the body, no matter what the other version is. Others are recessive, which means they have no effect when paired with a dominant gene. A recessive gene has no effect unless you have two copies—one from each parent.

Blood groups
Your blood group depends on which combination of three alleles (A, B, and O) you carry. Alleles A and B are both dominant genes, while allele O is recessive. Only people with two O genes have blood group O.

X-linked genes
Some genes are carried by the X chromosome. Since boys have only one X chromosome while girls have two, faulty genes are more likely to cause problems in boys than girls. Such conditions are known as X-linked disorders. A common example is color blindness, which is tested by images like the one above. If you can't see the number 74 in the image, you might have the gene for color blindness. Color blindness affects 8 percent of males of European descent but only 0.5 percent of girls.
Science is the search for the hidden laws that govern the way everything in the Universe works, from atoms and light to gravity and magnetism. Technology is how we apply this knowledge to create ever more complex machines and devices.
You might feel solid, but your body is a bag mostly filled with liquid and gas. Solids, liquids, and gases are types of matter—the stuff, formed from atoms, that fills the world. Most of your body is made from just four kinds of atoms—oxygen, carbon, hydrogen, and nitrogen—but to build the whole world you would need about 100. Join atoms together in different ways and you can make anything from a tree to a toothbrush.

WHAT IS MATTER?
Everything you can see around you is matter. It is built up from atoms into bigger and more complex units, such as molecules (collections of atoms), and the cells that make up living things. There are even smaller bits of matter inside atoms, such as protons and neutrons—and there are even smaller bits of matter inside those.

Matter in the Universe
We think of the Earth as land (solid) with air (gas) and oceans (liquid) drifting around us, and space as mostly emptiness with stars and planets dotted around. In fact, only a tiny amount of the Universe is ordinary matter—most is contained in two mysterious forms called dark matter and dark energy.

Dark matter
Unlike matter that we can see around us, dark matter is invisible. We can only tell it is there from the effect it has on ordinary matter. Astronomers first suggested dark matter as a way of explaining why some stars and galaxies seem to have less mass than expected.

Matter on Earth
Everything around us is either matter or energy. Every day we use thousands of different materials. We can define all these things as either living or nonliving matter. Although both are built from atoms, they work in different ways. Living matter constantly renews itself, while nonliving matter only changes when things around it force it to change.

Living matter
Living things grow and change by absorbing energy and matter from the environment. They are powered by sunlight, which enables plants to grow, providing food for animals too.

Nonliving matter
Earth is mostly rock, containing dozens of chemical elements that people have used in many ways. Nonliving matter is the power behind everyday products and inventions.

Energy
Albert Einstein discovered that tiny amounts of matter can be turned into vast quantities of energy. This process powers the Sun, producing the light energy that supports life on Earth.

Building Blocks of Matter
All matter on Earth is built from about 100 different elements, each of which is made up of atoms. Atoms can join together to form larger structures called molecules. Compounds are substances formed when atoms from different elements combine. We can understand almost everything on Earth by inspecting what it’s made of.

Living matter
Cells are the building blocks of life. Although we can think of something like a leaf as a collection of atoms, we can’t really understand it properly at such a minute level. Thinking about bigger units (cells) makes it easier to understand how a leaf lives and dies.

Nonliving matter
Like plants, nonliving things, such as plastic toothbrushes, are built from atoms and molecules—the atoms in a toothbrush and a leaf are virtually the same. However, the atoms in a toothbrush form long, springy molecules, which is why plastics are so flexible.

Inside nonliving matter
Toothbrush bristles are made from nylon, which is a plastic built from polymers—long chains of repeating molecules called monomers. Each monomer is made from four different atoms.
CHANGING MATTER
Living things are ever changing, while nonliving things always seem the same—there are rocks on Earth that are hundreds of millions of years old. When living things die, they can turn into other living things (such as dead leaves that fertilize the tree they fell from). Often, living things are reborn as nonliving ones. Oil forms under the sea when dead microscopic plants decay over millions of years.

Types of change
There is always a scientific logic behind the changes that occur in our world. We can understand this by looking at the living or nonliving things present before and after a change, and seeing whether there was a physical, chemical, or biological change.

Our Chemical World
From the food on our plates to the shoes on our feet, chemistry powers much of our lives. It's the science of the elements and how they combine, but there is much more. Our chemical world.

Science in action
In ancient times, people used the simple materials around them, such as stone, wood, and bone. Later, they invented ways to make better materials, such as heating copper to make bronze. Today, scientists understand thousands of materials and the things that make each one best for a particular job.

Comparing Materials
Everyday decisions often involve comparing one material to another. You might eat eggs for breakfast instead of toast, because they fill you up more. That is a choice between two materials based on how much energy each one contains. Depending on the weather, you might wear a thick wool sweater or a thin cotton shirt. That is a choice of materials based on their physical properties—how well they insulate your body heat. When you wash, you might use a bar of soap or a shower gel. That is a third choice based on chemical properties—how well they break down dirt.

Properties of materials
Every material is good for some things and bad for others because of its properties (how it behaves). The physical properties of a material include how strong or hard it is, how easy it is to work into shape, and how it is affected by heat, electricity, and light. A material's chemical properties include the ways in which it changes when it comes into contact with substances such as acid or water.

<table>
<thead>
<tr>
<th>Substance</th>
<th>Floats</th>
<th>Color</th>
<th>Transparency</th>
<th>Luster</th>
<th>Solubility</th>
<th>Conductivity</th>
<th>Texture</th>
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<tbody>
<tr>
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<td>red</td>
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<td>shiny</td>
<td>in acid</td>
<td>conductor</td>
<td>smooth</td>
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<td>in acid</td>
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<td>dull</td>
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<td>insulator</td>
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<td>in water</td>
<td>both**</td>
<td>jagged</td>
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<td>no</td>
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<tr>
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<td>transparent</td>
<td>sparkling</td>
<td>no</td>
<td>insulator</td>
<td>smooth</td>
</tr>
</tbody>
</table>

** Insulator when solid/conductor when dissolved

Where do raw materials come from?
Earth is like a giant warehouse packed with virtually every material humans could ever need. Unfortunately, raw materials take time to form. Even a tree takes decades to grow, while coal and oil deposits form over hundreds of millions of years. As Earth's population grows rapidly, raw materials such as oil will become too expensive to use. Scientists and inventors will have to find alternatives or innovative ways to make existing materials last longer.

Distribution of raw materials
Countries often owe their wealth to the raw materials buried beneath them. The Middle East has huge oil deposits, while China and the United States have enormous amounts of coal.

<table>
<thead>
<tr>
<th>Key</th>
<th>Material</th>
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</thead>
<tbody>
<tr>
<td>Bauxite</td>
<td>Sulfur</td>
</tr>
<tr>
<td>Copper</td>
<td>Coal</td>
</tr>
<tr>
<td>Kaolin (clay)</td>
<td>Iron ore</td>
</tr>
<tr>
<td>Oil</td>
<td>Salt</td>
</tr>
<tr>
<td>Natural gas</td>
<td>Wood</td>
</tr>
</tbody>
</table>
Atoms and molecules

All the matter in the Universe that we know of is made of tiny, invisible particles called atoms. Atoms are crammed into everything you can see—from the skin on your fingers to the words in this book—and things you can’t see too, such as the air you breathe and the cells rushing through your blood.

The idea of atoms is one of the oldest in science. Some Ancient Greek philosophers thought atoms were the smallest possible bits of matter and couldn’t be broken down further. They chose the name atom because it means “uncutable” or “indivisible.” This early concept of atoms lived on for thousands of years, until, in the early 20th century, ingenious scientists “split the atom,” smashing it apart into even tinier particles.

When atoms combine, they make bigger clumps called molecules. Although there are only about 100 types of atoms, together they can form millions of different types of molecules.

The nucleus
A cluster of protons and neutrons make up the nucleus of an atom. It makes up most of an atom’s weight, but only takes up a tiny amount of its volume. Outside the nucleus, more than 99.99 percent of an atom is just empty space. If an atom were the size of a football stadium, the nucleus would be the size of a pea in the center of it, and the electrons would be zooming around the outer stands.

Proton
Protons have a positive electric charge, and are attracted to electrons.

Neutron
These are around the same size as protons. Neutrons are neutral, which means they don’t have an electric charge and aren’t attracted to electrons or protons.

An adult human is 50,000 trillion trillion times heavier than the smallest atoms. 60 million trillion—the number of atoms in a single grain of sand.
Electron shells
An atom usually has an equal number of negatively charged electrons and positively charged protons. Some big atoms have more than 100 of both. The carbon atom shown here has six of each. Electrons are arranged in layers (called electron shells) around the nucleus, like satellites around a planet. Bigger atoms have more shells than smaller ones. Imagining electrons in shells helps us to understand how atoms join together to form molecules.

Making molecules
Atoms can join together—or bond—to make molecules. A molecule can be made of the same atoms or different ones. Gases such as hydrogen have simple molecules made of just two atoms, while plastics can be made from endlessly repeating molecules made up of thousands of atoms joined together in very long lines.

Carbon dioxide (CO₂)
A carbon dioxide molecule is made from two atoms of oxygen joined to one atom of carbon.

How atoms bond
Atoms bind together to make molecules using their electrons, which they give, take, or share with each other. Three main types of bonds hold atoms together.

Ionic bond
One atom gives electrons to another. The first atom becomes positively charged and the second atom becomes negatively charged, so the atoms attract and lock.

Covalent bond
Two atoms share their outer electrons by making their outer electron shells overlap.

Metallic bond
Metals bond into what’s called a crystal lattice by sharing their outer electrons in a giant cloud.

Quarks and strings
If the nucleus of an atom is built from protons and neutrons, what are these things made of? It seems that each consists of three even smaller particles called quarks. Some scientists believe that everything is really made from vibrations of matter or energy called strings. But so far, no one knows what, if anything, strings are made of.

The structure of an atom
Inside an atom are even tinier particles of matter called protons, neutrons, and electrons. Protons and neutrons are found in the center of an atom, which is called the nucleus, and are locked tightly together by powerful forces. Electrons spin up, down, and around outside the nucleus within areas called electron shells.
The Large Hadron Collider
This gigantic machine runs for 17 miles (27 km) in a circular tunnel buried 330 ft (100 m) underground. It whizzes two beams of atomic particles around the tunnel, in opposite directions, at up to 99.9999999 percent the speed of light, and then diverts them so that they smash together. These blistering particle collisions are studied using four detectors spaced around the loop called Alice, Atlas, CMS, and LHC-b.

Inside the tunnel
The tunnel contains a thick blue pipe with two thinner pipes inside it that carry the particle beams in opposite directions. Wrapped around the thin pipes are more than 1,600 magnets, which bend the particle beams, steer them, and then squeeze them together so they collide.

Alice
This 11,000-ton machine smashes lead ions (atoms with an electric charge) together to make a plasma (ultra-heated gas) that is 100,000 times hotter than the Sun’s core. Alice re-creates the conditions that existed just after the Big Bang, when the atomic particles that make up our Universe were first formed.

Atlas
This detector uses a huge doughnut-shaped system of magnets clamped around a beam pipe to watch collisions between protons. It’s looking for a mysterious particle called the Higgs boson. If scientists find it, they hope it will help them to understand how other particles come to have their mass.
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**Atom smasher**

The Universe is the biggest thing we can imagine, but the secrets of how it formed may be locked inside the smallest things—atoms and the tiny particles packed inside them.

Most of what we know about atoms has been discovered by smashing them apart in machines called particle accelerators. The earliest of these were built in the 1930s and used electricity to speed particles down short, straight tubes. Later, scientists found they could make particles race around tracks until they reached incredibly high speeds. When the particles crashed together, they shattered apart in spectacular collisions, splitting into a storm of smaller bits that could then be captured and studied.

Today, the world’s biggest particle accelerator is located in an international laboratory called CERN on the French-Swiss border. CERN is currently running the boldest and most expensive science experiment ever devised. Known as the Large Hadron Collider (LHC), it’s attempting to reproduce the conditions that existed when the Universe was formed in the Big Bang, almost 14 billion years ago.
Solids, liquids, and gases

Place an ice cube on the palm of your hand and you will soon have a pool of water. Leave it for long enough and the water will evaporate and disappear. What makes water appear as ice rather than a vapor? What makes it change between solid, liquid, and gas?

Every substance is made up of atoms or molecules that jiggle around in constant motion. Depending on how hot or cool it is, and how much “squeezing” (pressure) a substance receives from its surroundings, its atoms or molecules move quicker or slower, spring together or bounce apart. It’s the strange dance of atoms inside a substance that makes it shift between solid, liquid, gas, or plasma—the four main states of matter.

Although the solid, liquid, or gas forms of a substance contain the same number of atoms, they have different inner structures. Ice, water, and water vapor look very different and behave in amazingly different ways—all because of the patterns their atoms take up inside them.

**Solids**

When something is cooled or put under pressure, its atoms or molecules lock tightly together to form the strong bonds of a solid. These powerful links between atoms make solids difficult to bend or reshape. Some materials form orderly solids called crystals, while others form more random (amorphous) solids.

**Crystalline solid**
If you cool a liquid slowly, it has time to arrange its atoms and molecules into a very regular form called a crystal. Many metals are like this.

**Amorphous solid**
Some materials cool and snap together into a more random structure. Glass is like this—a mix between an orderly solid and a chaotic liquid.

**Liquids**

Liquids are usually hotter and less compressed than solids, so their atoms and molecules are slightly further apart from one another. The forces between the particles are weaker, so they can move around more freely. This is why liquids have no fixed shape, but spread out to line the container in which they are placed.

**Water in a liquid state**
Life exists on Earth because there is water. It’s a liquid at everyday temperatures and pressures, which means it’s easy to transport and recycle, and just as easy for plants and animals to absorb.

**Viscosity**
The weaker bonds between atoms and molecules in liquids allow liquids to flow as you pour them. A liquid’s viscosity means how slowly or quickly it flows.

**Water has very low viscosity, and drips and splashes easily**

**Oil is less viscous, and does not splash much**

**Honey is very viscous, and flows slowly**

**Water boils at lower temperatures when the pressure falls. On top of Mount Everest, where air pressure is low, it would boil at around 160°F (70°C).**
Changing states of matter

Boil a kettle and you will transform water from a liquid to a gas (steam). Freeze food and you will change the water inside it into a solid (ice). It’s easy to make water change states because its solid, liquid, and gas forms can exist at everyday temperatures and pressures. It’s harder to change materials like metals into liquids or gases, since much higher temperatures and pressures are needed.

Gases

In gases, atoms and molecules are not bonded together but move quickly and freely and have enough energy to flow all by themselves. Constantly bumping into one another, they spread out to fill whatever container they are inside.

Water in a gaseous state

Gases are normally hotter than their liquid forms, which is why steam is hotter than water. Gases can also form when the pressure is low. In clouds, water is a cold gas (water vapor), due to the low air pressure high above Earth.

Plasma

Heat a gas or lower its pressure enough, and the atoms come apart to form a cloud with an electric charge, called a plasma. Plasmas are made of charged particles, called electrons, and ions (atoms missing electrons), so they behave in strange ways when electricity and magnetism are nearby.

Steam takes up about 1,600 times as much space as the same amount of water.

Sublimation

You can change a solid directly into a gas without making liquid first. The dry ice used to make smoke in concerts is made from frozen lumps of carbon dioxide. Once exposed to the air, it heats up rapidly and forms a cold gas.

Deposition

Gases can turn directly into solids without first becoming liquids. If water vapor in the air is cooled enough, it condenses and freezes to form snow in clouds, or frost on the ground.

Freezing

As liquids lose energy, their atoms and molecules move about more slowly and gradually come together. Bonds form between them and they lock in a rigid structure, making a solid.

Melting

Solids change to liquids by melting. For instance, ice cream quickly soaks up heat from the atmosphere. Water molecules in the ice gain energy and move apart, becoming liquid.

Evaporation

When you heat a liquid, the atoms and molecules gain much more energy. They collide more often and start to push apart. Some have enough energy to escape from the liquid, forming a gas (vapor) directly above it.

Condensation

If you cool a gas or lower its pressure, it will turn into a liquid. Water vapor inside your home will often condense on your windows on cold days if the outside temperature falls low enough.
The elements

Elements are the basic chemical building blocks of matter, and atoms are the basic unit of an element. Snap together atoms of a few chemical elements and you can make anything on Earth, from the smallest beetle to the tallest skyscraper.

You could build living things from a handful of elements based on carbon, and you could make the water that covers most of our planet from just two elements—hydrogen and oxygen. But to make everything on Earth you would need about 100 elements in total. Most elements occur naturally—they are locked in rocks or drifting around in the atmosphere. But since elements are made from protons, neutrons, and electrons glued together by strong forces, it’s also possible to build brand new ones. Scientists have done just this in laboratories, pushing the total number of known elements to 118.

The Periodic Table

If we sort the elements into a grid according to their atomic structure, patterns emerge. Elements that behave in similar ways group together, so we can predict how an element will behave from its place in the grid. This idea is called the Periodic Table, and it was created by a Russian chemist called Dmitri Mendeleev in 1869.

Growing atoms

Atoms get bigger and heavier as we move down each column (group) of the table. This is because there are more protons in the nucleus and more electrons in the shells (rings) around it. A shell is added each time we move another step down a group.

Shrinking atoms

As we move along each row (period) of the table, atoms gain more protons and electrons. Each atom has the same number of electron shells, but there are more positively charged protons pulling the shells inward. This shrinks the atom, and makes it more tightly packed.

Transuranic elements

Elements with a greater number than uranium (92) are called transuranic. Unlike elements 1–92, these aren’t found in nature and have to be created in particle accelerators or nuclear reactors, which makes them very expensive to use.
Under everyday conditions, two of the elements—mercury and bromine—are liquids, 11 are gases, and the rest are solids.

**What is an element?**
The elements are different substances (solids, liquids, and gases) made from atoms that have different inner structures. If two atoms have the same number of protons, they are atoms of the same element. An atom is the smallest amount of an element you can have.

- **Atomic number:** This is the number of protons inside the nucleus of the atom. The metal titanium has 22 protons and an atomic number of 22.
- **Atomic mass:** This is the total number of protons and neutrons in an atom.
- **Name:** The name of an element often describes its properties. Titanium is named after the Titans, Ancient Greek gods of incredible strength.
- **Chemical symbol:** This is a shortened way of representing an element. Some elements have symbols made up from their names.

**96% of your body is made of just four elements: OXYGEN, CARBON, HYDROGEN, and NITROGEN.**

**Building blocks**
The Periodic Table is made up of rows called periods and columns called groups. As we move across each period, the elements change from solid metals (on the left) to gases (on the right).

**Period**
The elements in a period all have the same number of electron shells.

**Group**
The elements in groups are similar because they have the same number of electrons in their outer shell.

**Series**
Within the table are bigger blocks of elements that behave in similar ways. On the left are reactive metals such as sodium (Na). Most everyday metals occur in the middle of the table in a set called the transition metals. Nonmetals are mostly on the right of the table. Rare earth metals are all soft metals.

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Chemical reactions

When you watch a display of fireworks shooting, screeching, and banging their way across the sky, you are seeing the power of chemistry bursting into action.

The world often seems unchanging, but in fact, little stays the same for very long. Atoms and molecules are constantly rearranging themselves—breaking down old things and building up new ones. Chemistry helps to explain how this happens through step-by-step changes called chemical reactions.

In a reaction, elements join together to make bigger units called compounds, or compounds split back into their original elements. Many reactions are silent and invisible. Others, like an exploding firework, are energetic and violent. Reactions are the amazing transformations that drive many of the things around us. When candles flicker and cakes rise in your oven, reactions are rearranging atoms into new and different forms.

What is a firework?
A firework is a missile packed with explosive chemicals that shoots high into the sky before shattering in a series of carefully controlled and very colorful reactions. In most chemical reactions, the end products are what matter most—how they are produced isn’t important. A firework display is the opposite—the chemical reaction itself is what we want to see.

1 Launch
Most chemical reactions need to be kick-started using what’s called activation energy. When a firework is launched, an electric spark lights its fuse. A small, explosive charge at the bottom of the firework starts burning, and then the firework is blasted out of its tube.

2 The outer shell explodes
Once the firework is safely in the sky, the time-delay fuse burns to its outer shell and sets fire to the stars inside. These burst into dozens of small separate explosions as they race through the sky.

What is a chemical reaction?
In a chemical reaction, one ingredient (called a reactant) combines with a second one. During the reaction, the bonds that hold together the atoms or molecules of the reactants split apart. The atoms then rearrange themselves and new bonds form between them to make a different set of chemicals called the product.
DISPLACEMENT REACTION—ATOMS OF ONE TYPE SWAP PLACES WITH THOSE OF ANOTHER, FORMING NEW COMPOUNDS

DECOMPOSITION REACTION—ONE REACTANT BREAKS APART INTO TWO PRODUCTS

SYNTHESIS REACTION—TWO OR MORE REACTANTS JOIN TOGETHER

The chemistry of colors
Chemical reactions give off light when atoms are heated up and emit energy. Different sized atoms absorb and give out different amounts of energy, which makes different colored light. In a firework, each color is produced by a separate metal compound.

MAGNESIUM
COPPER SALTS
STRONTIUM NITRATE
BARIUM NITRATE
SODIUM SALTS
IRON

The biggest fireworks can be launched more than 1,000 ft (300 m) into the air.

Beautiful shapes
The pattern the firework makes in the sky depends on how the stars are arranged inside the shell.

The final explosion
The time-delay fuse burns at a precise rate, so the final explosion happens when the firework has reached its highest point in the sky. Most of the explosive is packed into the middle of the firework so the final explosion is the biggest and most spectacular.

Types of chemical reaction
Although the products can be very different from the reactants, no atoms are created or destroyed. So, no matter how the reaction takes place, there are always the same number of each kind of atom after a reaction as there were before it. There are three main types of chemical reaction.

Combustion
Car engines, power stations, and home heating are three common things powered by a chemical reaction called combustion (burning). The reactants are a fuel (perhaps gas or coal) and oxygen from the air. Adding heat (setting fire to the fuel) provides activation energy that starts the reaction and releases more energy as fire.
Choosing materials
Although materials such as wood and plastic have many uses, no single material can do everything. When we’re choosing a material, we have to consider carefully what it will need to do. Should it be hard or soft? Does it need to be strong and long lasting, or weak enough to break down quickly in a landfill site?

Ceramics
Materials such as pottery and brick are examples of ceramics. They’re made from clays dug from the Earth, which are shaped and then fired so that they harden. They can survive high temperatures and insulate against electricity, but are brittle and fragile.

Glass
A unique, see-through ceramic, glass is inexpensive, easy to shape when it’s being made, and can withstand high temperatures. Although it’s fragile, it can be toughened by laminating it (sandwiching it between layers of plastic).

Plastic
Plastics are cheap, easy to mold, and come in any color (as well as clear). There’s a huge range, from tough ABS plastic (hard enough to make car bumpers) to light and flexible polyethylene, which is used for drink bottles.

Synthetic fabrics
Natural fibers such as wool are warm, but they’re not waterproof or easy to clean. That’s why many of us wear plastic-based fabrics such as nylon, polyester, and Lycra. These fabrics are particularly good for sports clothes.

Composites
Composites are made by combining two or more materials to make a better one. A surfboard, which needs to be strong, reasonably light, buoyant (able to float), and waterproof, is best made from a tough composite such as fiberglass (plastic reinforced with glass).

Material world
There are reasons why clothes aren’t made from concrete, books from metal, or bikes from glass. Every material does some things well, and materials science is all about putting the right material in the right place by understanding the structure of the atoms and molecules inside it.

What stops a rocket from tearing itself apart as it blasts into the sky? Why do rubber tires make a bicycle so much more comfortable to ride? Study materials through a microscope and you’ll find the answers to these questions hiding inside. In the tough steel alloys of a space rocket, atoms are locked together tightly. In the rubber of a bike tire, molecules will stretch far apart, making a soft and spongy cushion. Understanding the secret stories of matter helps us to pick the perfect material for every job—and develop even better materials in the future.

New materials
After thousands of years of inventing, you might think we have all the materials we will ever need. But scientists are constantly developing better ones that improve on traditional materials such as wood, glass, and metal.

Bioplastics
Plastics are hard to recycle and take up to 500 years to break down in the environment, so they cause a lot of pollution. Scientists have developed bioplastics from natural materials, such as cornstarch, which break down in soil in just weeks or months. They’re perfect for use as garbage bags.

Self-healing materials
Wouldn’t it be great if your car’s paintwork repaired its own scratches? Self-healing materials do just this. They have built-in repair capsules containing glues that leak out to fill any cracks. There are even aerospace materials that will automatically fill in bullet holes.

Color-changing plastics
Forehead thermometers and battery tester strips are made from thermochromic plastics, which change color as they get hotter or colder. Inside, they have layers of molecules that absorb and give out different frequencies (colors) of light as their temperature rises and falls.

Nanotechnology
If we could move atoms and molecules around under a microscope, we could theoretically use them to build any material we choose. This idea is called nanotechnology and will revolutionize the way materials are developed in the future.

Atomic building site
Nanotechnology will let us build tiny structures thousands of times smaller than a human hair. Layer by layer, we could build new medicines, body parts, tiny machines, or anything else we need.
Material teamwork

When professional cyclists speed along roads, they're powered by the latest advances in materials science. High-tech materials such as alloys and composites give cycling athletes an edge on the competition. Using a strong composite material for your bike will make it lighter and faster, while energy-absorbing plastics in your helmet and clothes will keep you safer if you crash.

Neoprene cycling shorts
Neoprene (artificial rubber) has tiny nitrogen gas bubbles locked inside it, which makes it good for absorbing impacts and great for keeping you warm.

Alloy pedals and cranks
Alloys are mixtures of metals and other elements. They're stronger because the small atoms of the other materials sneak between the big metal atoms, making a tougher overall structure.

Tires
In its natural form, rubber (latex) is stretchy and weak. Cooking it with sulfur forms strong bonds between the molecules, producing vulcanized rubber that's tough enough for tires.

Carbon-fiber frame
Carbon-fiber composites are strong and light. They're often made from tiny fibers of aerospace carbon set in a backing of nylon plastic.
FORCES

Whenever planes hurtle overhead or cars screech to a halt, forces are working hard behind the scenes. On a larger scale, gravitational forces span the Universe, causing stars to cluster into galaxies and keeping planets whirling in orbit around the Sun. At the other end of the scale, atoms cause forces like sticking and friction.

WHAT IS A FORCE?

A force is a push or pull that makes something happen. When you kick a ball, your foot supplies the force that makes the ball fly into the air. Forces are usually invisible. Gravity is the invisible force that pins us to the ground, while magnetism is another hidden force that makes a compass spin. Simple forces can change an object's shape, alter its direction, or change its speed.

Balanced forces

If two equal forces act in opposite directions, they cancel each other out and there's no movement or change of any kind. Architects design buildings so that the downward pull of gravity is balanced by upward forces inside the buildings.

Simple machines

Levers, wheels, pulleys, and gears all magnify forces and make jobs easier to do. These force magnifiers are called simple machines. If you sit on a seesaw, you can lift someone heavier by moving further from the balancing point. The seesaw works as a lever and multiplies your lifting force. You press down with a small force and the lever makes a bigger lifting force at the other end. Machines such as cranes are built from many simple machines working together.

Relative velocity

The difference in speed between two moving objects is called their relative velocity. Because velocity is speed in a particular direction, you have to take account of the direction in which the objects are moving when you calculate their relative velocity.

What's faster?

Machines with powerful engines, such as rockets, usually go fast because their engines produce enormous forces to push them forward at high speed. Objects can travel even faster in space as they move away from the downward pull of Earth's gravity.

MAKING MOVEMENT

Three rules explain how forces make movement: 1. Objects will stay still or go on moving steadily unless a force acts on them; 2. When a force acts, it moves something faster or changes its direction; 3. When a force acts, there's always a force just as big acting in the opposite way.

Velocity and acceleration

An object's speed in a certain direction is its velocity. If it speeds up or changes direction, its velocity changes. A change in velocity is called an acceleration. Force is needed to accelerate an object.

Increasing velocity

When a car speeds up, its engine produces more force to make the vehicle accelerate.

Changing direction

As a car turns, it accelerates, even if it keeps the same speed, since the change in direction changes the car's velocity.

Decreasing velocity

When the driver brakes, force is applied to the wheels, slowing the car. This is called deceleration, or negative acceleration.

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**GRAVITY AND THE UNIVERSE**

The force of gravity holds everything in the Universe together like a mysterious, invisible spider’s web. Gravity is also the force of attraction between your body and Earth that, quite literally, keeps your feet on the ground.

**The pull of gravity**
Everything in the Universe that is made of matter (and so has mass) pulls on everything else with gravitational force. The bigger and closer the objects are, the greater the pull of gravity between them. Earth’s gravity is the reason that we do not float off into space, and why objects fall down to the ground. Without air resistance to slow them down, all objects—from feathers to pool balls—would fall at the same rate.

**Gravity and relativity**
The gravity from a massive object, such as the Sun, still pulls at vast distances and never disappears entirely. It affects light as well as physical objects. According to a theory called relativity developed by German-born physicist Albert Einstein (1879–1955), the gravity of a body like the Sun actually bends space and time, rather like a heavy weight setting on a rubber sheet. Because space-time is bent, things moving near the Sun will curve toward it as though being pulled inward.

**FRICION**
Friction is a dragging force that occurs when one object moves over another. You may not realize it, but you use this force whenever you walk down the street. Friction helps your shoes grip the pavement so that you don’t slip.

**A rough force**
When one object moves over another, the rough surfaces of the two objects catch against one another and stick. This sticking process makes it harder to move the objects, producing a force between them that we call friction. In general, the rougher a surface is, the more friction it produces. But even polished surfaces that look and feel smooth will have microscopic bumps and ridges that produce some friction. One way to reduce friction is to make objects as smooth as possible, so they slide past one another more freely. Another way is to use lubrication.

**Water resistance**
It’s harder to move through water than through air, because water is a thick liquid. Water pulls against the bow (front) of a boat, slowing it down with what’s called drag. Boats solve this problem with curved front edges that plane (rise out of the water) as they move along, reducing drag.

**PRESSURE**
The same force can have very different effects. If you stand on snow in ordinary shoes, the force of your weight makes you sink. But if you wear skis, your weight is spread over a larger area. You don’t sink because you produce less pressure. Pressure depends on the size of the force and the area it acts over. The bigger the force or the smaller the area, the greater the pressure.

**Water pressure**
Water exerts pressure on anything submerged in it. The deeper you go, the more water pushing down on you, and the greater the water pressure.

**MAGNETISM**
A magnet is surrounded by an invisible field of magnetic force that is strongest at the north and south poles of the magnet. Magnets will push and pull on other objects with magnetism. Earth’s iron core is a huge magnet with its own magnetic field. A compass has a magnetic pointer that is attracted to Earth’s magnetic poles.
Laws of motion

No matter how quiet or calm it might seem, nothing in our world is ever still. Deep inside every object, even in the air that surrounds us, atoms and molecules are restlessly moving.

All motion—even the random dance of atoms—is caused by forces pushing and pulling. Forces act logically, so most things in the world move in ways we can understand and predict. For this, we use the three laws of motion: a simple set of scientific rules first thought up over 300 years ago.

**First law of motion**

All things will either stay still or move with a steady speed unless a force acts on them. This idea is called inertia. The more mass something has, the more inertia it has too—so it will be more likely to stay still or resist changes to its motion.

**At rest**

A soccer ball rests on the ground because there is no overall force acting on it. Its weight is perfectly balanced by the ground, and there is no sideways force.

**Force applied**

When you kick the soccer ball, you apply a force to one side. There’s nothing to counteract or balance this force so it makes the ball move.

**Motion stopped**

The ball shoots through the air or rolls across the ground with a fairly steady speed until it hits something, such as your foot. When your foot applies a force, the ball stops moving.

**Second law of motion**

When a force acts on something, it makes it accelerate (go faster, slower, or change direction). The amount of acceleration depends on the size of the force and the mass of the object. The bigger the force or the lighter the object, the more it accelerates.

**Small mass, small force**

Kick a ball lightly (with a small force) and it accelerates at a steady rate. The acceleration is equal to the size of the force divided by the mass of the ball.

**Small mass, medium force**

Kick the same ball with twice the force and you get twice the acceleration. If it flies in a straight line, it accelerates to twice the speed in the same time.

**Double mass, large force**

A heavier ball needs a bigger force to get it moving. If you use eight times your original force and the ball is twice as heavy, you get four times the original acceleration.

**Force = Mass × Acceleration**

The number of times per second that a dragonfly flaps its wings, producing a huge force that speeds it through the air.
Third law of motion
Newton's third law says that when a force acts on something, there is always another force just as big acting in the opposite direction. If the original force is called the action, the opposite force is called the reaction. That's why the third law is often written in a shortened form: every action has an equal and opposite reaction.

Action
Imagine you're on a skateboard and you push against a wall (action). The wall pushes back with a reaction force, causing you to roll away from the wall.

Reaction
If you push a friend, who is also on a skateboard, your force (action) moves them away from you. The reaction force makes you move in the opposite direction at the same speed as your friend.

Blast off
Newton's laws of motion proved that rockets would work long before anyone tried to make one. Robert Hutchings Goddard (1882–1945) was the father of the modern rocket, but when he first suggested building a spacecraft, in 1916, people thought he was crazy. They believed a rocket could never fly in space because there was no air to push against. The laws of motion proved that Goddard was right.

First law
When a rocket sets on the launch pad with its engines switched off, there's no overall force acting on it. Inertia keeps it in place so it goes nowhere.

Second law
The main engines and booster rockets fire out hot, high-speed exhaust gas. This creates a huge downward force that accelerates the rocket upward.

Third law
The action (the exhaust gas firing down) produces an equal and opposite reaction (the rocket shoots up). The rocket doesn't push against the air; it moves up because the exhaust blasts down, so it can fly even in the emptiness of outer space.

When you push against something, an equal and opposite force pushes back.

People move apart with the same velocity.

Wheels help to overcome friction.

A SPACE SHUTTLE’S MAIN ENGINE PRODUCES A FORCE OF 2 MILLION NEWTONS.
**Engines**

Whenever you travel by car, plane, ship, or even spaceship, you’re powered by fire—roaring flames or carefully controlled explosions happening inside the engine.

Fossil fuels such as oil, coal, and gas still provide about 80 percent of the power we use every day. Gasoline (made from oil) packs huge amounts of energy into a tiny volume of liquid, so it is particularly good for use in vehicles. Engines are the machines that release this energy, using a chemical reaction called combustion. When fuels burn with oxygen from the air, their molecules smash apart and release their energy as heat. Engines capture this heat and convert it into a force that powers us down roads, over waves, or through the sky.

**Internal combustion engine**

In car engines, fuel (gasoline or diesel) explodes inside sturdy metal cylinders, pushing pistons up and down to generate the power that drives the wheels. Piston engines go through four simple steps, called a four-stroke cycle, which repeat over and over again, moving the car along.

1. **Suck**
   - The cycle begins when the intake valve opens at the top of the cylinder. The piston moves down, and fuel and air are sucked in through the open valve. They swirl together to make a highly explosive mixture.

2. **Squeeze**
   - The valve closes and the piston rises, squashing the mixture into about a tenth of the space and heating it up. The more the mixture is compressed, the more energy it will release when it burns and expands.
Crankshaft
Each cylinder fires slightly out of step with the others, so there’s always at least one piston powering the engine. The pistons push connecting rods that turn the crankshaft. The crankshaft collects power from all of the pistons and drives the car’s gearbox.

Different types of engine
The faster something needs to go, the more energy it needs, and the quicker it must burn fuel. That’s why sports cars need bigger engines with more cylinders than standard cars, and why planes need huge jet engines.

A ROCKET ENGINE AT LIFTOFF CREATES ABOUT AS MUCH FORCE AS 50,000 CAR ENGINES.
Simple machines

You can’t lift a car, crack a nut, or split logs just using your bare hands, however strong you might be. But you can do all these things relatively easily with the help of tools that multiply the force you can make with your own body.

In science, any device that increases force is called a simple machine. Most of the tools we use around the house are devices of this sort, including hammers, drills, and screwdrivers. Even our own bodies have the simplest of all machines—levers—built into them in the form of our arms and legs. We generally use tools because they boost our body force. But some simple machines help us increase our speed as well. These include wheels and gears, which enable bicycles and cars to achieve amazing speeds our bodies can never hope to match.

Wheels and axles

A heavy load is hard to push across the ground because you have to work against the force of friction. If you put the load on a cart with wheels, the only friction is a tiny amount of rubbing between each wheel and its axle (the rod passing through the center of the wheel). This makes pushing a heavy load much easier.

Ramps, wedges, and screws

Ramps help you raise heavy objects. Instead of lifting something straight up, you push it up an incline, moving it a greater distance but with less effort. Wedges, such as axe blades, are similar. When you chop wood, it splits along the ramp of the blade.

How a screw works

A screw behaves like a ramp wrapped around in a spiral. The large head and spiral thread make it easier to drive a screw into the wall.

Pulleys

You can lift much heavier weights using a system of ropes and wheels called pulleys. The more wheels and ropes there are, the less force you need to lift something, but the further you have to pull the rope. Although a pulley reduces the lifting force, making it easier to lift the weight, you have to use just as much energy as you would without it (sometimes even more).

Levers

Levers are rods that turn a pushing or pulling force (effort) into a bigger force (load) with the help of a pivot (fulcrum). The longer the lever, the more it multiplies force. There are three types of levers, with the effort, load, and fulcrum arranged in different ways.

Class one lever

Pliers have much longer handles than jaws, so they multiply your pressing force when you squeeze them.

Class two lever

With the fulcrum right at the end of the nutcrackers, it produces a large squeezing force in between the arms.

Class three lever

With the effort near the fulcrum, tongs and chopsticks reduce your squeezing force but give you better control.
Gears
Two wheels touching work like two connected levers, and are called gears. With teeth around the edge to stop them from slipping, they turn together to give an increase of either speed or force.

Gear ratio
If a large gear turns a small one, the small one spins faster but with less force. If a small gear turns a large one, the large one turns slower but with more force.

Hydraulics
Liquids are almost impossible to squeeze into less space, so if you fill a pipe with liquid, you can use it to transmit a force. If the pipe is wider at one end than the other, the force increases, but you have to push the liquid farther. This idea is called hydraulics—and it’s used to power rams, cranes, and diggers.

Simple machines in action
Huge machines in the world around us work by linking many simple machines together. The engine of this giant crane powers a hydraulic pump that lifts the main crane boom up and down. The boom is a very long lever, so small movements at its base can swing the loads it lifts a long way. A pulley on the end of the boom helps to increase lifting force.

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How a hydraulic ram works
When you push the ram, liquid flows along the pipe and up to the lift. Because the lift pipe is wider than the ram pipe, you can raise the car with less force. However, you have to pump down farther than the car lifts up.

The number of pulleys used by the world’s biggest crane, in Shandong Province, China. It can lift loads up to 22,000 tons—the same weight as 10,000 large cars.
How a submarine dives
Water is heavy, so the deeper you dive underwater, the bigger the weight squashing down on you. This is what gives water its pressure, which is what makes objects float or sink. We can swim because the force of the water pressure pushing up from underneath us balances our weight pushing down. Although ships and submarines weigh much more, they float for the same reason. Submarines can either float or sink by pumping water in and out of huge buoyancy tanks to change their weight. If their weight equals the force pushing upward on them, they float—either on the surface or at any depth beneath.

1. Floating
   Air fills the tanks. The submarine weighs relatively little, so the water pressure underneath is enough to support its weight.

2. Diving
   Water fills the tanks, and the craft gains weight. The force pushing upward is less than the weight of the vessel, so it sinks.

3. Rising
   Air is pumped back into the tanks. The submarine loses weight, so the upward force due to water pressure pushes it to the surface.

Virginia class submarine
The Virginia is a stealthy war submarine designed to sneak through the sea at depths down to 1,600 ft (490 m). Powered by a nuclear reactor, it never runs out of fuel. Onboard air conditioning makes oxygen, and there’s enough frozen and canned food packed inside to feed the crew of 134 sailors for three months. There’s no night or day underwater, since light can’t penetrate to these depths, but life is otherwise normal, with a gym and a movie theater to keep sailors entertained.
Modern submarines have a maximum crush depth of about 2,400 ft (700 m), where water pressure crunches their sturdy steel hulls.

1620 The year the first submarine was built—an egg-shaped rowboat waterproofed with leather and wax.

**Flotation**

Ships struggle through waves whipped up by the wind. Submarines, on the other hand, sneak stealthily underwater by adjusting their buoyancy to maneuver up and down.

Whether things float or sink is not about how big or heavy they are, but how much they weigh compared to the water they displace (push out of the way). Heavy ships are able to float because they displace a colossal amount of water. Submarines, like the US Navy’s Virginia class, float or sink at will, using buoyancy tanks to change their weight.

**How sonar works**

There’s no light deep underwater, so submarines pinpoint underwater objects, such as enemy submarines and shipwrecks, by bouncing sonar (sound) beams off them.
Magnetism

Magnets helped discover the world as we know it. Earth is like a giant magnet, and its steady pull spun the compasses that pointed explorers like Christopher Columbus across the oceans. Compasses powered navigation, turning the unexplored, ancient world into a modern globe people could understand.

Like gravity, magnetism is an invisible force that streams through our world. But while we can see gravity at work, magnetism is harder for people to detect. Animals find magnetism much more useful: the hidden lines of magnetic fields that bend around the Earth help creatures such as pigeons and turtles to find their way home.

Although magnets seem to push and pull things almost by magic, the strange things they do are actually powered by electrons spinning inside atoms. This is why magnetism is so closely linked to electricity, which is also driven by the movement of electrons. Working together, electricity and magnetism whirl the generators and motors that power almost everything in our modern world, from electric trains to vacuum cleaners.

Magnetic forces

Magnets have two different ends called poles, which they use to pull things toward them (attract) or push things away (repel). Although we can’t see magnetism, we can watch its effects if we place two magnets close to one another. If the same ends (like poles) of two magnets are placed together, they repel. If opposite ends are placed together (unlike poles), they attract.

Attraction

When the opposite poles of two magnets approach each other, the magnetic field from the north pole of one magnet reaches out to the south pole of the other magnet. This pulls the two magnets together with an attractive force.

Repulsion

If two north poles or two south poles approach each other, their magnetic fields do not link together. This pushes the magnets apart with a repulsive force.
**Magnetic materials**
Most things that are magnetic are generally made from iron and its compounds or alloys (mixtures of iron with other elements). Magnets themselves are usually made from iron, nickel, cobalt, or other elements in the Periodic Table called the rare earth metals (especially neodymium and samarium).

**Magnetic objects**
Steel is an alloy of iron, and is used to make cans and paper clips. Some coins contain nickel.

**Nonmagnetic objects**
These objects don't respond to magnetic fields or repel them. Plastics aren't magnetic, nor are aluminum drink cans or brass instruments.

**Animal magnetism**
How do creatures find their way home without compasses or a GPS? Scientists have long believed that animals such as pigeons, newts, and turtles navigate using Earth's magnetic field. Pigeons have small magnetite crystals positioned in their heads, just above their beaks. Like a mini compass, these help them find their position and follow an accurate course.

**Electromagnetism**
Electricity and magnetism are closely linked: each can create the other. British scientist Michael Faraday (1791–1867) was the first person to see how useful this could be. In 1821, he fed electricity into a wire and made it spin around a magnet, inventing the electric motor. Ten years later, he showed that an electrical conductor moving through a magnetic field could make electricity, inventing the electricity generator. Faraday's work led to our modern world of electric power.

**Magnetic field around a wire**
When an electric current surges through a wire, it generates rings of magnetic field lines all around it. You can see this by placing a compass near a wire carrying a current. The bigger the current, the stronger the magnetism.

**Magnetic field around a coiled wire**
When a current flows through a coiled wire, it creates a more complex magnetic field. Each loop makes a field like a single wire and these fields combine, making an overall field pattern similar to one from a bar magnet.

**Using electromagnets**
Electromagnets can be used to pick up scrap metal. Turning the current on creates a strong magnetic field that picks up the metal. When the current is turned off, the magnetism disappears and the metal is dropped.

**The strength of Earth's magnetic field at its surface is very weak. A typical fridge magnet is 200 times stronger.**
Gravity
When the Earth spins on its axis, people on the equator hurtle round at about 1,000 mph (1,600 kph), but they don’t fly off into the sky. Gravity is the force that pins us to the planet, and it also keeps the stars spinning endlessly in space. Gravity is the pull of every object on everything else and it holds the Universe together like a giant, invisible spiderweb.

Earth's gravitational pull is lower the further you go from the center of the planet, so you weigh slightly less at the top of a mountain than you do down a mine. But, no matter how high up you go, even if you take a rocket to the stars, there is no escape from gravity altogether because it extends to an infinite distance. The only way to fight gravity is to balance it with another force. Planes and helicopters fight gravity by using lift to shoot into the sky. Not everyone wants to fight gravity, however. Skydivers embrace gravity by jumping out of planes and using the force to hurtle at great speeds toward the ground.

Force of attraction
Gravity is a force of attraction—always a pull and never a push. This is different from magnetism and other forces, which can either pull (attract) or push (repel). The gravitational pull between two things depends on their mass and the distance between them. The bigger the mass and shorter the distance, the greater the pull.

Falling apple
Gravity makes an apple and the Earth pull each other with the same force. The apple falls to the ground because the Earth has a greater mass and accelerates far less than the apple.

Mass and weight
The words mass and weight are often used to mean the same thing, but they are different. Mass is the amount of matter an object has, and weight is the force pulling on matter because of gravity. Your mass is always the same, but your weight varies from place to place because gravity varies across Earth.

Pull of the tides
The Moon is smaller and lighter than Earth, and about 240,000 miles (384,000 km) away. Even so, it is big enough to pull on the Earth’s oceans as it spins around our planet, and this is what causes tides. The Sun, which is further away, also affects the tides. Twice a month, when the Sun and Moon line up, we get higher and lower tides than usual because of their combined pull.

Earth versus Moon
People weigh about a sixth as much on the Moon as they do on Earth. Astronauts can leap further on the Moon because the gravitational force is much weaker there than on Earth.

It may seem impressive, but gravity is actually the weakest force in the universe.
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Expanded balloon
Made of a very thin plastic film, the balloon grew bigger as it soared higher into the sky.

Capsule
The pressurized and padded capsule protected Baumgartner on the way up.

Balloon ascending
As the atmospheric pressure dropped, the helium inside the balloon expanded.

1 Supersonic speeds
Baumgartner accelerated rapidly to a maximum velocity of 843.6 mph (1,357.6 kph), which is 1.25 times the speed of sound, and faster than a passenger jet.

2 Air resistance increases
Air resistance grew rapidly until it was exactly equal to the force of gravity. At this point (terminal velocity), Baumgartner flew down at a steady speed. In total, he was freefalling for a record four minutes and 20 seconds.

3 Parachute deploys
Baumgartner opened his parachute at a height of 8,253 ft (2,516 m). This rapidly increased his air resistance and slowed him down, and he landed about nine minutes after leaving the capsule.

Record-breaking skydive
Freefall is a way of fighting gravity. Although you accelerate when you first jump from a plane, air resistance soon increases, canceling the effect of gravity so you fall at a steady speed. In October 2012, Austrian skydiver Felix Baumgartner became the first person to freefall faster than the speed of sound. He also set a world record for the highest freefall jump.
The Sikorsky X2, the world’s fastest helicopter, can travel at speeds of up to 300 mph (480 kph).

Flight

Forces normally pin us to the ground, but if used in the right way they can sweep us high into the sky. If you want to fly, you need lift—an upward force—greater than your weight. Airplanes and helicopters create lift using wings and rotors to move vast quantities of air.

An airplane has large, fixed wings that generate lift as air gusts around them. Its engines simply power it forward, pushing the wings through the air. It’s the wings that launch an airplane into the sky. The bigger the wings and the faster they move, the greater the airflow and subsequent lift. Unlike airplanes, helicopters, such as the United States Navy’s Sikorsky Seahawk, don’t need to fly forward to generate lift. A helicopter’s rotors are tiny compared to an airplane’s wings, but they spin hundreds of times a minute, generating enough lift to push the craft up into the air.

Airplanes can glide for a time without their engines: as long as they move forward, their wings will continue to generate lift. If the engines in a helicopter fail, it can freewheel its rotors in order to make a safe landing.
Seahawk helicopter

One of the Seahawk's main jobs is flying search and rescue missions at sea. The nose of the helicopter is packed with electronic radar and radio equipment for finding objects, as well as night vision cameras. Meanwhile, sonar (sound-detecting) kit on the side can locate objects underwater. The wide cargo doors, and a cabin big enough to hold several stretchers, are specially designed to rescue casualties at sea.

The year Igor Sikorsky built his first helicopter, a model made from rubber bands.
ENERGY

Every second of every day, the Sun pumps energy toward Earth, firing our planet with light and life. Though you can't always see it, energy is everywhere you look. It's locked in the atoms bouncing inside things, and it keeps the heart that pumps blood through your veins beating steadily. It shoots comets through space and makes trees reach for the sky. Energy is the secret power behind everything in our world.

WHAT IS ENERGY?

Things happen because forces push and pull, and whenever forces are at work, energy is needed to power them. Mass (the ordinary matter around us) is another kind of energy. Tiny amounts of mass can be converted into huge amounts of energy.

Measuring energy

We measure energy in units called joules (J), named after English physicist James Joule (1818–89), who investigated energy forms.

Converting energy

There's a fixed amount of energy in the Universe. When we think we're using energy, we're really just converting it into a different form. The total energy before something happens is exactly equal to the total energy afterward.

Lightning

There are few more spectacular examples of energy than a lightning strike. A typical bolt delivers about a billion joules of energy—as much as a power station makes in a second.

Types of energy

Energy can exist in many different forms, most of which can be converted into other forms. When you burn a lump of coal, you change the chemical energy locked inside the coal into heat. If you do this in a power station, you can convert the heat energy into electricity. Once energy is in electric form, it's easy to change it into movement, light, heat, sound, or virtually any other kind of energy.

Kinetic energy

Moving things have kinetic energy. The heavier and faster they are, the more kinetic energy they have.

Electrical energy

Electricity is energy carried by charged particles called electrons moving through wires.

Heat energy

Hot things have more energy than cold ones, because the atoms inside them move around more quickly.

Light energy

Light travels at high speed and in straight lines. Like radio waves and X-rays, it is a type of electromagnetic energy.

Potential energy

This is stored energy. Climb something, and you store potential energy to jump, roll, or dive back down.

Chemical energy

Food, fuel, and batteries store energy within the chemical compounds they're made of.

Sound energy

When objects vibrate, they send energy waves traveling through the air, which we hear as sounds.

Nuclear energy

Atoms are bound together by energy, which they release when they split apart in nuclear reactions.

Dark energy

Most of the Universe's energy is in the form of mysterious dark energy. No one really knows what it is.

ENERGY WAVES

When energy moves through materials such as air and water, it travels as waves. We can see waves on water, but we can't see light waves or seismic waves carrying earthquakes underground.

Different types of waves

<table>
<thead>
<tr>
<th>Up-and-down oscillation</th>
<th>Direction of wave</th>
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<tbody>
<tr>
<td>Compression</td>
<td>Direction of wave</td>
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<tr>
<td>Transverse wave</td>
<td>Ocean waves are transverse. As energy races over the surface, the water moves up and down while traveling forward.</td>
</tr>
<tr>
<td>Longitudinal wave</td>
<td>As you bang a drum, the air is squeezed (compressed) and stretched (rarefied) as the sound waves race toward your ears.</td>
</tr>
</tbody>
</table>

Measuring waves

Energy waves have an up-and-down pattern of crests and troughs. We can measure waves in three ways. The height of a wave is its amplitude. The distance from one wave crest to the next is the wavelength. The number of crests passing in one second is the frequency.

AN AVERAGE MAN'S BODY MASS CONTAINS AS MUCH ENERGY AS A NUCLEAR POWER PLANT CAN PRODUCE IN 90 YEARS.
**ENERGY SOURCES**

Cooking, heating, traveling, and making things—all these need energy. Prehistoric people relied on fire for their energy needs, but today we use a wide range of energy sources. Some energy sources, such as the fuel that powers our cars, are in limited supply. Renewable energy comes from unlimited natural sources, including sunlight, wind, and waves.

### Timeline of energy

- **Fire** Prehistoric people burned wood, peat, and animal dung to release heat.
- **Animal power** Ancient people rode animals and used them to carry goods from place to place.
- **Wind power** Wind energy was harnessed by sailing ships and windmills in medieval times.
- **Coal** In the 18th and 19th centuries, coal was burned to power engines and machinery.
- **Oil (petroleum)** Oil became the fuel for road vehicles, ships, and planes in the 20th century.
- **Nuclear power** In the mid-20th century, scientists learned how to release energy by splitting atoms.
- **Renewables** In the future, we may rely on sources such as wind, solar, and wave power.

### Pollution

More than 80 percent of our energy comes from fossil fuels (coal, gas, and oil). The problem with these fuels is that burning them causes pollution—releasing toxic waste that harms the environment. Other forms of energy, such as nuclear power, also have an impact on the climate.

#### Air Pollution

Exhaust fumes from car engines and harmful gases from power stations and factories cause air pollution, which can lead to health problems such as asthma.

#### Acid Rain

Sulfur dioxide gas escaping from power stations mixes with rain and makes it acidic. This acid rain can damage trees, poison lakes, and kill fish.

#### Radioactive Waste

Nuclear power stations produce radioactive waste that is difficult to dispose of safely. It can leak into rivers and seas and travel a long way as water pollution.

#### Reef Erosion

Fossil fuels are causing the planet to get hotter. One result is damage to coral reefs, which die and turn white in water that is too warm.

#### Noise Pollution

Cars, planes, and machines all waste some of their energy by making noise. Noise pollution disturbs people and animals, causing stress and anxiety.

#### Oil Spills

Accidental spills from tankers, rigs, and refineries release huge amounts of oil into the sea, which can be deadly to seabirds, fish, and other marine life.

### World energy use

As the world’s population has grown and we’ve invented gas-guzzling cars and built fuel-hungry homes, our energy needs have increased too. Total worldwide energy use has increased by about 14 times since the early 20th century.

#### Energy equivalents

One reason cars are so popular is because oil is rich in energy, so it carries vehicles a long way. Uranium, which makes electricity in nuclear power stations, is packed with even more energy. Although coal contains a lot of energy, it’s difficult to transport and creates pollution. Natural gas is easy to send through pipelines, but it takes a huge amount to produce the same energy that you get from a few barrels of oil or a pile of coal.

1 URANIUM PELLET (shown actual size) = 3.5 BARRELS OF OIL (147 gallons/556 litres) = 1,789 lbs COAL = 17,000 FT³ NATURAL GAS

### Heat loss and insulation

If your house were perfectly sealed, you could heat it once at the start of winter and it would stay warm until spring. In reality, all houses leak heat. Energy is expensive, so it pays to insulate homes using materials that keep heat in and cold air out.

- **Attic insulation** A quarter of the energy you pump into your home vanishes through the roof. Thick layers of attic insulation reduce this effectively.
- **Leaky walls** About 30 to 40 percent of the heat in your home escapes through the walls.
- **Double glazing** Trapping air (a good insulator) between two panes of glass creates a barrier to reduce heat loss.

- **Cavity wall** Air spaces between walls can be filled with foam, fiberglass, or other materials that stop heat from escaping.
- **Hot water tank** A padded jacket or foam outer cover keeps water hot in your tank.
- **Doors and windows** A porch cuts heat loss from your door when you go out, and heavy curtains trap insulating air next to windows.
Electromagnetic spectrum

As the Sun sends its rays to Earth, it lights up our world. But there’s more to the world than the things we can see with light alone.

As light races through space, it makes electricity and magnetism ripple down its path like waves on the sea. Light is not the only energy that behaves like this: there’s a whole collection of similar waves called the electromagnetic spectrum. Some of these waves are very long, with large spaces from one peak to the next. Others are extremely short and close to each other. Different waves have different uses, depending on their length.

Although we can’t see most electromagnetic waves, they are incredibly useful, helping us with everything from spotting broken bones to watching TV shows.

Where electromagnetic radiation comes from

Light is made when atoms flash on and off like fireflies. If you heat an iron bar, it glows red hot. The atoms inside absorb heat energy, but it makes them unstable. To return to normal, they have to get rid of the energy again, and do so by giving off a flash of light. Other kinds of electromagnetic waves are made in the same way.

On your wavelength

The longest waves on the electromagnetic spectrum are radio waves, which can be thousands of miles long from the top of one wave to the next. At the other end of the spectrum, gamma rays are even smaller than atoms, and are packed full of energy. The shortest waves have the most energy and the highest frequency (meaning they vibrate the fastest), while the longest waves vibrate more slowly and have less energy. As you travel along the spectrum you can see how different wavelengths are used for a variety of useful tasks.

Radio waves

Radio waves carry TV (as well as radio) signals between giant antennas like this one. Long (AM) radio waves bounce off part of the Earth’s atmosphere called the ionosphere, especially at night, which is why you can pick up more distant radio stations in the evening.

Microwave ovens cook with waves about 5 in (12 cm) long.

Radar

Shortwave radio waves, typically as long as a finger, are used for ship and airplane navigation.
The visible or color spectrum
The light that looks white to our eyes is really a mixture of different colors. We can see this by firing a light beam through a wedge-shaped piece of glass called a prism, which causes light to spread into the spectrum. Rainbows work in exactly the same way. As sunlight shines through rain, each water droplet acts like a miniature prism.

7.5 The number of times that light can go around the world in one second. It travels at a blistering 186,000 miles (300,000 km) per second.

Infrared rays
We feel the heat that things give off when the atoms in our bodies absorb a kind of hot light called infrared radiation. Although invisible, infrared radiation shows up on thermal (heat-sensitive) cameras, like the one that photographed this elephant.

Gamma rays
The smallest electromagnetic waves are like super-energetic X-rays, but do much more damage to the human body. They’re made when atoms split apart in nuclear explosions.

Ultraviolet
Shorten blue light waves and you get energetic radiation called ultraviolet (UV). Sunlight contains two kinds of ultraviolet: UV-A and the more harmful UV-B. Small amounts of UV give a nice suntan; in bigger doses, it ages skin and causes cancer.

X-rays
These short waves have enough energy to pass through soft body tissue (skin and muscle) but not bone. That’s why an X-ray photo shows bones as shadows. High doses of X-rays can be very harmful.
Signals from space

Whether you’re scrambling up Mount Everest or trekking the Sahara Desert, you’re never more than a few seconds from your friends. That’s because telephones and the Internet, linked by space satellites, can zap messages from any place on Earth to anywhere else at the speed of light.

Earth might seem huge, but no two places are more than half its circumference (12,400 miles or 20,000 km) apart—and a beam of light can cover that distance in less than a tenth of a second. When you chat to friends in faraway countries by phone or online, the sound of your voice, the image of your face on your webcam, or the message you type is bounced across the Earth in less than a second via satellites in space. Signals from space satellites can also tell us exactly where we are. Thanks to technology like GPS (Global Positioning System), getting lost has now become almost impossible.

Assisted GPS

A cell phone can locate roughly where it is by its connection to the nearest transmitter tower. Assisted GPS uses Wi-Fi and GPS signals to precisely locate a cell phone’s position, so it can tell you exactly where you are.
GPS satellites

No single satellite could cover every place on Earth at once. That’s why the GPS system has a network of at least 24 separate spacecrafts. No matter where you are, at least four of them are sending signals to your phone.

GPS signals

GPS satellites work differently from ordinary communications satellites. Each beams out two coded signals toward the Earth. A short signal travels fast and lets people locate themselves fairly accurately. A more precise signal helps the military to fire missiles with pinpoint accuracy.

Finding your position

It takes less than a second for a GPS signal to reach Earth from space, traveling at the speed of light. Knowing how long the signal took, a GPS receiver calculates how far away the satellite is. Using signals from at least three satellites (preferably four), it’s possible to calculate your precise location.

1. One satellite
   If the satellite is a certain distance away from you, your position must be somewhere on a sphere with that distance as its radius.

2. Two satellites
   If there are two satellites, your location must be in the area where their signals overlap.

3. Three or more satellites
   There is only one place on Earth’s surface where three signals meet. This is your precise location.

Satellite navigation

A car’s navigation system uses a stored database of maps linked to GPS satellite positions. As you drive along, a GPS receiver detects your changing position. A computer in the system calculates how fast you are moving and continually redraws the map to show your progress.

Satellite

GPS satellites catch signals from Earth and send new signals straight back.

Large solar panels generate electric power from the Sun.
Light

Light is a type of radiation that moves through space. Animals such as humans have eyes sensitive to light to see and understand the world around them.

Although light seems special, it’s really just another kind of electromagnetic energy, like microwaves and radio waves. Light normally travels in straight-line rays, and reflects and refracts (bends) in very precise ways as it speeds through the world. Most of the light we see with our eyes is very weak because it has already reflected off things. Not all light is so weak, however: light beams made by lasers are super concentrated and can be powerful enough to slice through metal.

Reflection

We see things because light bounces off them into our eyes. If a surface is smooth, like a mirror, the light rays all bounce off at the same angle to make a single beam. This is called specular reflection. If the surface is rough, the rays bounce off randomly in different directions. This is called diffuse reflection.

The law of reflection

A light ray shooting at a mirror bounces off again at exactly the same angle. In more scientific terms, we say the angle of incidence is equal to the angle of reflection.

How a mirror reverses things

Mirrors don’t reverse things left to right—writing looks reversed in a mirror because you’ve turned it around to face the glass. Mirrors actually switch things from back to front, along a line through the mirror.

Real and apparent depth

Refraction makes fish appear nearer to the surface. Because our brains assume light rays travel in a straight line, rather than bend, we see the fish higher up than they really are.

Reflection in action

Still water acts like a flat (plane) mirror. It reproduces what’s above it through specular reflection. When the water ripples, light bounces off at random angles so the reflection becomes blurry.
**Interference**

When two or more light rays, water waves, or sound waves meet, they combine to make interference. In some places, the waves add together (interfere constructively) and in others, they subtract or cancel out (interfere destructively). The result is a new wave that's bigger in some places and smaller in others. This explains why an ocean wave can be followed by another wave that may be much bigger or smaller.

**Constructive interference**

When two waves of the same length and height (amplitude) overlap exactly in step (in phase), they add together. The new wave they make has the same wavelength, but twice the height. If two light waves added together like this, it would make light twice as bright.

**Destructive interference**

When two identical waves add together, but are moving out of sync (out of phase), they cancel out altogether. The wave they make has zero amplitude. If two light waves added together like this, they would make darkness.

**Diffraction**

Light waves spread out when they pass through tiny gaps or holes. The smaller the gap, the more spreading (diffraction) that occurs. You can see diffraction for yourself if you squint your eyes almost closed and stare at a streetlight. As you close your eyes, you'll see the light spreading out as it diffracts through the gaps between your eyelashes.

**Lasers**

Lasers make very powerful beams of light. Unlike in normal lamps, the light waves from lasers are in sync and add together (constructive interference). This is why laser light is strong enough to travel incredible distances and why the most powerful lasers (carbon dioxide lasers) can weld metal or slice right through it.

**Inside a laser**

Lasers make light when a power source flashes energy through a central tube. The atoms become excited, give out flashes of light (photons), and excite other atoms so they flash too. The light bounces back and forth between two mirrors until it emerges from one end as a concentrated beam.

**Colorful soap bubbles**

Interference makes soap bubbles swim with color. The soapy film varies in thickness over the bubble. As light rays shoot into a bubble and reflect off its inner and outer surfaces, they add or subtract to make waves of different colors.

**Diffraction through a narrow gap**

For diffraction to work, the gap has to be about the same size as the wavelength of the waves. Sound waves also diffract, which is why we can hear through open doorways and around corners into other rooms.

**A light wave is about 5.5 million times smaller than an FM radio wave.**

When the Channel Tunnel was dug between Britain and France, laser beams helped to ensure the two ends met beneath the sea to within 0.8 in (2 cm).
Telescopes

Most of what we know about the Universe comes from large, professional telescopes, some of which are as big as office blocks. They use lenses and mirrors to catch and bend light, making distant stars snap crisply into focus.

Giant mirrors can be heavy and expensive to build, so several telescopes can be linked together to work as one. The world’s biggest optical (light-based) telescope is the Very Large Telescope (VLT) in Chile. It can link together two or three telescopes, each with mirrors 27 ft (8.2 m) wide, to make a single instrument that can create clearer images of bright objects than individual telescopes are able to.

Paranal Observatory

The VLT consists of four giant telescopes fixed in place, four small auxiliary (additional) telescopes that shuttle along rails to different positions, and about 20 scientific instruments for analyzing the light these telescopes capture. The large telescopes are named Antu, Kueyen, Melipal, and Yepun (the names for the Sun, Moon, Southern Cross, and Venus in one of Chile’s native languages).

Images of outer space

With two or three telescopes working together, the VLT can reveal tiny details no other telescope on Earth can hope to capture. Since it started operating in 2000, the VLT has taken some incredible images of stars, galaxies, and nebulas that have helped to enhance our understanding of the Universe. Recently it has taken images of exoplanets (planets outside our Solar System).

Sombrero Galaxy

It takes about 30 million years for light to reach the VLT from the Sombrero Galaxy, which is shaped like a Mexican hat. Altogether, the galaxy weighs as much as 800 billion Suns. It has an outer ring of stars, gas, and dust, and a dense central nucleus of mature stars.

Crab Nebula

The Crab Nebula is the remains of a huge star that exploded into a supernova. Captured by the VLT, this image shows a blue region at its center made of high energy electrons spiraling around in a magnetic field. The Crab Nebula is about a thousand years old and five light years in diameter.

N70 Nebula in the Large Magellanic Cloud

Virtually the neighbor of our own Milky Way galaxy, the Large Magellanic Cloud is 160,000 light years from Earth. Ancient astronomers thought it looked like a fuzzy cloud or hazy mountains. N70 Nebula is a giant bubble of gas within the Large Magellanic Cloud.
Path of light
Light from space is captured by the giant concave (inward-curving) main mirror. This reflects the rays back up to a smaller secondary mirror, which bounces the concentrated light beam along a series of other mirrors to scientific instruments. When two or three telescopes are linked together, the light is beamed underground through tunnels to join up with the beams captured by the other telescopes.

Telescope mechanics
The complete moving mechanism at the heart of the telescope weighs 500 tons—more than the entire International Space Station.

Primary mirror
The 26 ft (8 m) main mirror weighs 22 tons—more than three adult elephants. It can swivel horizontally or vertically to point at any place in the sky.

Actuators
The 160 actuators (hydraulic rams and electric motors) make constant tiny adjustments to stop the heavy mirror from buckling under its own weight.

To VLTI lab

Each of the VLT telescopes can spot things 4 billion times fainter than we can see with the naked eye.

25 times more detail can be seen when three VLT telescopes are linked together. The one large telescope that is created is called an interferometer.
Sound

When someone shouts hello, billions of molecules push and shove through the crowded air between you, speeding the sound to your ears. If we could watch this happen, we’d see that sounds are waves of energy that squeeze and stretch the air as they travel.

All sounds travel in waves, and what makes one sound different from another is simply the shape of its waves. Unlike waves on water, which snake up and down as they move forward, sound waves push and pull in the same direction that they travel.

Sound is ultimately just another type of energy, like light or heat, but it’s special to us because it carries words and music at high speed. Without sound we wouldn’t be able to listen to birds singing in the trees or the latest hit songs on the radio. It has the ability to affect our emotions and stir up our interest in the world around us.

How sound travels

If you bang a drum, its skin vibrates, shaking the air molecules around it. These push on nearby molecules, which shake others, and the sound quickly ripples outward, spreading energy in all directions. When the energy finally reaches our ears, it makes the air inside them vibrate too and we hear sounds.

Speed of sound

We see lightning flash several seconds before we hear thunder claps, because light travels much faster than sound. At ground level, at an air temperature of about 68°F (20°C), sound travels at 1.125 feet per second (768 mph or 1,235 kph). However, it doesn’t move at the same speed in every material. Because sound moves by shaking energy through atoms or molecules, its speed depends both on the inner nature of a material—how close together its atoms are—and the temperature.

Supersonic motion

By the time you hear a jet plane screaming overhead, it’s already shot past. Flying faster than the speed of sound, it leaves its own noise far behind. Supersonic planes make so much noise because they ram and squeeze the air in front of them, trailing huge shock waves behind.

Speed of sound in different materials

You can walk faster through air than through water, so you might expect sound to do the same. But sound waves travel fastest in solids (since the atoms are closest together), slower in liquids, and slower still in gases. Sound travels over 17 times faster in steel than in air.

Louder sounds are carried by taller waves (higher amplitude)

Quieter sounds are carried by shorter waves (lower amplitude)

Higher pitched sounds vibrate quicker (higher frequency)

Lower pitched sounds vibrate slower (lower frequency)

Pitch

The pitch (frequency) of a sound comes from how often it vibrates. A tight drum skin vibrates more than a loose one, making higher pitched (higher frequency) sounds. These vibrate more often than lower frequency sounds.

Loudness

It takes more energy to make louder sounds. The harder you beat a drum, the more its skin shakes up and down. That makes the air molecules push and pull harder, producing a louder sound in your ears.

Loudness

Normal planes trail behind their own sounds so you can hear them coming.

At the speed of sound

Sound waves bunch together to form a shock wave.

Faster than sound

Shock waves trail behind the plane making a sonic boom you can hear on the ground.
The Doppler effect
When a police car hurtles toward you, its siren sounds high-pitched. This is because the car is driving forward into the sound waves sent out by the siren, so the waves get closer together and arrive at your ears more frequently, giving them a higher pitch. After the siren passes, you hear a sudden drop in pitch. This is because the car is moving away in between the sound waves, so they grow further apart, and therefore sound lower pitched. This is called the Doppler effect after the physicist who discovered it.

Shifting sirens
The pitch of a siren is helpful in working out if a car is moving toward or away from you. In the moment the car passes you, you will hear its siren exactly as the driver of the car hears it.

Musical sound
Our brains instantly spot the difference between noise and music. Musical notes are made from sound frequencies connected in precise ways. If you play the eight notes in an octave (musical scale), the highest has exactly twice the frequency of the lowest. If you play the same note on different instruments, you make complex waves that have the same frequency but different shapes.

Tuning fork
Bang a tuning fork and it makes a simple, regular, up-and-down sound wave pattern called a sine wave. Each fork produces only one note (frequency) and you need different forks to make other notes.

Violin
When you play a violin, the strings vibrate, setting the air moving inside the hollow wooden case. A violin’s sound wave is a sharp and spiky wave.

Flute
Flutes make sounds when you blow into them, vibrating and making waves inside the pipe. The sound waves are similar to the sine wave from a tuning fork, but slightly more complex.

Cymbal
Percussion instruments make sounds when you hit them. Their sound waves are more like a short burst of random noise (white noise) than the precise wave shape of a tuning fork.

It’s possible for a powerful singer to shatter a crystal wine glass by singing at the same note or frequency that the glass makes when clinked.
Heat

When an ice cream cone dribbles down your hand, blame science. Heat (kinetic energy hidden inside things) moves around our world in very distinct ways according to rules that cannot change.

Heat is a type of energy stored when atoms and molecules move around inside objects. Hotter objects contain more heat than colder ones because their atoms and molecules move faster. Heat doesn’t always stay in one place—if something hot is near something cold, it passes heat on until the two temperatures are equal. When the hot object cools down, it loses a certain amount of energy to the cold one, which gains exactly the same energy and heats up.

Kinetic theory

The hotter a gas, the faster its atoms and molecules move around. The faster they move, the more they collide with the container, making pressure. If you heat or squash a gas, the particles move faster and collisions happen more often, increasing the pressure and temperature. This idea is called kinetic theory.

Temperature

The temperatures that people experience on Earth fall within a tiny range of less than 150 degrees. The maximum possible range of temperatures, from absolute zero (the coldest possible) up to the high temperature inside the Large Hadron Collider, is about 2 trillion degrees.

Absolute zero

At the coldest possible temperature, the atoms and molecules inside things stop moving and lock down. We call this absolute zero. No one has yet made anything this cold, although scientists have gotten to within fractions of a degree of this temperature.

How heat travels

Like other forms of energy, heat tends to spread out evenly. Hot objects pass energy to colder ones nearby by three processes, called conduction, convection, and radiation. Often, more than one of these processes happen at the same time. A radiator in your room might pass heat to the wall and floor by conduction (direct contact), convection (warm air currents), and radiation (beaming heat directly to your body).

Conduction

When something hot touches something cold, the atoms in the hotter object are moving faster and agitate their colder neighbors. The colder atoms do the same—and soon the heat flows all along the object.

Metal changes color

Atoms in the bar take in heat energy but give some back out as light, so the bar glows white, yellow, or red hot.

Convection

Extra pressure moves piston down

Gas molecules move faster

Gas molecules spread out

Expanding cools a gas

Atoms in the gas have more space to move. The overall heat energy is spread over a bigger space, so the gas is cooler.

Compressing heats a gas

As the piston moves in, the atoms are squashed closer so they collide more often with the container, and heat it up.
Measuring heat
Temperature measures how hot or cold something is, but not how much heat energy it has. An iceberg is enormous so, even though it seems cold, all its moving atoms and molecules contain lots of heat energy. A cup of coffee, though hotter, is much smaller than an iceberg and therefore contains less heat energy overall.

Different measurements
We measure temperature with three different scales. Fahrenheit is the official scale in the US and a few other countries. Celsius is the most common unit of measurement, while Kelvin is mostly used by scientists.

Absolute maximum
The hottest temperature scientists can imagine is 140 million trillion trillion degrees K (known as the Planck temperature). The Universe is believed to have been this hot a fraction of a second after the Big Bang, but nothing has been anywhere near this temperature since then.

Convection
Convection is the way heat circulates through flowing liquids and gases (fluids). When you heat water in a pan, the rising hot water and sinking cold water gradually warm the entire liquid.

Radiating heat
Like light, heat beams out from hot objects and can even travel through a vacuum. The more surface area something has, the faster it radiates heat and cools down.

Cooling quickly
Object made of eight blocks with 28 sides of surface area radiates heat faster.

Cooling slowly
Object made of eight blocks with 24 sides of surface area radiates heat slower.
Electricity

Leaping bolts of lightning are fueled by electrons. These tiny charged particles that whiz around inside atoms are about the smallest things we can imagine. Yet everything electric is ultimately driven by them.

From heating and lighting our homes to powering trains, electricity can do a remarkable range of things. When electrons march through wires, they carry energy from place to place, making what we call an electric current. Electric currents power everything that plugs into a socket at home and, through batteries, fuel cell phones and laptops when we are on the move. When electrons build up in one place, they make static electricity. It’s static electricity that crackles when you take off your sweatshirt—and static buildup that causes lightning bolts to zap back to Earth.

**How a battery works**

Batteries are portable power supplies that make electricity using chemistry. They have a negative terminal (the metal case and plate at the bottom), a positive terminal (the metal knob on top), and an electrolyte (chemical mixture) in between. When you connect a battery into a circuit, chemical reactions start up inside it, generating electrons and positive ions (atoms missing electrons). The positive ions drift through the inside of the battery. The electrons flow around the circuit outside, powering whatever the battery is connected to.

**What happens when a current flows?**

When you plug a lamp into an outlet or turn on a light switch, electrical energy flows along the wire. The atoms in the wire stay put, while electrons flow all around them, each one carrying a tiny amount of electricity called a charge. Although each electron moves slowly, the wire is packed with them. That’s why electricity takes no time at all to flow from its source to where it’s used. The lamp lights instantly.

**Electric circuits**

The path that electrons flow along is called a circuit. An electric circuit carries energy from a power source (such as a battery) to something that uses power (such as a lamp) and back again. Electricity only flows if a circuit forms a complete (closed) loop. If the loop is broken somewhere along the line, electrons can’t get across the gap and the electric current stops flowing. Switches work by breaking circuits in this way.
**Static electricity**

We usually think of electricity as flowing through something, but when electrons build up with no circuit for them to flow along they create static electricity. Static electricity is what makes your hair stand on end when you pull on a polyester T-shirt, or a balloon stick to the wall after you have rubbed it on your sweatshirt. The surfaces of things like balloons steal electrons from other surfaces and the extra electrons make them negatively charged.

**Negative charge**

If you rub a balloon on your sweatshirt, the balloon develops a negative charge. If you hold the balloon up to a wall, it pushes away negative electrons and makes the wall’s surface positive. The balloon sticks in place.

**Plasma spheres**

The swirling streams inside this clear glass sphere, filled with a mixture of gases, are produced by static electricity. When the rod in the middle is charged to a high voltage, atoms of gas inside the ball are pulled apart to make a plasma (a soup of atoms split into ions and electrons). Electricity builds up in the center and then zaps through the ions and electrons to the outer edge, making streams of mini lightning bolts.

**Electric currents**

Light streams are electric currents flowing from the center to the edge of the sphere.

**Lightning bolts speed through the air** at around **200,000,000 mph** (322,000,000 kph).

**Lightning can heat the air surrounding it to a temperature that is more than five times hotter than the Sun’s surface.**

**Negative charge**

If you rub a balloon on your sweatshirt, the balloon develops a negative charge. If you hold the balloon up to a wall, it pushes away negative electrons and makes the wall’s surface positive. The balloon sticks in place.

**Unlike charges attract**

Negative and positive charges attract, so the balloon sticks to the wall.

**Plasma sphere**

A glass ball filled with a low pressure gas such as neon or argon.

**Like charges repel**

Two negative charges repel each other, so the balloons push apart.

**High-voltage center**

The inner rod and ball feeds high-voltage electricity into the middle of the sphere.
From source to the home
Electricity surges through a complex grid network linking the power stations and generators that produce it to the many things that use it. How much electricity we use rises and falls through the day, but the many different forms of electricity generation can be balanced to meet demand, so we never run out of power.

Power network
Chunks of coal, gusts of wind, raging rivers, and shattering atoms—these are some of the things we use to make electricity, our most versatile form of energy.

Before the first electric power stations were developed in 1882, people had to make energy by burning fuels such as wood and coal, which was often dirty and time-consuming. Large-scale electricity generation solved these problems. Electricity could be made in one place, then sent hundreds or thousands of miles down wires to where it was needed. Coal and wood can only provide heating, while gasoline only powers vehicles. But electricity can be used in many different ways—for heating, lighting, and powering motors that drive everything from tiny electric toothbrushes to huge electric trains.
Sources of electricity
Most countries make the majority of their electricity from fossil fuels (coal, natural gas, and oil). In some countries, like France and Japan, nuclear power generates a lot of electricity too. Wind and solar are the best-known types of renewable energy. Even so, most renewable energy is actually produced with hydroelectric power.

![World Electricity Production in 2012](chart)

Green energy
Burning fossil fuels causes pollution, which adds to the problem of global warming, and these fuels will eventually run out. Although nuclear power uses no fossil fuels, it relies on uranium mined from the ground, which will run out too. Wind, hydroelectric (water), and solar power will never run out and are genuinely renewable forms of green energy.

![More Green, Less Green](chart)

Consumption
Huge electrical machines in factories use much more power than home appliances and office machines, and that’s why factories need higher-voltage electricity. But there are many more homes in total. Overall, homes, offices, and factories each use just under a third of the total electricity produced.

Feeding electricity back into the grid
Homes that generate electricity often produce more than they can use. Like tiny power stations, they can feed the surplus energy back into the grid, earning money for their owners. When homes generate more electricity than they use, their electricity meters spin backward!

Homes
Homes consume about a third of all electricity. Most is used for heating and cooking and by large appliances such as washing machines, clothes dryers, and dishwashers.

Skyscrapers
Large buildings might contain hundreds of homes or offices, so they need much more power than individual homes.

Substation
Voltage is reduced to 25,000 volts for homes and offices.

Railway lines
Electric trains take electricity from overhead power lines. When they slow down, their brakes feed energy back to the power lines instead of wasting it as heat.

Big cities
Cities consume more electricity than towns or villages, but use it more efficiently. Less electricity is wasted because buildings are closer together and people travel more efficiently by subways and other public transport.

The amount of electricity the world uses in a year is enough to power 10 trillion toasters for a whole hour.
Radioactivity

Nuclear power stations make electricity by smashing atoms apart. Atoms are locked together by huge forces, and they release massive amounts of energy when they disintegrate.

Many elements have atoms with slightly different forms, called isotopes. Some of these are very unstable (radioactive) and naturally break apart to turn into more stable forms, releasing energy. Atoms can also be forced to split apart artificially, in nuclear power stations and atomic bombs. Although radioactive atoms are dangerous enough to kill people, they can help to save lives as well. Radioactive particles are used in smoke alarms, and they help to preserve foods by killing harmful bacteria. They are also used to treat and detect life-threatening illnesses such as cancer.

**Types of radiation**

Unstable atoms break up to release three types of radioactivity—alpha, beta, and gamma. Alpha and beta radiation are made from bits of the broken atoms. Gamma rays are a type of electromagnetic radiation, similar to light but more energetic and highly dangerous.

**Alpha radiation**
The slowest and heaviest forms of radioactivity are called alpha particles. Each alpha particle has two protons and two neutrons (the same as the nucleus of a helium atom).

**Beta radiation**
Beta particles are smaller and faster forms of radiation. In fact, they are just streams of electrons that unstable atoms shoot out at about half the speed of light.

**Gamma radiation**
Gamma rays are a type of electromagnetic radiation, similar to light but more energetic and highly dangerous.

**Penetrating power**
Alpha, beta, and gamma radiation can go through different amounts of matter because they have different speeds and energy. Alpha particles can’t even get through paper. Beta particles can get through skin, but not metal. Gamma rays can only be stopped by very thick lead or concrete.

If you could wire a nuclear power station up to an electric kettle, you could boil the water for a cup of tea in 50-millionths of a second.
Energy from atoms
Atoms release energy in two ways. When large, unstable atoms (such as uranium) split into smaller atoms, they give off heat. This process is called fission (splitting). It creates heat because the total energy in the smaller atoms is less than the energy in the original atom. A second process is called fusion (joining), when small atoms (hydrogen isotopes) smash together, combine, and release energy. All of the world’s nuclear power stations currently work by fission, but scientists hope to build fusion stations because they will be much cleaner.

How nuclear power works
In a nuclear power station, the heat that boils steam to make electricity isn’t made by burning coal or gas, but by splitting atoms inside a giant nuclear reactor and capturing their energy. The amount of power can be controlled by raising and lowering rods to speed up or slow down the nuclear reactions.

How fission works
A neutron is fired into an atom of uranium, splitting it into two smaller atoms. More neutrons are released in the process, producing a chain reaction.

How fusion works
Two heavier isotopes of hydrogen (deuterium and tritium) smash together to make helium. A spare neutron is fired out and heat energy is released.

Other uses of radioactivity
From archaeological digs to making bombs, radioactivity has lots of uses, many of them medical. Heart pacemakers once used tiny nuclear power units, because they lasted decades longer than batteries. Medical scans often involve people swallowing or being injected with safe radioactive substances. Scanning equipment outside of their body detects the radiation and creates detailed images of their illness. Radioactivity can also treat cancer. Radiotherapy treatment bombs tumors with gamma rays, killing the cancer and stopping it from spreading.

Nuclear weapons
Most atomic weapons use nuclear fission and need pure uranium or plutonium so their chain reactions continue over and over. Hydrogen (H) bombs are even more powerful and work through nuclear fusion.

Radiometric rock dating
Rocks on Earth contain unstable radioactive atoms (such as uranium) that are constantly changing into more stable atoms (such as lead) at a precise rate. If we compare the amount of uranium and lead in a piece of rock, we can work out how old it is.
Electronics

Electrons traveling through circuits can play your favorite songs, turn your television on and off, or capture digital photos of your friends. When gadgets use electrons in this way, we say they’re electronic—they use electricity in a way that’s more precise and finely controlled than the kind that powers simple home appliances. Electronics is the secret power behind calculators, computers, robots, and the Internet.

WHAT IS ELECTRONICS?
It takes quite a lot of electricity (large electrical currents) to boil water or heat a home. Electronics uses carefully controlled electric currents thousands or millions of times smaller, and sometimes just individual electrons, to do useful things.

Controlling
We can use electronics to switch things on and off. When you press a button on a TV remote control, an electronic circuit detects what you want and sends an invisible beam to the TV set. The TV detects this and another circuit responds.

Amplifying
Electronic circuits can boost tiny electric currents into bigger ones. An electric guitar uses electromagnets to convert the movement of the strings into electric currents. These are boosted in an electronic amplifier, which powers a loudspeaker.

Processing information
The electronic circuits in computers digest information. When you type, electronic circuits decode the keys you press, understand what you are typing, and work out where to display the letters.

Communication
In cell phones, electronic circuits convert our speech or text into a form that can be beamed through the air using invisible radio waves. They can also convert radio waves from other phones back into spoken words or text messages.

COMPONENTS
An electronic circuit is made of building blocks called components. A transistor radio might have a few dozen components, while the processor and memory chips in a computer could have billions. Four components are particularly important and appear in almost every single circuit: resistors, capacitors, diodes, and transistors.

Resistors
Resistors reduce an electric current so it’s less powerful. Some have a fixed size, while others vary. The volume on a TV set is a variable resistor. As you move it, its resistance rises or falls, altering the current, and making the sound quieter or louder.

Capacitors
Capacitors store electricity in a sandwich of metal foil separated by air or plastic. It takes a precise time for them to charge up, so they are often used in circuits that work as timers. Capacitors are also used to detect key punches on cell phone and tablet touchscreens.

Diodes
A diode is the electronic version of a one-way street: a current can only flow along it in one direction. Diodes are often used to convert electricity that flows in both directions (alternating current) into electricity that flows only one way (direct current).

Transistors
Transistors can switch electric currents on and off or convert small currents into bigger ones. Most transistors are used in computers. A powerful computer chip contains a billion or more transistors.
INTEGRATED CIRCUITS

Electronic components such as transistors are about as big as a pea, so a computer with a billion of them would be enormous. It would also be difficult to make, unreliable, and power hungry. In 1958, two US engineers named Jack Kilby and Robert Noyce found ways of shrinking electronic components and their connections into a tiny space. This idea became known as an integrated circuit, or chip.

Making chips

Chips are intricate and have to be made in ultraclean, dust-free conditions. Many chips are made at once on the surface of a thin wafer sliced from a crystal of silicon (a chemical element found in sand).

Moore’s law

Engineers are constantly finding new ways to add more components into chips. This graph shows that the power of computers (number of transistors on a chip) has doubled roughly every two years since the first single-chip computer appeared in 1971. This is called Moore’s law, named after Gordon Moore (1929—), a founder of the Intel chip company.

DIGITAL ELECTRONICS

Most of the gadgets we rely on every day use digital technology: they convert information into numbers (digits) and process the numbers instead of the original information. Digital cameras turn pictures of the world into patterns of numbers (digital photos), and cell phones send and receive calls not as sounds but as long strings of numbers. Gadgets like these use integrated circuits to convert, store, and process information in digital form—a technology known as digital electronics.

Analog and digital

Ordinary information, like the sound waves made by a guitar, is called analog information. If you use an oscilloscope (an electronic graph-drawing machine) to draw these sound waves, they look exactly like the sounds you can hear—the waves rise and fall as the sound rises and falls. Digital technology converts this analog information into numbers through a process called sampling.

Logic gates

Computers process digital information with circuits called logic gates. These compare two numbers (0 or 1) and produce a third based on the result. The main types are AND, OR, and NOT.

Calculators

Calculators use logic gate circuits to add and subtract numbers. Dividing is done by subtracting repeatedly; multiplying is done by adding a number over and over again.

Memory

Computers store information as well as process it. This happens in memories made from transistors. To store a word, a computer converts it into a pattern of zeros and ones called binary code. Each zero or one is stored by its own transistor, switched on or off.
Digital world

What’s better, a computer or a brain? Computers can rattle through billions of equations every second and tell you the name of every king and queen that has ever lived. But the fastest supercomputer on the planet is less powerful than a mouse’s brain and takes up a million times more space.

Computers are electronic machines we can use to do many different things just by changing the instructions (programs) stored inside them. The first computers were little more than giant calculators. Later, people found that computers had superb memories: they could store more information much more reliably than the human brain. Many people now use their computers as communication tools to make friends, send emails, and share the things they like. This is possible because virtually all of the world’s computers are connected together in a giant worldwide network called the Internet. Part computer and part human brain, the online world of the Internet brings us the best of both.

Early Computers
Computers are based on calculators that simply add numbers. The first mechanical calculators appeared in the 17th century. When people found ways to make calculators automatic, computers were born. The first electronic computer that could be programmed to do different jobs was ENIAC, completed in 1946. It was bigger than a delivery truck and had more than 100,000 separate parts.

Difference Engine
Mathematician Charles Babbage (1791–1871) was the first person to design a computer that worked by itself. Babbage never finished the Difference Engine in his lifetime, but this impressive replica was built after his death.

How a computer works
Computers are electronic machines that take in information, record it, work on it in various ways, and then show the results of what they’ve done. These four stages are called input, storage, processing, and output, and they’re carried out by separate pieces of equipment. You can input information using a keyboard, mouse, touchscreen, or microphone. The information is usually stored in either a hard drive or memory chips. Processing is done by the main processor chips. The results are output on a screen or spoken through speakers.

Types of computer
A desktop computer has four separate units for the keyboard, mouse, processor, and screen. Laptops have all of these things built into a single, portable unit. Tablet computers squeeze the same parts into even less space by building the keyboard and mouse into the screen.

There are more mobile devices connected to the Internet than there are people on Earth.
How the Internet works
The Internet is a worldwide network that links together virtually every computer on the planet—well over a billion of them. Each computer has its own address (Internet Protocol, or IP, address) so that any other machine on the network can instantly send emails or messages to it or receive them from it.

Supercomputers
Some scientific problems are so huge and complex that an ordinary home computer might take years to solve them. For intricate problems, such as weather forecasting, we need more powerful computers that work a different way. Some of them have tens of thousands of processors all working on a problem at once.

Getting online
Well over half the world’s population is now online. People in richer countries, such as the US, were first to get connected in the mid-1990s, but even people in some of the poorest developing countries are now online. Having access to up-to-date information is expected to make it easier for people in poorer countries to gain a decent education.

Packet switching
When you email a photo, it doesn’t travel over the Internet in one big lump. Instead, it’s broken into tiny packets. Each one is given the final IP address and travels separately. This makes data stream across the Internet very efficiently.

NASA supercomputer
The American space agency NASA runs this powerful supercomputer called Pleiades. It has 112,896 individual processors arranged inside 185 separate workstations.

Social networks
Many people use their computers for chatting with friends and sharing photos or news. Popular websites such as Facebook and Twitter have hundreds of millions of regular users.

150 billion—the estimated number of emails sent across the Internet every day.
Robotics

Ingenious inventors have dreamed up machines that can do almost anything, from playing chess to exploring Mars. But there’s no single robot that can do everything—yet.

Part mechanical and part electronic, robots are automated machines that clank, scuttle, and whiz around doing dirty and dangerous jobs that people prefer not to. Robots sniff out bombs, drag survivors from earthquakes, and can even make nuclear explosions safe.

Most robots that exist today can’t think for themselves, and have to be reprogrammed every time they do something new. In the future, robots might become autonomous—with built-in computer brains, they will think for themselves, learn from their mistakes, and possibly do things even better than humans.

**NAO robot**

This robot, built by Aldebaran Robotics in France, is determined to be your friend. It can recognize your face, hear what you’re saying, speak back in 19 languages, and even dance. Like a person, it senses things around it, thinks about them, and responds. Unlike a person, it does these things with 50 electronic sensors, a microprocessor (computer chip) brain, and limbs moved by 25 electric motors.

**Eyes**

Behind the eye sockets, two detectors fire out beams of infrared radiation and pick up the reflections. NAO uses these infrared sensors to communicate with other devices, such as TVs. It also has two digital cameras mounted in its head, taking photos that enable it to recognize objects such as faces and balls.

**Digital camera**

**Four microphones**

These pick up spoken commands and help to locate where sound is coming from.

**Stereo speakers**

Play music and speak.

**Chest**

NAO’s chest is a busy hub filled with electronic circuit boards that are used to control its different joints and sensors.

**Moving limbs**

Gears attached to electric motors control limb movements precisely.

**Sonar sensors**

These detect nearby obstacles so NAO can avoid them.

**Prehensile hands**

Fingers with knuckles can grasp things firmly but gently.

**Digital camera**

These pick up images that enable NAO to recognize objects such as faces and balls.

1966

The year the first-ever factory robot, Unimate, appeared on a TV show, where it hit a golf ball, poured a glass of beer, and conducted an orchestra.
Arms
Like human limbs, NAO's 13 joints are hinged so they can pitch (bend up and down), roll (twist without moving), or yaw (swing from left to right). The elbows are able to roll or yaw, while the knees can only pitch. There are six motors in each of NAO's arms.

Cheetah
Robots find it hard to walk upright like humans, so future robots may mimic four-legged animals instead. This robotic cheetah can run at over 28 mph (45 kph).

Rescue robot
Students at Warwick University in the UK designed this all-terrain robot to find people buried by earthquakes. Its telescopic head includes cameras and a carbon-dioxide gas sensor for detecting signs of life.

Artificial intelligence
Computers and robots are only as clever as the people who create them, but what if we program them so they learn from their mistakes? Gradually, they'll get smarter—they will become artificially intelligent.

The Turing Test
One person sits in a room and questions another, hidden from view. If the hidden person is actually a computer, but answers like a person, it means they are as intelligent as a person.

Robots on the move
Most robots are based in factories. They're stationary and programmed to repeat fairly simple jobs, such as welding or painting. In the future, autonomous robots will venture out into the world, no longer reliant on human operators.

For every robot in the world, there are about 1,000 people.

Factory robots that are built for welding can join metal together about three times faster than humans.

The world's smallest robot is less than half the size of a comma.
Human history includes terrible wars and disasters, but also amazing advances in culture and technology. From the Stone Age to the Space Age, great civilizations have risen and fallen, shaping the world we live in today.
THE ANCIENT WORLD

The story of humanity begins with our earliest human ancestors, hardly distinguishable from apes, who appeared in Africa around 7 million years ago. The first modern humans only developed about 200,000 years ago. They spread throughout the globe, starting out as isolated bands of hunters, but eventually settling in farming villages, and later founding small towns and cities. Stone tools were replaced by metal, and around 8,000 years ago, villages began to grow into cities. By 500 BCE, the Classical period had begun, in which advanced cultures across the globe created great empires with cities full of magnificent buildings, and made enormous strides in human knowledge.

THE STONE AGE

Around 2.6 million years ago, one humanlike species, Homo habilis, began to use stones as tools. For more than 2.5 million years after this, people lived in small groups, hunting with stone axes and spears, and gathering roots, berries, and other plants. They lived in caves or shelters made of branches, and used fire to cook.

Early humans
Modern humans (Homo sapiens) spread from Africa across the globe. Their most successful migration began around 60,000 years ago, when much of the Earth was in the grip of an ice age. Highly intelligent and adaptable, they replaced the Neanderthals (a humanlike species) in Europe, built boats to reach Australia, and crossed the frozen ocean to North America in about 15,000 BCE. These early humans developed sophisticated stone tools, invented the bow and arrow, and created the first musical instruments.

First villages
About 8,000 years ago, humans began to form larger groups and settle in villages. They built houses out of whatever materials were available nearby. Most villagers farmed the surrounding land. Since time previously spent hunting was freed up, specialists, such as potters, builders, and priests, appeared.

From stone to metal
People began to make simple metal tools around 7000 BCE. Copper was used first, and later alloyed (mixed) with tin to make bronze—a harder metal suitable for armor and weapons. From around 1000 BCE, blacksmiths learned how to make iron, which was even stronger.

Agriculture
Farming began around 11,000 BCE when communities in the Fertile Crescent, an area of the Middle East, began to sow and harvest wild rye seeds. Gradually, farmers developed more productive crops, and also tamed animals such as cattle and sheep. As the food supply became more reliable, larger villages and small towns appeared.

THE RISE OF THE EMPIRES

The first cities emerged around 4000 BCE in Mesopotamia (modern Iraq) and Egypt. The great rivers of these areas made the land fertile and prosperous, providing enough food to support larger communities of people living together. The rulers of some of these early cities became wealthy and powerful, taking control of surrounding lands to build the first kingdoms. Some sent their armies to conquer neighboring states, creating the first empires.

First cities
The first cities of Mesopotamia were built by a people called the Sumerians. They grew rich thanks to new farming methods and more productive crops. This allowed them to build temples and palaces in mini-kingdoms (or city-states) such as Uruk, Ur, Nippur, and Lagash. They were soon followed by cities in other regions such as Egypt. The invention of writing around 3100 BCE made it easier for rulers to keep records and for merchants to trade.

From stone to metal
Cold working (hammering of gold or copper) is the first type of metalworking.

8000 BCE
Bronze is created by adding tin to copper in a smelting furnace to make harder tools.

5500 BCE
Copper smelting (heating of ores to extract pure metal) appears in the Middle East.

3200 BCE
Metal casting, the molding of molten metal, is first used in Mesopotamia.

3000 BCE
Bronze is created by adding tin to copper in a smelting furnace to make harder tools.

1300 BCE
In Egypt, furnaces with bellows create the heat needed for iron smelting.

HUMANS' DISTANT ANCESTORS FIRST USED STONE TOOLS MORE THAN 2.6 MILLION YEARS AGO.

Agriculture
Farming began around 11,000 BCE when communities in the Fertile Crescent, an area of the Middle East, began to sow and harvest wild rye seeds. Gradually, farmers developed more productive crops, and also tamed animals such as cattle and sheep. As the food supply became more reliable, larger villages and small towns appeared.

Ruins of Karnak Temple Complex, Egypt
The Ancient Egyptians were capable of creating elaborate, large-scale buildings, as the vast ruins at Karnak show.

Ruins of Catalhöyük, Turkey
Stone or metal blade for cutting through the soil

Yoke attaches to shoulders of beasts such as oxen

An early plow
Plows were developed to cut furrows in the soil, so that seeds could be sown. This was far easier than breaking up the ground with hoes, and allowed more land to be used for farming.

or Kebrit, Syria
Mud brick houses built closer together.

Orkney, Scotland
These stone houses even had stone beds.

Scotland
Long family houses made of wood and sod.

Khirokitia, Cyprus
Round houses built of stone.

Çatalhöyük, Turkey
Mud brick houses built close together.

An early plow
Plows were developed to cut furrows in the soil, so that seeds could be sown. This was far easier than breaking up the ground with hoes, and allowed more land to be used for farming.
The Egyptians
Around 3100 BCE, Ancient Egypt was united to create an advanced civilization that would last for 3,000 years.

The Indus Valley
Around 2600 BCE, large cities arose on the River Indus. They shared a system of trade and writing, but did not form an empire.

Mesopotamia
Sargon of Akkad united rival city-states around 2300 BCE, founding the first great empire of the Middle East.

The Hittites
Anatolia (modern Turkey) was ruled by the Hittites, fierce enemies of the Egyptians, from 1800 to 1200 BCE.

Shang China
The Shang ruled China from 1766 to 1122 BCE, fighting off raiders from the north and rival kingdoms to the east.

The Olmec
Giant pyramid temples, built from about 1500 BCE, mark Olmec cities on the coast of Mexico.

The early kingdoms
Early civilizations varied widely. Some were empires united by a strong ruler, others were alliances of city-states.

- The Egyptians
- The Indus Valley
- Mesopotamia
- The Hittites
- Shang China
- The Olmec

Areas of Classical empires

THE CLASSICAL WORLD
From around 500 BCE, the great civilizations of Greece, Rome, Persia, India, China, and Central America reached new levels of sophistication and power. They developed scientific ideas, and rich forms of art and writing. New religions emerged, such as Buddhism and Christianity. Larger empires were able to support larger armies, which led to long and bitter wars, such as those between Rome and Carthage, and Greece and Persia.

Conquering the world
Wealth, organization, and ambition drove Classical civilizations to build empires far bigger than the world had seen before. Some, like the Persian Empire, ruled vast areas of wilderness lined with important trade routes. Others, such as the Roman Empire, expanded into busy, populated areas, spreading their culture in the form of laws, art, buildings, and religion.

Important megaliths

1. **GÖBEKLI TEPE, TURKEY**
The earliest known megalith, built around 8000 BCE, is a hilltop temple with massive pillars of limestone that may originally have supported a roof.

2. **CARNAC, FRANCE**
This series of over 3,000 standing stones (menhirs) was set up between 4500 and 3000 BCE. The rows, or alignments, may have had some astronomical significance.

3. **STONEHENGE, ENGLAND**
A series of large bluestones formed the first circle at Stonehenge in around 2500 BCE. Giant sandstones, along with huge stone crosspieces, were added 200 years later.

4. **NEWGRANGE, IRELAND**
This tomb, built around 3200 BCE, consists of a room with a massive stone roof, topped by an earth mound. The dark interior of the tomb is lit up once a year by the rays of the rising sun shining down the connecting passageway.

The first emperor of China, Qin Shi Huang, is buried in a tomb guarded by an army of more than 8,000 terra-cotta soldiers.

New thinking
During the Classical period, the first philosophers and scientists emerged, as well as new ideas in astronomy, mathematics, physics, medicine, and architecture.

- **Math**
  Greeks such as Pythagoras and Archimedes established key principles of math, while the Chinese developed tools such as the abacus for calculating.

- **Politics and law**
  Classical Athens saw the world's first democracy, in the 5th century BCE. In China at around the same time, Kong Fuzi (Confucius) laid out an ethical system for the law.

- **Medicine**
  Early texts of the Ayurveda (Hindu medicine) appeared in India in the 6th century BCE. Hippocrates turned medicine into a science in Greece in the 5th century BCE.

- **Philosophy**
  Great thinkers across the world began to ask questions about who we are and how we should live. Plato, Aristotle, and Socrates are some of the most famous.
The first humans

The earliest humanlike animals, our ancestors, evolved from apes millions of years ago. Many different species rose up and died out before modern humans appeared.

Around 5 to 8 million years ago (MYA), the line that would lead to modern humans split off from chimpanzees—the living animals most similar to us today. Over millions of years, these ancestors (or hominins) gradually evolved, developing legs suitable for walking upright, smaller jaws, and larger brains.

The course of human evolution
Scientists have discovered the remains of many different hominins. We can learn a lot from these skeletons, such as how a particular species walked (whether on two legs or on all-fours) and what they ate.
The number of years ago *Homo floresiensis*, the last surviving human species, apart from ours, became extinct.

The average height of *Homo habilis* was 40 in (1 m).

The earliest hominins all lived in Africa. It wasn’t until just less than 2 MYA that new species began to spread to other parts of the world. They developed new tools and settled as far away as East Asia.

Around 40,000 years ago, early humans began to make paintings deep inside caves, evidence they had developed the idea of art. Paintings often show animals these early people hunted and may have had a magical meaning.

Humans made rapid advances after the last ice age ended 11,000 years ago. Agriculture and pottery were invented and people began to live in farming villages. Around 6,000 years ago, the first towns appeared and writing developed.

The number of years ago *Homo habilis* lived between 2.4 and 1.4 MYA. They are the earliest species known to have used stone tools—the first step on the long road to civilization.

Between 4 and 2 MYA, a group of species called australopithecines were the most successful hominins. They had larger brains than our previous ancestors, and they were less heavily built than apes.

Around 2.6 MYA, stone tools came into use around the Palaeolithic Age, or Early Stone Age.

Scientists know they were bipedal from the shape of their hip and leg bones.

A stone called flint was used to make early tools, since it can be chipped into sharp edges. One common tool was a hand axe, like this one from 1.7 MYA, made by striking chunks off a large piece of flint using another stone.

Isolated from Africa for more than 3 MYA, *Homo habilis* had a brain larger than that of *Homo erectus*. Their fingers were long and powerful, good for grasping but not suitable for delicately moving small objects.
The first towns

During the late Stone Age, nomadic tribes of hunters began to settle down. They planted crops instead of gathering food from the wild, and built farms and houses instead of living on the move.

Farming offered a more reliable food source than hunting and gathering. Farmers could grow the most fruitful crops and breed the fattest and most peaceful livestock, so that they could produce more food every year. Extra food could be stored in case of later famine, and permanent houses made of brick or sometimes stone provided a base to store food and tools.

Staying in one place made these settlers vulnerable to raiders, who could steal livestock and stores. Townspeople had to be able to defend themselves—for example, by building walls around their homes. They also exchanged spare food and goods with other tribes, sometimes over long distances, marking the beginnings of global trade.

Stone Age tools

The earliest settlements grew up during the Stone Age, before humans had begun to use metal. Their inhabitants made tools from whatever materials they could find. The most useful were hard substances that were easy to carve or chip into shape. Wood could be used for bows, spears, or axe handles. Stone such as flint and obsidian (volcanic glass) was chipped into sharp edges, to make arrowheads, knives, and hammers. Bones from animals could be carved into fine points to make needles and combs.

Çatalhöyük

This settlement, in modern Turkey, is one of the largest early towns yet discovered. Up to 8,000 people lived here from 7400–6000 BCE. The houses were packed together with only small spaces in between, so that any attackers would find it hard to gain access.
Animals were not just tamed for food. Dogs helped with hunting and herding, and protected livestock.

Hunting scene
The walls of some houses were painted with scenes from everyday life, such as hunting.

Gathering food
Although farming provided a regular food supply, people still needed to gather fruit, nuts, and berries.

Beasts of burden
Cattle could be used for labor such as carrying burdens and plowing.

Working in clay
Permanent fireplaces were used to bake clay into hard terra-cotta. This allowed people to make durable pots and dishes, as well as decorative objects, such as this statue. It was found in a food store at Çatalhöyük, and is thought to be a religious idol.

Weaving
The invention of the loom provided strong, colorful cloth for clothing, blankets, and decoration.

Wall paintings

Grave site
At Çatalhöyük, the dead were buried under clay platforms in the floors of the houses.

The people of Çatalhöyük slept on clay platforms under which they buried their ancestors’ bones.
Early empires

As early towns grew, they had to develop new systems of government, new means to store and distribute food, and new ways to protect themselves. The strongest settlements expanded their territory by conquering their neighbors, creating the first empires.

One of the most powerful early empires belonged to the Babylonians. In the 18th century BCE, they conquered a large area in what is now the Middle East, but were then defeated by their rivals, the Hittites. They rose to power again in the 6th century BCE, and their capital city, Babylon, became one of the richest and most magnificent in the ancient world.
The city of Babylon
This great city sat at the heart of the Babylonian Empire. The huge buildings were constructed around 580 BCE by King Nebuchadnezzar II, who wanted his capital to be the most magnificent city in the region.

Royal palace
The lavish royal palace was the symbol of the king’s power, designed to inspire awe in his subjects and enemies.

City walls
Wealthy cities were targets for raiding nomads and enemy armies. Babylon was defended by strong walls of mud brick.

Wonders of the World
The Hanging Gardens of Babylon were one of the Seven Wonders of the World. Nobody knows for sure where they stood, but the foundations of terraced gardens were found in Babylon in the early 20th century.

Defensive technology
Babylon was famously well defended. Soldiers on the walls could rain rocks, spears, and arrows down on any attackers.

River Euphrates
Early cities depended on water supplies for drinking and fertile soils for farming. The Euphrates provided both, as well as a vital trade route for boats.

Monumental buildings
The rulers of new empires often ordered their subjects to build great monuments. This was a good way to demonstrate their power and wealth, and impress their enemies and rivals. The great Etemenanki Ziggurat in Babylon is thought to have been 300 ft (90 m) tall—that’s twice the height of the Statue of Liberty in New York City. However, it was dwarfed by the Great Pyramid at Giza, which rose to 479 ft (146 m) and was the tallest building in the world for more than 3,700 years.

Code of law
As empires grew, their people required detailed written laws to resolve disputes and protect property. The Babylonian king Hammurabi created a detailed system of laws in about 1750 BCE, with brutal punishments if they were broken.

Hammurabi’s Code of Law
Ancient Egypt

For more than 3,000 years, Egypt was home to one of the most advanced civilizations of the ancient world. They left behind many clues about their way of life, from religious texts to huge, mysterious pyramids.

The Ancient Egyptians were ruled by kings called pharaohs, who were thought to be the children of the gods. Their complex society had strict layers—from priests, governors, and mayors to soldiers and peasants—and they developed a detailed system of writing to keep records of wealth and ownership.

Egyptian life was full of ritual. They worshipped hundreds of gods and goddesses, and the pharaohs and priests performed complex rituals to ensure good crops, keep away disease, and bring success in war. They also built massive tombs for their dead, many of them stuffed with gold and treasure.

The kingdoms

Ancient Egypt was seen as two kingdoms, united under the pharaohs. The Lower Kingdom was the lands around the mouth of the Nile. The farmlands along the Nile banks further upstream were the Upper Kingdom. They were unified in around 3000 BCE. Ancient Egypt went through three periods of strength: the Old Kingdom, the Middle Kingdom, and the New Kingdom. In between, wars and disasters such as crop failures left the country weakened.

Words in pictures

Ancient Egyptian writing used pictures called hieroglyphics. Each symbol could represent a sound, a word, or an action. Instead of paper, the Egyptians used flattened sheets of a type of reed called papyrus. Inscriptions could also be pressed into clay, painted on pottery, or carved in stone. Writing was seen as a gift from Thoth, the god of wisdom, and only priests and specially trained scribes were taught how to read and write.

Famous names

The names of important figures, such as kings and queens, were written inside an oval called a cartouche, as a symbol of eternal life.
Life on the Nile

Egypt is surrounded by desert, so the ancient kingdom depended entirely on the River Nile. Every year the river flooded, submerging the farmland along its banks. The floods washed rich soil down from the highlands to the south. The Egyptians built ditches and low walls to trap the mud and water in fields along each side of the river, giving them fertile soil in which to grow crops such as wheat, barley, grapes, and vegetables. The whole kingdom depended on the floods. In a dry year, many people would starve.

Journey of the dead

The Egyptians believed that the soul of a dead person undertook a perilous journey to another world. After death, the soul wandered the underworld until it could be judged by the gods. The god Anubis would weigh their hearts to measure their worth. Good people were rewarded with a happy afterlife, but bad people were devoured by Ammit, a fearsome beast with the head of a crocodile, the chest of a lion, and the torso of a hippopotamus.

Scales of judgment

The dead person’s heart sits on the left side of the scales. On the other side is the feather of truth. An evil person’s heart will be heavier than the feather.

The gods bear witness

The soul of the dead person would also have to swear before the gods that they had not sinned.

God of the dead

The jackal-headed god Anubis makes sure the scales are even.

Gods and goddesses

The Egyptians worshipped a large number of gods, often in the form of animals and natural forces. The greatest god was Ra, the sun god, who created the universe. Cow-headed Hathor was goddess of motherhood. The god of wisdom, Thoth, had the head of an ibis, while Sobek, god of the Nile, was shown as a crocodile. The goddess Nut arched her body over the earth to form the sky.

Symbols of Ra

The god Ra journeys across the sky as the sun. The disc on his head produces light. He stands on a boat that sails across the sky from morning until night.
The pharaohs

Ancient Egypt was ruled by the pharaohs, powerful kings who were worshipped as gods. They are most famous today for their great pyramids and temples, and the priceless treasures found in their tombs.

An Egyptian pharaoh wielded enormous power. He could write laws, set taxes, lead the army into battle, and judge legal cases. However, he also had many responsibilities. He was thought to control the flooding of the River Nile, which was essential for growing the kingdom’s food. If disaster or famine struck, the pharaoh had to beg the gods for assistance, and might be blamed by the people if the situation did not improve.

After death, pharaohs and other important figures were mummified to preserve their bodies in the afterlife. Some of the earliest kings of Egypt were laid to rest in huge pyramids, while later kings were buried in underground tombs.

Tutankhamun’s tomb

Tutankhamun became pharaoh at the age of nine. He died suddenly, just nine years later, in 1327 BCE. He was buried in an underground tomb in the Valley of the Kings, on the west bank of the River Nile. Although grave robbers stole some of his burial treasure, thousands of precious artifacts lay undisturbed for more than 3,000 years before archaeologists rediscovered the tomb in 1922.
The approximate number of artifacts found in Tutankhamun’s tomb.

296 lb (110kg) of pure gold was used to make Tutankhamun’s inner coffin.

The process of mummification was a religious ritual and was carefully supervised by priests. One would wear a jackal mask to represent Anubis, the god who guided spirits of the dead. Making a mummy

1 Removing organs
After washing the body with wine, priests removed the internal organs. Special hooks were used to pull the brain out through the nostrils. The heart was left behind, since the Ancient Egyptians believed it was the home of the soul.

2 Drying out the body
The hollowed-out body was packed with bags of natron, a natural salt that drew water out of the flesh. It was left like this for 40 days while the natron did its work.

3 Washing the corpse
Once the body had completely dried out, it was washed in wine to remove the salt, then packed with sawdust or resin-soaked linen. The skin was rubbed with oils and perfumes, and often painted with resin for extra protection.

4 Wrapping in bandages
The next stage was to wrap the mummy in layers of bandages. Amulets (pieces of jewelry with magical powers) were included to keep the spirit safe on its journey to the next world. The finishing touch was a decorated mask.

5 Into the coffin
The mummy was placed in a coffin, or sarcophagus, which was painted or carved with a likeness of the dead person. The mummies of rich people were enclosed in several coffins, which in turn sat inside large wooden shrines.

6 The funeral
Exactly 70 days after death, the mummy was laid to rest. A procession would carry the coffin and burial goods to the tomb, often sealing them away so that robbers could not break in.

Priests of the dead
The process of mummification was a religious ritual and was carefully supervised by priests. One would wear a jackal mask to represent Anubis, the god who guided spirits of the dead.

MOST TOMBS IN THE VALLEY OF THE KINGS HAVE PAINTED WALLS. ONLY THE BURIAL ROOM IN TUTANKHAMUN’S TOMB IS PAINTED, SUGGESTING IT WAS PREPARED IN A HURRY.
Ancient Greece

From math masters to playwrights, great philosophers to military conquerors, Ancient Greece produced some of the most famous figures in western civilization.

Greek culture began on islands in the Eastern Mediterranean around 2000 BCE, with trading empires such as the Minoan civilization on Crete. As time went on, power shifted to the mainland, in warlike city-states such as Mycenae. As these city-states grew more sophisticated, they gave rise to great thinkers, builders, and writers, and the first democracy, in Athens. They also defeated the armies of the powerful Persian Empire to the east. Greek power reached its peak with Alexander the Great, a military genius whose empire stretched all the way to India.

Ancient Priene
The polis, or city-state, was the main kind of Greek settlement. Each one centered on a powerful city, which controlled an area of the surrounding countryside. The most important city-states, such as Athens, Corinth, or Sparta, owned large areas of territory and grew very rich. Priene (now in southwestern Turkey) was a typical Greek city-state. It was originally founded around 1000 BCE, but was completely rebuilt in about 350 BCE.

Gods and goddesses
The Greeks believed in many gods, and the stories told about them have been remembered in art and literature to this day. The main gods, who were seen as behaving in very human ways, lived on Mount Olympus, ruled over by Zeus and his wife, Hera. On Earth, the deeds of great heroes, such as Heracles and Odysseus, and warriors, such as Achilles and Hector (who fought in a war over the Greek city of Troy), formed part of many stories.
The Greek held regular athletic contests in honor of their gods. The most important of these were the Olympic Games, founded in 776 BCE and held (like the modern version) every four years. The athletes who took part had to be Greek citizens, but they competed individually, not for their home cities. Victors were rewarded, not with valuable prizes or medals, but with wreaths of wild olive leaves. The games began as a single day of events but were later extended to five days.

**Five days of Olympic events**

**Day 1**
The first day was marked with a religious procession. Athletes swore before the gods that they would compete without cheating, while judges swore not to be biased.

**Day 2**
The pentathlon, held on the second day, involved five events: long jump, discus, javelin, running, and wrestling. In later years, chariot racing also took place on day two.

**Day 3**
Younger athletes competed in running, wrestling, and boxing. On this day, 100 oxen were sacrificed to Zeus, and the best meat burned before his temple.

**Day 4**
The fourth day was for adult wrestling, boxing, and pankration—a brutal sport combining wrestling and boxing. A foot race in full armor also took place.

**Day 5**
The last day of the festival saw olive wreaths presented to all winning athletes. A banquet of meat from the oxen sacrificed on the third day concluded the celebrations.

**“WE SWEAR WE WILL TAKE PART IN THE OLYMPIC GAMES IN THE SPIRIT OF CHIVALRY, FOR THE HONOR OF OUR COUNTRY, AND FOR THE GLORY OF SPORT”**

1920 OLYMPIC OATH INSPIRED BY ANCIENT GREECE

**From island to empire**
For centuries, Greece was made up of many small rival states. They were united by shared traditions and language, and sometimes allied together to face common enemies such as the Persians. Greece was united under Alexander the Great and his father, Philip. But when Alexander died, his empire fell apart and Greece came under the power of the Romans.

**Minoan period**
From 2000 BCE, the Minoans of Crete built up a trading empire. They became very wealthy, allowing the building of great palaces such as Knossos. Around 1500 BCE, earthquakes, revolts, and invasions caused the Minoan culture to collapse.

**Mycenaean period**
Around 1600 BCE, new tribes began to settle in centers such as Mycenae and Tiryns. A warlike people, they conquered Crete and engaged in pirate raids as well as trading. Around 1200 BCE, new invaders destroyed most of the Mycenaean cities.

**Homeric period**
From about 1100 BCE, Greece entered a Dark Age, about which little is known. Around 800 BCE Greek civilization began to recover and many small city-states emerged, with a common language and alphabet. The poet Homer wrote of this time in the Iliad, his epic poem.

**Archaic and Classical periods**
City-states grew in size and spread to colonies abroad. Greece was invaded twice by huge armies from the Persian Empire, but defeated both attacks. This era also saw wars between city-states, especially Athens and Sparta.

**Hellenistic period**
In 338 BCE, after decades of war, Philip, king of the state of Macedon, conquered all of Greece to create one kingdom. His son, Alexander the Great, invaded Persia in 335 BCE and conquered it. Greek civilization spread to this vast area, creating a new Hellenistic culture.
Ancient Athens

In the fifth century BCE, the Greek city of Athens was home to some of history's most brilliant artists, philosophers, and politicians. Its citizens formed the world's first known democracy, and their writings and ideas are still famous today.

In the early part of the century, Greece was invaded twice by vast armies from the empire of Persia to the east. Athens played a significant role in defeating both invasions, at the land battle of Marathon in 490 BCE, and the sea battle of Salamis in 480 BCE. These victories brought the city great wealth and power, and its citizens built beautiful temples, theaters, and public buildings. Toward the end of the century, Athens began a long and costly war with neighboring Greek states such as Sparta. After military defeat and a terrible plague, Athens was eventually conquered by the Spartans in 404 BCE.

The Parthenon

The religious center of Athens was the Parthenon. This great temple was dedicated to Athena, the goddess of wisdom and courage in battle, who was believed to be the city's special protector. It was also the city's treasury, where tribute was stored.

22,000 tons of marble are estimated to have been used to build the Parthenon and the gateway to the Acropolis.

A defensive wall 4 miles (6 km) long protected Athens' access to the sea.

220 lb (100 kg)—estimate for the weight of gold in Phidias's statue of Athena.

Wooden beam

Statue of Athena

The statue was made by the sculptor Phidias. It was covered in gold and ivory.

Nike

The goddess of victory sat in Athena's palm.

Pediments

The sculptures on this side told the story of the birth of Athena. On the other side, they showed the contest between Athena and Poseidon for control of Athens.

Inner frieze

Sculptures around the inner walls showed a procession of citizens in honor of Athena.
Enemy neighbors
Sparta was a Greek city-state with a very different culture. It was ruled by kings instead of a democracy, and its people valued fighting ability above all else. Young boys underwent harsh military training. The Spartans allied with Athens against the Persians, but later became fierce enemies.

"FOR NO MAN EVER PROVES HIMSELF A GOOD MAN IN WAR UNLESS HE CAN ENDURE TO FACE THE BLOOD AND THE SLAUGHTER, GO CLOSE AGAINST THE ENEMY AND FIGHT WITH HIS HANDS."
TYRTAEUS, SPARTAN POET

The first democracy
All political decisions in Athens were taken by popular vote. However, voting was restricted to male citizens, who only made up about 12 percent of the population.

Athenian Society

ATHENIAN SOCIETY

12% voters
28% voters' families
32% slaves
28% foreigners

The Acropolis
The Parthenon stood on a hill, or Acropolis, at the center of ancient Athens. Originally a defensive fort, the Acropolis became a place of worship as Athens grew more secure. Within its walls were several temples and holy sites, while outside was a theater dedicated to the god Dionysus, used for festivals of drama.
The legacy of Rome
The Romans are still remembered today, for good reason. Their politics and philosophy inspired Western thinking for many centuries. Many of their amazing buildings, supported by advanced engineering skills, still stand today. Roman words crop up in many modern languages, and even some modern laws follow Roman examples.

Law and learning
Roman authors produced great works of history, poetry, politics, and philosophy. Copies of these were spread all over the empire. The Library of Celsus at Ephesus in modern Turkey contained about 12,000 scrolls.

Architecture and engineering
The Romans were astonishing engineers. They used concrete to build strong, watertight structures, and they invented stone arches. This aqueduct at Pont du Gard in France is just one of many great Roman landmarks still standing today.

A connected empire
The Romans built a huge network of roads, allowing armies, messengers, and traders to move quickly around the empire. Combined with careful record-keeping, roads helped the Romans to control a huge and prosperous empire.

“The Romans had one of the first fire brigades under Augustus’s reign.”

Conquering the known world
By 200 BCE, Rome had conquered most of Italy and defeated the powerful city of Carthage in North Africa. Between 262 and 146 BCE, Rome gained Sicily, Sardinia, Spain, and North Africa. Gaul (France) was conquered by 50 BCE, as well as much of Turkey and the Middle East. Britain was invaded in 43 CE. The empire was at its largest around 117 CE, when it held Dacia (Romania) and parts of modern Syria and Iraq.
**53,000 Gauls were sold into slavery when Julius Caesar defeated their armies and captured their territory.**

Rome's rise and fall

As the Roman army grew stronger, its generals became more powerful than the Senate. After a series of civil wars between military leaders, the Republic collapsed and Julius Caesar became sole ruler. His adopted son, Augustus, became the first Roman emperor. In 395 CE, the empire was split. The western part was ruled from Rome, but a new emperor ruled the eastern half from the city of Constantinople (or Byzantium). The west gradually lost territory to barbarian tribes, and the last emperor was deposed in 476 CE.

**The Roman army**

The Roman army was highly trained and well equipped. It was divided into legions, each split into 10 groups, or cohorts, of about 480 men, backed up by cavalry. The Roman army also trained soldiers from conquered nations as auxiliaries. These included cavalry, slingers, archers, and even camel troops. Roman soldiers were famed for their discipline, using rigorous formations and clever tactics to defeat their opponents.

*Orb*

This defensive grouping was used when soldiers were surrounded by enemies. It protected the legion's standard, the symbol of its honor.

*Cavalry defense*

If charged by cavalry, the legion could form a square, with javelins protruding from a wall of shields to kill enemy horses.

*Testudo*

When facing volleys of arrows, soldiers could form a tortoise (testudo), with overlapping shields protecting them from attack.

*Skirmish*

These loosely spaced lines allowed soldiers to let off a volley of javelins (throwing spears) against an approaching enemy.
Roman society

The city of Rome stood at the heart of the Roman Empire. For more than 500 years it was the most powerful city in the western world.

Rome was in many ways like a modern city. It had paved roads, underground sewers, and even multi-story apartment buildings. Food was imported from across the empire to feed the populace, and aqueducts brought in fresh water from the surrounding countryside. The rulers of Rome, emperors and powerful politicians, filled the streets with great monuments to demonstrate their power. The heart of the city was the Forum, an open space for public meetings and celebrations. Around it were built great arenas, temples, bathhouses, theaters, markets, and palaces, many of which are still standing thousands of years later. As the empire grew, the city of Rome became richer and its population swelled. It is thought that 1,200,000 people lived there at the empire’s height around 100 CE, as many as in modern-day Dallas, Texas.

Professional fighters

There were more than 20 types of gladiator, each with different weapons and armor. The Romans enjoyed watching gladiators of different kinds fighting each other, to see which styles and equipment were most effective. Gladiators were slaves, but if they fought well enough they could sometimes win their freedom. The most successful ones became celebrities to their adoring fans.

Gladiator helmet

This bronze helmet was used by a murmillo, a heavily armed gladiator who carried a short sword and large, rectangular shield into battle.

Social sitting

The seating levels in the Colosseum mirrored the social classes in Roman life. The front rows were reserved for richer and more important people, while the less fortunate sat further back. The emperor had a private box reserved for him and his guests. Slaves attended the circus only to serve their masters.

Social classes of ancient Rome

- **Emperor**: The ruler of the empire, often threatened by enemies.
- **Senators**: Politicians whose power depended on the emperor.
- **Equestrians**: Aristocratic families, often wealthy and influential.
- **Plebians**: Working people, such as merchants and laborers.
- **Foreigners**: Visitors from other parts of the empire.
- **Slaves**: Treated as property, slaves had no rights and had to obey their masters.

Underground lift

Wild beasts such as lions, wolves, and elephants fought against each other and against trained hunters. The animals were kept in cages underground. They were brought up to the surface in elevators and released into the arena through trapdoors.
The Colosseum

This huge arena was the site of elaborate public shows called circuses. They included acrobats, wild beast fights, public executions, and battles between professional warriors called gladiators.

Retractable shade
A huge awning could be extended to protect spectators from the heat of the sun.

Awning masts
A special group of sailors from the Roman navy was assigned to operate the awning ropes and masts.

Crowd of thousands
Circuses were paid for by the emperor as a gift to the people, and huge crowds attended.

Famous faces
The outside was decorated with statues of generals and politicians.

Many exits
Spectators entered through the 80 archways spaced around the outside.

Gladiators
Once the beast fights were finished, the gladiators entered the arena. This was the most popular part of the show. They would fight in pairs around the ring. Although most gladiators were slaves, they could win their freedom if they fought well in the arena.

Emperor’s box
The emperor and his guests sat in their own special box. When a gladiator was wounded and unable to fight on, he could appeal for mercy. The emperor would then decide whether the beaten gladiator should be spared or killed by his opponent.
THE MEDIEVAL WORLD

In the 5th century CE, the Roman Empire in Europe collapsed, splitting into smaller kingdoms that were poorer and less advanced than the Romans had been. A huge Arabian empire arose in the Middle East, which preserved and built on the knowledge of the Ancient Greeks and Romans. In China and India, new empires discovered scientific advances that would not be matched in Europe for hundreds of years.

THE FALL OF ROME

In the 4th century CE, the Roman Empire split between east and west. The Western Empire, ruled from Rome, became weaker, because its armies could not defend against the barbarian raiders from Germany. By the end of the 4th century, it had lost much of its territory, and in 476 CE, the last emperor of Rome lost his throne.

The Byzantine Empire

The Eastern Roman Empire (or Byzantine Empire) survived longer than the Western Empire. Emperor Justinian recaptured Italy and North Africa in the 6th century, but the empire was invaded by Muslim armies soon after. The Ottoman Turks conquered the empire’s capital, Constantinople, in 1453.

A Christian city

This mosaic shows two Byzantine emperors dedicating Constantinople to Jesus and the Virgin Mary.

Barbarian raiders

By around 450 CE, barbarian tribes had set up kingdoms in land previously owned by the Romans. The new kings took up some Roman customs, such as giving out written laws.

HUNS

This tribe from Germany mounted devastating raids on the Roman Empire in the 5th century.

GOTHs

The Goths sacked Rome in 410. They later split into the Visigoths (Spain) and Ostrogoths (Italy).

ANGLES AND SAXONS

These raiders from north Germany conquered former Roman lands in England, setting up new kingdoms.

MAGYARS

From Central Asia, the Magyars raided Eastern Europe from 850 CE, settling in Hungary in 900.

VIKINGS

Fierce Viking warriors raided European coasts from 793 for 200 years, taking land in France, Ireland, and Britain.

The Holy Roman Empire

In Germany, Christian rulers took on the power and lands of the Western Roman Empire. 400 years after it fell. In 800 CE, a king called Charles the Great crowned himself emperor and set about rebuilding a Christian empire in Europe. By 900, his empire had fallen apart, but ambitious German princes took on the title of Holy Roman Emperor for centuries afterward.

CHANGING EUROPE

Everyday life in medieval Europe was dominated by the Church on the one hand and powerful kings on the other. France was conquered by the Franks, a Germanic tribe, but went on to become the most powerful country in Europe, fighting a Hundred Years War with England in 1337–1453. The Moors, an Islamic people from North Africa, conquered Spain in the 8th century. They were driven out in a series of wars lasting until 1492. Most devastating of all was the Black Death, a plague that killed millions as it swept across Europe.

AN ESTIMATED 45 PERCENT OF THE POPULATION OF EUROPE DIED OF THE BLACK DEATH.

Feudalism

Under the feudal system that arose in Europe, noblemen became the followers (vassals) of a king by swearing loyalty (fealty) to him and promising to support him in time of war. In exchange, the vassal was given land to rule as he saw fit.

King

The king was at the head of feudal society and the chief nobles (known as tenants-in-chief) were his vassals, and given land in return.

Vassal

Nobles sometimes had their own vassals, such as knights, who received smaller portions of land in return for service (normally military).

Peasant

The lowest members of society, peasants also swore fealty to a lord, but worked his land instead of doing military service.

Church and state

The Christian Church grew more powerful during the medieval period. Most people paid a tithe of one-tenth of their income as a tax to the Church, and huge new cathedrals sprang up in cities across Europe. The head of the Church was the Pope, based in Rome, and his power often made other rulers resentful.
WARS OF FAITH

In the early 7th century, the tribes of the Arabian Peninsula were united under a new religion, Islâm, led by the Prophet Muhammad. Arab Muslim armies took Christian Byzantine land in North Africa, Palestine, and Syria, and captured Jerusalem, a city holy to both Islam and Christianity. From the 11th to the 13th century, Christian armies tried to take Jerusalem back in a series of Crusades, invading the Holy Land and even setting up kingdoms there for a short time.

Arab learning

Islamic learning was often much more advanced than medieval European ideas. Muslim armies occupied Persian and Byzantine lands, where they rediscovered Ancient Greek and Roman manuscripts, and Arab scholars made great advances in math and medicine.

The Islamic world

As the Islamic empire grew, its cities expanded, housing the palaces of rulers as well as great mosques, hospitals, and libraries. They also became centers of trade and learning.

EMPIRES OF ASIA

The greatest empires of the medieval period were in Asia. India, China, and Japan had courts and governments that were far more advanced than those in Europe. Between the 12th and 15th centuries, however, China was conquered by the Mongols, a nomadic people from Central Asia, Japan was engulfed in civil wars, and India was invaded by tribes from the north.

India

From around 320 CE, much of India came under the rule of the Gupta Empire, famous for its wealth and advances in literature, art, and science. After almost 150 years of peace, the Gupta Empire fell apart around 570. North India came under the rule of the Harsha Empire, but when its leader died in 647, India broke up into smaller kingdoms, only reuniting in the 13th century.

The Mongol Empire

In 1206, the nomadic tribes of Mongolia were united under one ruler, Genghis Khan. He conquered a vast empire, including much of Central Asia, Persia, and China. The Mongols were famous as astonishing archers, master horsemen, and brutal warriors.

Islamic learning was often much more advanced than medieval European ideas. Muslim armies occupied Persian and Byzantine lands, where they rediscovered Ancient Greek and Roman manuscripts, and Arab scholars made great advances in math and medicine.

The rise of Islam

The Prophet Muhammad began preaching in around 610, and by the time he died in 632, Muslim armies had conquered most of the Arabian Peninsula. Under the leaders who followed after Muhammad’s death (the caliphs), the Islamic caliphate (empire) grew beyond Arabia, until it included Egypt (in 641), Persia (in 640), and most of Syria and Palestine. Under the Umayyad dynasty, which ruled from 661, Muslim armies invaded the rest of North Africa and, from 711, captured most of Spain. In the east, the borders of the Islamic caliphate extended to Afghanistan and northern India.
Viking raiders

From the late 8th century CE, fierce warriors from Scandinavia terrorized coastal settlements across northern Europe. The Vikings attacked without warning, killing anyone who resisted them and carrying off treasure and slaves.

The Vikings may have had a fearsome reputation, but they were more than just brutal raiders. They were also champion shipbuilders, whose ships traveled quickly and safely across the roughest seas. They were bold explorers, reaching the Americas centuries before anyone else from Europe. They built settlements in northern Europe, Iceland, and Greenland, where their culture influenced local life for centuries.

Raiding party

Viking raiders traveled in longboats—fast, sleek ships that could strike anywhere along coasts and rivers. They carried large, square sails, and oars for use when the wind was against them.

Dragon figurehead

At the front of Viking raiding ships was a fierce monster head, perhaps representing a warlike spirit.

Slim hull

Longboats had narrow hulls (bodies) and sat high in the water, so that they could sail up shallow rivers to raid inland.

Deep keel

A deep keel (a beam sticking out from the hull) kept the ship stable in rough seas.

Double-edged longsword

Vikings were skilled at metalworking. Their weapons included broad axes that were swung with two hands, and large-bladed knives called saxes, which doubled as tools for everyday use.

Setting sail

Large, square sails were made out of woolen cloth. The material was so valuable it was sometimes used as currency.

Viking helmets

Like metal armor, helmets were difficult to make and very expensive. Steel was hammered into plates, which were riveted together with metal strips. The helmet was lined with cloth padding inside, and leather straps held it on the owner’s head.

Viking clothes

Vikings wore tunics made of linen or leather stuffed with horse hair.

Expensive armor

Wealthy warriors could afford chain mail armor and helmets made out of steel plates.

Chest containing rower’s belongings

Deck boards had storage space underneath.
Great explorers
As well as fierce warriors, the Vikings were bold explorers. From their homes in Scandinavia, Viking ships traveled for thousands of miles in every direction. Vikings were the first Europeans to land in the Americas, almost 500 years before Christopher Columbus. The remains of a Viking settlement have been found in Newfoundland, Canada. They also traveled widely across Europe, sailing or rowing around coasts and along rivers, and even carrying their ships over land when they could not continue by water.

Skilled craftsmen
Viking craftsmen produced fine leatherwork and intricate metal jewelry. At first their work mostly featured monsters and giants from their traditional legends. However, around the 11th century, many Vikings converted to Christianity, and crucifixes began to replace the old symbols.
Fortresses

With towering stone walls bristling with arrow slits, murder holes, and other defenses, castles were a formidable obstacle to any medieval invader.

Castles were built all across the world, ranging from simple wooden enclosures to vast stone palaces. A large number were built by feudal lords in Europe, who needed a place to keep their families and treasures safe from rivals while they were away at war. The Crusaders depended on castles to protect their settlements in the Holy Land, where they might come under attack at any time.

At the center of the castle was the keep, a tall tower where the lord and his family made their home, and which could be defended even if the rest of the castle fell. Around the keep were wards, open areas where the castle’s other inhabitants lived and worked, all protected by stone walls.

Life in a castle

During peacetime, a castle like this 13th-century concentric fortress was home to the lord, his family and servants, and guards known as men-at-arms. Many castles were like little villages inside, with kitchens, blacksmiths, gardens, stables, and a chapel. If they were attacked, the people inside had everything they needed to survive until help came.

The moat at Saone castle in Syria was 58 ft (18 m) wide and 85 ft (26 m) deep—that’s big enough to contain a tennis court standing on its end.

In some sieges, attackers launched dead bodies over castle walls, trying to cause disease inside.

The gatehouse was heavily defended. It was often built as a narrow tunnel with wood or iron gates at either end. Holes in the ceiling (murder holes) could be used to pour boiling oil or water on attackers in the tunnel.

Lord’s chambers
The lord and his family had private rooms in the strongest part of the castle, known as the solar.

Gatehouse
The castle entrance was heavily defended. It was often built as a narrow tunnel with wood or iron gates at either end. Holes in the ceiling (murder holes) could be used to pour boiling oil or water on attackers in the tunnel.

Moat
Cut into the rock and often filled by diverting a nearby stream, the moat kept attackers away from the walls.
During a **long siege**, when supplies ran low, defenders might have to eat horses, dogs, and even rats.

3,500 soldiers defended Rhodes against a besieging army of 70,000 Ottoman Turks in 1480.

### Types of castles

#### Motte and bailey
Most common in: 10–11th century  
**Construction:** wooden castle built on a mound (motte), surrounded by a fortified enclosure (bailey)  
**Strengths:** quick and cheap to build  
**Weaknesses:** vulnerable to attack by battering rams and fire

#### Concentric defenses
Most common in: 12–15th century  
**Construction:** central fortress, or keep, surrounded by layers of stone walls  
**Strengths:** long lasting and very hard to break into  
**Weaknesses:** took a long time to build; defenders could become trapped inside; vulnerable to cannon fire

#### Star forts
Most common in: 16–20th century  
**Construction:** stone or concrete  
**Strengths:** angles deflect cannon fire, and allow defenders to fire on enemies from several sides  
**Weaknesses:** modern high explosives

#### Attacking a castle

Before the invention of gunpowder, castle walls were almost impossible to break into. Invading armies had two options: to batter the walls with siege engines, or to block all access to the castle in the hope the people inside would run out of supplies, and be forced to surrender before they starved.

- **Fire**  
  Flaming arrows could be used to set buildings alight inside the castle. Fires could be built in holes dug under the castle walls, in an attempt to make the walls collapse.

- **Siege towers**  
  Soldiers could climb up inside to get on top of castle walls.

- **Battering rams**  
  Heavy rams were swung against castle gates to break through.

- **Trebuchets**  
  Used to throw heavy stones to damage defenses, or to bombard defenders inside the walls.

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**Blacksmith**  
Skilled metalworkers provided armor, weapons, and other equipment.

**Gardens**  
Vegetables were grown to eat in case of siege.

**Great hall**  
The feasting room, where the lord would hold banquets for his knights and guests.

**Banners**  
The symbol of the lord and his king.

**Dungeon**  
Prisoners could be locked away underground, with no hope of escape.

**Arrow slits**  
Defenders could fire arrows out, but attackers could not shoot in through these narrow holes.

**Postern gate**  
An emergency exit in case the castle was ever conquered.
Wars of faith

Between 1095 and 1271, European armies set out on a series of Crusades. These were military expeditions to retake Christian holy sites, which had been in Muslim hands since the 7th century.

The First Crusade began in 1095, after Pope Urban II called on Christian knights to “take the cross” and pledge to capture Jerusalem. Thousands responded and, with the Muslim rulers of the Holy Land divided, they were able to take the city. The Crusaders set up small states and built castles, often defended by orders of religious knights such as the Templars. But when rulers such as Saladin and Baybars united the Muslims, the Crusaders slowly lost ground. The Muslims took Jerusalem in 1187, and in 1291 the last Crusader fortress fell.

The first four Crusades

Since they involved the largest armies and the biggest battles, the first four Crusades, between 1095 and 1204, are sometimes called the Principal Crusades. Apart from these, there were five Minor Crusades in the later years, as well as many other expeditions in between.

Key
- First Crusade
- Second Crusade
- Third Crusade
- Fourth Crusade

Rome
The popes, based in Rome, dreamed of restoring Jerusalem to Christian rule. They called for each Crusade, asking European rulers to provide knights and men-at-arms to go to war in the Holy Land.

London
King Richard I (called the Lionheart for his bravery) set out for the Third Crusade soon after he was crowned in London in 1189. He managed to defeat the great Muslim leader Saladin, but could not retake Jerusalem.

German princes
As well as French and British crusaders, several armies set out from the Holy Roman Empire and states in what is now Germany.

Crusader knights
European knights wore heavy armor and fought mainly on horseback. They were supported by foot soldiers called men-at-arms.
The approximate number of Crusader knights left in Acre when it fell to Sultan Baybars in 1291.

The number of ships in the fleet that carried the English knights of the Second Crusade in 1147.

The number of Crusader knights left in Acre when it fell to Sultan Baybars in 1291.

The approximate number of Crusader knights left in Acre when it fell to Sultan Baybars in 1291.

The Crusaders called their Muslim opponents Saracens. They wore armor of interlinked metal rings and were excellent archers.

Jerusalem
A holy city to Christians and Muslims, Jerusalem became the capital of a Christian kingdom after the Crusaders captured it in 1099. However, they did not have enough knights to defend it for the long term.

Egypt
Some later Crusades landed in Egypt, hoping to defeat the Muslim sultans who ruled from Cairo. In 1250, the Mamluks, a new Muslim dynasty, took over in Egypt. Their ruler, Sultan Baybars, seized many of the remaining Crusader forts in the 1270s.

Century of conflict
The First Crusade captured lands in the Middle East, founding Christian kingdoms. But as years went on, the Muslims fought back, and the Crusaders were driven out.

November 1095
Pope Urban II preaches the First Crusade at Clermont in France, calling on Christian knights to take back holy sites in Palestine.

July 1099
The Crusaders capture Jerusalem after a short siege. Many inhabitants (Muslims, Jews, and local Christians) are massacred.

October 1144
Edessa, a Crusader kingdom in Syria, is captured by the Muslim leader Zengi. The Second Crusade sets out to take it back.

July 1148
The remaining armies of the Second Crusade besiege the Muslim city of Damascus, but are defeated.

May–June 1191
King Philip Augustus of France and King Richard I of England arrive with Crusading armies at the city of Acre, near Jerusalem.

October 1202
In exchange for the use of the Venetian fleet, the Crusaders attack Venice’s enemies in the Christian town of Zara.

September 1191
Richard defeats Saladin, helped by Crusader knights from the Templar and Hospitaler orders.

April 1204
The Crusaders sack the Christian city of Constantinople after a quarrel over money with the Byzantine emperor, Alexius IV.

1228–29
Emperor Frederick II of Germany leads the Sixth Crusade, which retakes most of Jerusalem.

December 1144
Edessa, a Crusader kingdom in Syria, is captured by the Muslim leader Zengi. The Second Crusade sets out to take it back.

November 1147
One of the armies of the Second Crusade, led by Otto II of Germany, is defeated by Seljuk Turks.

July 1187
Crusaders living in the Holy Land lose almost all their territory to the Muslim leader Saladin. The Third Crusade is launched in response.

May–June 1191
King Philip Augustus of France and King Richard I of England arrive with Crusading armies at the city of Acre, near Jerusalem.

October 1202
In exchange for the use of the Venetian fleet, the Crusaders attack Venice’s enemies in the Christian town of Zara.

1217
Arms of the Fifth Crusade fail to take Jerusalem, invading Egypt instead. They are defeated outside Cairo in 1221.

1228–29
Emperor Frederick II of Germany leads the Sixth Crusade, which retakes most of Jerusalem.

1291
Sultan Baybars captures Acre, the last major stronghold of the Crusaders.
World religions

Millions of people around the world worship a greater power that gives meaning to their lives. For many, religion is an intrinsic part of their very existence.

A religion is a set of beliefs that deal with every aspect of life, from birth to death, joy and sorrow, good and evil. Some people worship a god or gods, others follow a religious teacher. Religion includes not just beliefs themselves, but the religious rituals and ceremonies that are the outward expression of those beliefs. Religion can bind a small community, or offer people membership of a huge global organization. There are six major religions in the world: Christianity, Judaism, Islam, Hinduism, Buddhism, and Sikhism. These account for 85 percent of all the world’s believers. Millions of others belong to religions old and new, making religion a rich, diverse, and sometimes controversial aspect of human history.

World religions

Apart from the followers of the six largest religions, about 12 percent of people belong to other faiths, sects, and cults. Pagans, for example, including witches and druids, revere nature. All religions share a quest to understand the world and make sense of our existence.

World religions by percentage

- Christianity (33%)
- Islam (21%)
- Hinduism (13%)
- Buddhism (6%)
- No religious belief (14%)
- Sikhism (0.5%)
- Judaism (0.2%)
- Other religions (12.3%)

Judaism

The religion of Jewish people, Judaism centers on the first Jew, Abraham, who taught Jews to worship one God. There are around 14 million believers today, but there are different forms of Judaism, including Orthodox and Liberal. Jews worship in synagogues, observe many rites of passage, and have a day of rest, called the Shabbat (Sabbath). They have struggled against hatred—in World War II, more than 6 million Jews were killed in the Holocaust. Most Jews now live in the United States and Israel.

Torah scroll

The most holy Jewish book is the Torah, which contains the rules for everyday life. In the synagogue, the Torah is read from precious scrolls.

Islam

Followers of Islam are called Muslims. There are 1.5 billion Muslims in the world, divided into Sunni and Shi’a. Their faith is based upon the Five Pillars: belief, worship, fasting, alms-giving, and pilgrimage. They follow a Holy Scripture known as the Qur’an, the word of God as told to the Prophet Muhammad.

Mosque

Many Muslims visit a mosque daily to say their prayers, but on Fridays all attend to listen to the Imam (teacher). Larger mosques have libraries and classrooms.

World religions

Christianity

Christians follow the teachings of Jesus Christ, believing he was the Son of God. There are about 2.1 billion Christians worldwide, and they are united in the belief in one God, the Bible as a holy text, and the use of prayer in worship. However, different branches of Christianity—Protestant, Catholic, and Orthodox—have different ideas about how their faith should be practiced.

<table>
<thead>
<tr>
<th>Protestant</th>
<th>Catholic</th>
<th>Orthodox</th>
</tr>
</thead>
<tbody>
<tr>
<td>No official leader</td>
<td>Led by the Pope in Vatican City</td>
<td>Led by Patriarchs</td>
</tr>
<tr>
<td>Began with Martin Luther, a 16th-century scholar who rejected Catholic teaching</td>
<td>Believe that popes inherit their authority from Saint Peter, one of the 12 apostles of Jesus</td>
<td>Formed in 451 CE after Christians in Rome and Constantinople disagreed over the Church’s teachings</td>
</tr>
<tr>
<td>Found across the world, but chiefly in Northern Europe, North America, New Zealand, Australia, and parts of Africa</td>
<td>Found across the world, but especially in Southern Europe, Eastern Europe, and South America</td>
<td>Found mainly in Greece, the Balkans, Russia, the Middle East, and North Africa</td>
</tr>
<tr>
<td>Emphasize simple worship in language everyone can understand</td>
<td>Use elaborate ceremonies, sometimes in Latin, to glorify God</td>
<td>Use elaborate ceremonies in different languages, including Greek and Syriac, to glorify God</td>
</tr>
<tr>
<td>Do not generally have monasteries, but use churches or cathedrals</td>
<td>Have monasteries for men and women</td>
<td>Have monasteries for men and women</td>
</tr>
<tr>
<td>Believe everyone can speak directly to God through prayer</td>
<td>Believe most people can speak to God only through the help of a priest or saints</td>
<td>Believe most people can speak to God only through the help of a priest or saints</td>
</tr>
</tbody>
</table>
**Hinduism**

To the 900 million Hindus worldwide, Hinduism is quite a varied religion. Hindus believe in a great spirit called Brahman who cannot be seen, but is present everywhere. They worship a wide range of gods and goddesses, each depicting a different aspect of Brahman’s power. The three most important gods are Brahma, the creator; Shiva, the destroyer; and Vishnu, the protector. According to Hinduism, every person has a soul, which lives on after a person dies. The soul takes on a new form and begins a new life, and this cycle continues. This is known as reincarnation. For Hindus, the aim is to escape this cycle and gain freedom to be with Brahman. Each good deed takes them a step closer. A bad deed takes them further away. This is the law of karma.

**Brahma**

The creative aspect of Brahman, Brahma is depicted with four arms, and four faces, each reciting one of four holy texts.

**Shiva**

The force of destruction and transformation, Shiva can be both kindly and fearsome. As Nataraja, he dances inside a ring of flames.

**Vishnu**

Blue-skinned Vishnu is charged with upholding the dharma—the law that maintains the Universe.

**Lakshmi**

The goddess of luck and wealth, Lakshmi is one of the most widely worshipped Hindu deities. She is often seen sitting on a lotus.

**Hanuman**

A monkeylike being (or vanara), Hanuman is best known for aiding the hero Rama in his war against the demons.

**Ganesh**

Elephant-headed Ganesh is the patron of wisdom, writing, art and science, and new endeavors.

**Buddhism**

Buddhism originated in India 2,500 years ago when a man called Siddhartha Gautama gained enlightenment and became the Buddha (“the Enlightened One”). Buddhism gradually spread from India to other countries. Today, about 376 million people across the world follow the teachings of the Buddha—the dharma, which seeks to end suffering (dukkha) and find answers to the true meaning of life. By respecting the Eightfold Path, including right thoughts and deeds, keeping Five Promises, and repeating three prayers (Three Jewels), Buddhists hope to attain a state of peaceful enlightenment called nirvana.

**Statue of Buddha meditating**

Buddhists worship by meditation (dhyana), trying to clear their minds of earthly distractions in order to perceive the Universe more clearly.

“WE ARE WHAT WE THINK. ALL THAT WE ARE ARISES WITH OUR THOUGHTS. WITH OUR THOUGHTS, WE MAKE THE WORLD.”

BUDDHA
The Ottoman Empire

For more than 600 years, the Muslim Ottoman Turks ruled one of the largest empires ever seen. It stretched across the Middle East, central and southern Europe, and Africa. Powerful emperors called sultans ruled this huge territory with the help of the janissaries, a personal army of slave-soldiers.

The Ottoman Empire began as a tiny state in the northwest of present-day Turkey. The Ottomans were skillful warriors, and they quickly increased their territory. In 1453, they captured Constantinople, which had been the capital of the Eastern Roman (Byzantine) Empire for 1,100 years. Renamed Istanbul, it became the center of their Islamic empire, and its rulers, the sultans, were leaders of the Muslim world.

In the 15th and 16th centuries, the empire became very powerful and wealthy. The sultans built grand mosques and palaces, many of which can still be seen today. The different cities became famous for the beautiful decorative arts practiced by their craftsmen: Iznik for ceramics, Bursa for silks and textiles, Cairo for carpets, and Baghdad for calligraphy.

Islamic conquerors
The Ottoman Empire was founded by invaders from Central Asia, who carved out a homeland in northwest Turkey around 1300. They soon began to expand, and conquered territory across Europe and the Middle East. However, they were slow to adapt to new military tactics, and after 1700 they started to lose territory to Europe and Russia. A series of weak sultans and corruption in government caused further damage, and the empire collapsed in 1919 shortly after being defeated in World War I.

City of Islam
When the Ottomans captured the city of Constantinople, they renamed it Istanbul and set about remodeling it as their new capital. They built magnificent mosques, and filled the streets with beautiful gardens, hans (markets), and grand tombs. A luxurious complex called the Topkapi Palace was constructed as the center of government and home of the sultans.

Religious conversion
The church of Hagia Sophia stood at the center of Constantinople under the Byzantine Emperors. The Ottomans converted it into a mosque, adding minarets and painting over the Christian images inside.

Ottoman art and design
The religion of Islam does not allow realistic pictures of humans and animals to be shown in public places. Instead, the Ottomans created beautiful patterns based on plants, flowers, or Arabic script to decorate their mosques and other buildings. At Topkapi Palace in Istanbul, the most talented artists, designers, weavers, and calligraphers gathered in workshops to produce official products for the sultan and his household. Their designs were the height of fashion across the empire.

Wall tile from Iznik
The Ottoman town of Iznik, in northwestern Turkey, was famous for its beautiful ceramic tiles.
The sultans

The Ottoman Empire was ruled by the descendants of a single family for 600 years. The early sultans were warriors who fought to gain more land. Under them, life in the empire was mostly peaceful and secure. Later sultans were less ambitious, and the Empire was overtaken by rivals in Europe.

Orhan

The second Ottoman sultan inherited a tiny state from his father, Osman I, and spent his life expanding it into an empire. He fought wars with the Christian Byzantine Empire and seized much of northwest Turkey from them, making the city of Bursa the first Ottoman capital. It was during Orhan's reign that Ottoman armies first invaded Europe.

Murad I

Under Murad the empire expanded even further into Europe, conquering Macedonia, Bosnia, and Bulgaria. Murad moved the Ottoman capital city to Edirne (Adrianople), in northwestern Turkey, and fought off local Muslim rivals to the empire. He reorganized the janissaries into a paid army in the service of the sultan, and created the devshirme recruiting system.

Mehmed II

Also known as "the Conqueror," Mehmed II was just 21 years old when he led his army to capture the Byzantine capital, Constantinople. As well as a fierce warrior, he was a patron of culture, science, and law. Some of Europe's best artists and scholars visited Mehmed at his palace, and he invited people of different races and religions to live in the capital.

Süleiman I

Known as "the Magnificent," Süleiman was one of the greatest Ottoman sultans. Under his rule, the empire became a world power. Süleiman was a brave military leader who personally led his army into battle, but he also loved the arts and wrote poetry.
The Silk Road

For more than a thousand years the great overland trading route known as the Silk Road carried precious goods between China and the Middle East and Europe.

When the Han dynasty of China conquered Central Asia around 200 BCE, it became possible to travel safely all the way to the borders of Persia and then westward to the Mediterranean Sea. Merchants who transported goods such as silk and gold along this route could make large profits, and the places they stopped at along the way often became rich cities. The Silk Road was at its height in the time of the Chinese Tang dynasty (618–907 CE) and then under the Mongols (13th–14th century).

Profitable exchange

Merchants on the Silk Road did not just carry silk. Traders heading toward the Arab world and Europe also brought other Chinese products, such as jade, lacquer, pottery, and bronze objects, which were highly prized in the west. Trading caravans heading toward China carried gold (to pay for the silk) and goods that were rare in China, such as ivory and glass.

Valuable trade items

The Chinese did not know how to make glass until the 5th century, and the Arabs and Byzantines only learned how to manufacture silk in the 6th and 7th centuries, so both these trade items were very valuable.

A perilous journey

As trade increased along the Silk Road, nomads such as the Xiongnu people began to attack the caravans in which the merchants traveled. The Chinese were forced to take control of the Central Asian oases, and stationed soldiers there to protect the trade. Some sections of the route traveled through perilous landscapes such as the Lop Nur salt desert, and groups not carrying enough water faced dying of thirst. The places where merchants stopped turned into towns, and artistic and religious ideas moved along the Silk Road with the travelers. This resulted in a great spreading of ideas, such as the introduction of Buddhism from India into China in the 2nd century CE.
craftsmen were deported by Genghis Khan to Mongolia after he captured Samarkand in 1220.

Mongol raiders
For centuries, Mongol horsemen raided Silk Road caravans. In 1206, led by Genghis Khan, they conquered most of Central Asia and northern China, taking control of the eastern Silk Road.

Kashgar
This ancient oasis town lay at the point where the northern and southern routes of the Silk Road joined.

Central Asia
This region was dominated by blistering deserts and towering mountains. In the 8th century, Arab conquests spread Islam to the region, giving rise to great Muslim empires that contributed to Silk Road trade. The Timurids conquered a swath of territory in the 14th and 15th centuries, leaving behind beautiful cities such as Samarkand. To the south, the Mughal Empire spread across India in the 16th century.

Constantinople
The capital of the Byzantine Empire, Constantinople, was the meeting point between European and Asian traders. A rich and powerful city, it controlled one of the main crossing points over the Bosphorus, the strip of water separating Europe from Asia.

Isfahan
As the Silk Road passed out of Central Asia and into Persia, it passed through Isfahan, a city famous for its wealth. The city became so important that in 1598 it became the capital of Persia under the Safavid dynasty.

Samarkand
Also known as Maracanda, this was one of the main cities on the northern section of the Silk Road. It changed hands many times between Chinese, Arabs, and Huns before it was conquered by the Mongols in 1220.

Beijing
The city was the winter capital of the Mongol rulers of China in the 13th century, and it was here that Marco Polo visited their ruler Kublai Khan in 1275. The journey from Venice took Polo more than three years.

Dunhuang
The westernmost point of Chinese territory, Dunhuang was an important stopping point before travelers set out on the month-long crossing of the Lop Nur Desert. A treasure trove of important Buddhist manuscripts was found here in 1900.

Xi’an
Chang’an (now Xi’an) was the capital of China in Han and Tang times, and the setting-off point for merchants traveling westward along the Silk Road. It became very wealthy, and in the 8th century was the world’s largest city, with about a million inhabitants.
Samurai warriors

Japan in the Middle Ages was ruled by an emperor but governed by military generals called daimyo, who often fought among themselves. At the head of their armies were some of the most fearsome warriors of all time: the samurai.

The samurai lived at the top of a strictly layered society. While the emperor and his family held the most respect, the samurai controlled the wealth and political power. Rich and influential daimyo gave their samurai supporters gifts of land, and the samurai would fight for the daimyo in exchange. Peasants working on the land paid taxes in food and money to support their masters.

Although most famous for warfare, the samurai valued music, poetry, and art. Many were attracted to Zen Buddhism, which teaches that perfect understanding of the universe lies through meditation and escaping from the self, which can be achieved just as well through painting as swordsmanship.

220 years—the length of time Japan isolated itself from the outside world, from 1633–1853. No foreigner could enter on pain of death.

Weapons and armor

Samurai favored hand-to-hand combat using razor-sharp swords. Their fighting style depended on nimble movement, so their armor had to be light enough not to slow them down. Samurai did not have shields; they used the sides of their swords to block enemy attacks.
28 in (70 cm) — the usual length of a katana blade.

2,370 °F (1,300 °C) — the heat of the furnaces used to forge samurai swords.

1 million — the number of layers of steel in a samurai sword blade.

Sword cross-section
Samurai swords are famous for their incredible strength and sharpness. Swordsmiths achieved this by allowing different parts of the blade to cool at different rates. The edge of the blade was hard and sharp, but the body was soft and flexible, and so less likely to snap.

Katana (long sword)
The samurai’s main weapon was wielded with two hands.

Armor layers
Samurai armor needed to be strong but light to match their nimble fighting style. It was made of thin strips of metal covered with varnish called lacquer and bound together with silk. In the 16th century, with the arrival of guns, samurai started to include plates of steel to cover vulnerable areas such as their chests.

White Heron Castle
Powerful samurai lords built castles as homes, fortresses, and symbols of their power. This one was built in the city of Himeji in the 17th century.

An honorable death
To be a perfect warrior, a samurai must always behave with honor, even toward his enemies. Battles were often fought according to strict rituals, starting with an exchange of bow shots between generals, followed by a volley of arrows from both sides, and then single combat between swordsmen. Samurai were completely loyal to their lords and unafraid of death. Dishonored samurai would undergo seppuku (ritual suicide) rather than live in shame. The preferred method was hara-kiri: the samurai would cut open his own stomach before being finished off with a chop to the neck by a friend.

Warring states
The samurai began as bodyguards to the emperor, but by the 12th century they had become the real rulers of Japan. Although the emperor was still officially in charge, true power rested with the shogun, the head of the most powerful samurai clan. Many battles were fought between rival daimyo for the honor of becoming shogun. The greatest of these took place between 1550 and 1600, the Sengoku period, during which all of Japan was plunged into civil war. The victor was Tokugawa Ieyasu, who ushered in a peaceful age known as the Edo period. In 1868, a new government replaced the Tokugawa rulers. To modernize Japan, they abolished the samurai.
THE AGE OF DISCOVERY

The world experienced huge changes between 1450 and 1750. A wave of new ideas swept across Europe as explorers founded new colonies and trading networks all across the world. European rivals often went to war with each other, and with the powerful empires of Asia, in the scramble for new territory.

NEW WAYS OF THINKING

In the medieval period, the Christian Church controlled art and learning in Europe. This changed around 1450 when important works by Greek and Roman authors were rediscovered and became popular. Scholars such as Erasmus (1466–1536) created a new movement called humanism, teaching that art and science should be based on experiment and observation rather than old traditions.

The Renaissance

A great deal of Roman art and architecture survived in Italy around 1400. It inspired artists, such as Michelangelo, Leonardo da Vinci, and Raphael, and architects, such as Brunelleschi, to produce daring new works of their own. Their artistic movement is called the Renaissance, and it soon spread across Europe.

Vitruvian Man

Renaissance artists such as Leonardo da Vinci studied human anatomy carefully to make their art as realistic as possible.

The Reformation

In 1517, a German priest called Martin Luther attacked the wealth of the Church and the right of the Pope to decide what people should believe. This movement—the Reformation—created a split between traditional Christians (Catholics) and supporters of Luther, called Protestants.

“WHY DOES THE POPE NOT BUILD [CHURCHES] WITH HIS OWN MONEY, RATHER THAN WITH THE MONEY OF POOR BELIEVERS?”

MARTIN LUTHER

Scientific thinking

The invention of the printing press by Johannes Gutenberg meant that books could be produced quickly, and knowledge could spread more rapidly. New ideas emerged, including the notion that the Earth orbits the Sun, proposed by Polish astronomer Copernicus in 1543, and Isaac Newton’s theory of gravity, published in 1687.

Scientific instruments

Isaac Newton invented a new model of telescope in 1678. It used a series of mirrors to create a better-quality image.

GLOBAL AMBITIONS

Spices such as pepper and nutmeg were very expensive in Europe in the 15th century, because they could only be obtained by trade with East Asia. Land routes such as the Silk Road were controlled by Islamic empires, so European explorers sought sea routes, founding colonies and outposts in India, Southeast Asia, and the Americas.

Voyages of discovery

Christopher Columbus reached America in 1492. Portuguese captain Vasco da Gama rounded southern Africa to reach India in 1498. Spaniard Ferdinand Magellan led the first voyage around the world in 1519–21, followed by Englishman Sir Francis Drake in 1577–80.

OF 237 MEN WHO JOINED MAGELLAN ON HIS VOYAGE AROUND THE WORLD ONLY 18 RETURNED ALIVE.

Rival explorers

Many brave explorers set out to map new sea routes and claim new territories. Some achieved great fame, but many were lost at sea.

Trading empires

Trade with Asia and colonies in America brought great wealth to the European powers. Spanish and Portuguese ships carried huge quantities of gold and silver from the Americas, often harassed by pirates and privateers encouraged by rivals such as Britain.

Vast riches

Spanish mines in the Americas produced 100 tons of silver every year—the weight of 10 buses.

European powers

The influx of new wealth made some European states very powerful. Wars and rivalry were common, but the new empires also saw scientific advances and flourishing new movements in art and literature.

ELIZABETHAN ENGLAND

England grew rich during the reign of Elizabeth I (1558–1603), despite conflict between Protestants and Catholics and the threat of war with Spain.

FERDINAND AND ISABELLA OF SPAIN

The rulers of Spain, Ferdinand of Aragon and Isabella of Castile, took control of new territories in the Americas, thanks to a treaty with Portugal in 1494.

FRANCE UNDER LOUIS IV

France became the most powerful country in Europe during the long reign of Louis XIV (1643–1715), famous for his strong army and cultured court.

RISE OF THE HABSBURGS

This family of minor nobles gained control of much of central Europe. They went on to become kings of Spain and rulers of the vast Holy Roman Empire.
THE NEW WORLD
Before the arrival of European explorers, the people of the Americas had built civilizations and empires. However, they did not have gunpowder, and even large armies could be defeated by the guns of Spanish soldiers. The Europeans also brought new diseases that killed huge numbers of indigenous Americans.

IT IS ESTIMATED THAT UP TO 90 PERCENT OF THE INDIGENOUS POPULATION OF CENTRAL AMERICA WAS WIPED OUT BY DISEASE AND WARFARE FOLLOWING THE ARRIVAL OF THE SPANISH.

Incas, Aztecs, Mayans
The most advanced peoples the Spanish encountered were the Incas (in Peru) and the Aztecs (in Mexico), both of whom controlled large empires. The Spanish attacked the Aztecs in 1519 and the Incas 1531 and soon captured their capital cities.

EASTERN POWERS
In Asia, great empires continued to fight off European competition, but often suffered internal turmoil. In China, the Ming dynasty collapsed in 1644 and was replaced by the Qing, who made China strong again. Japan sealed itself off from European influence, banning foreigners for more than 200 years. Two Muslim empires, the Mughals in India and the Ottomans in Turkey, gained great power, before growing stagnant and collapsing.

Ottoman expansion
The Ottoman Empire, based in modern Turkey, quickly expanded to fill the space left by the collapse of the Byzantine Empire. They took control of the Middle East, ruling much of the Arab world. Their advance on Europe was halted by the Poles and Habsburgs on land, and in the Mediterranean by rich Italian city-states such as Venice.

SIEGE OF CONSTANTINOPLE
In 1453, the Ottoman sultan Mehmed II captured Constantinople, the capital of the Byzantine Empire. He used huge cannons to break down the strong walls. He then made the city his capital.

BATTLE OF LEPLANTO
The Ottomans captured Cyprus in 1570. A strong Spanish and Italian fleet was sent to take it back. They defeated the Turks at Lepanto, off the Greek coast, in 1571. Their victory ended Ottoman dominance in the Mediterranean.

Mughal India
In 1526, a Muslim prince from central Asia called Babur captured Delhi and founded the Mughal Empire. The Mughals expanded steadily from northern India, making their greatest gains under Sultan Akbar (1556–1605). The Mughal court was a rich one, famous for its magnificent works of art and beautiful buildings.

Combining cultures
Mughal buildings, such as the tomb of Sultan Humayun, who died in 1556, combined Islamic tradition with Indian culture to create a new style.

Tokugawa Japan
In Japan, a period of civil war ended when powerful general Tokugawa Ieyasu declared himself shogun (military ruler). He moved the capital to Edo (Tokyo) and reduced the power of the daimyo (warlords) who had previously dominated Japan. The Tokugawa family ruled Japan until 1868, and isolated it from the outside world.

Qing China
In 1644, the Ming dynasty was overthrown by a series of peasant revolts. The new rulers, the Qing, came from Manchuria in northeast China. They tried to make people adopt Qing customs, like the wearing of a ponytail, but this proved very unpopular. Nevertheless, they overcame opposition and increased Chinese territory.

Greater empire
The Qing conquered new territory to make China larger than ever. The new territories included Taiwan and Mongolia.

Combining cultures
Mughal buildings, such as the tomb of Sultan Humayun, who died in 1556, combined Islamic tradition with Indian culture to create a new style.
Voyage to the Americas

For centuries the people of Europe and Asia had no idea the Americas existed, until 1492 when Christopher Columbus led a voyage across the Atlantic Ocean.

Columbus did not know of the existence of the Americas. He intended to discover a new route from Western Europe to East Asia. He was astonished to discover a new land, and he and his wealthy sponsors, King Ferdinand and Queen Isabella of Spain, were quick to exploit the new territory. Explorers brought back gold, silver, and new plants such as tobacco. They established colonies in the new land, taking advantage of fertile soil to grow sugar and cotton. However, for the indigenous peoples living in the area, the arrival of European explorers was catastrophic, bringing disease, war, slavery, and death.
"At two o'clock in the morning the land was discovered, at two leagues' distance...they found themselves near a small island, one of the Lucayos, called in the Indian language Guanahani."

Log of Christopher Columbus, October 12, 1492

**Columbus’s voyages**
Columbus undertook four voyages to the Americas. On his first, he visited islands in the Caribbean, where his second voyage established colonies a year later. It wasn’t until his third visit, in 1498, that he set foot upon the American mainland, touching the coast of what is now Venezuela. His last voyage, begun in 1502, took him along the coast of Central America, seeking a passage through to the Pacific Ocean beyond.

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**Afterdeck and aftcastle**
The open space above the quarterdeck was known as the afterdeck. Two small cannons were mounted here. The space above the admiral’s cabin was called the aftcastle, and with a clear view on all sides was an ideal place to take navigational readings.

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**Finding your way**
Explorers like Columbus often had no maps, and had to navigate by other means. They used a compass to measure the direction the ships were moving in, and an hourglass to keep track of the time. They also used a device called a quadrant, to calculate their latitude by measuring the angle of the sun and stars.
**Human sacrifice**
The Aztecs believed that the blood of human victims was needed to feed the Sun to make sure that it did not go out. Many people sacrificed to the Sun were captured in wars. The priest would plunge a sharp knife into the victim's chest and then pull out his still-beating heart.

**Death mask**
This mask was made from the skull of a sacrificial victim and was probably worn by an Aztec priest who performed sacrifices.

**The Incas**
Between 1438 and 1500, the Inca people conquered a large empire in what is now Peru. Their capital was the mountain city of Qusqu. They built a road network to connect their territory, and grew rich and powerful, but the empire was destroyed by Spanish invaders in the 1530s.

**Ancient Americas**
From about 3000 BCE until 1500 CE, a series of advanced cultures dominated South and Central America. Centered on powerful city-states, they were often at war with one another.

The first cities were built by the Chavin people (in South America) and the Olmecs (in Central America) in around 1000 BCE. Both of these cultures constructed huge, pyramid-shaped temples, which became a feature of the cities that were built in the region over the next 2,000 years. Different cultures rose and declined over the centuries, until most of the city-states had become part of the Inca Empire (in Peru) or the Aztec Empire (in Mexico). However, both of these empires were eventually conquered by European invaders in the early 16th century.
Mayans
Mayan cities in Guatemala and the Yucatan peninsula of Mexico were at their most powerful between 300 and 900 CE, but were then abandoned, probably due to overpopulation. The Mayan writing system of glyphs tell us a lot about their history.

Aztecs
From 1375, the Aztecs conquered a large empire based around their capital, Tenochtitlan, attacking their neighbors to capture prisoners to sacrifice to their gods. Although they were fierce warriors, the Aztecs were conquered by Spanish invaders in 1521.

Cortés
The Spanish adventurer Hernán Cortés arrived in 1519. His army took over the Aztec Empire.

Palenque
The most powerful of Palenque’s kings, K'inich Janaab Pakal, was found buried in a tomb under the Temple of Inscriptions.

Tikal
The pyramid temples of Tikal are among the most magnificent in the Mayan world.

Chichen Itza
This city became important after Mayan centers further south were abandoned in around 900 CE.

MAYAN RAIN GOD STATUE
GOLD AZTEC LIP ORNAMENT
The Renaissance

An explosion of new ideas transformed Europe in the 15th century, bringing revolutionary works of art, science, and invention. This period has gone down in history as the Renaissance, or “rebirth.”

The Renaissance began in Italy in around 1400, where scholars rediscovered the writings of Greek and Latin mathematicians, artists, and philosophers. The ideas in these texts gave rise to a school of thought called humanism, which prized experiment and experience as the sources of knowledge, in contrast to the tradition and superstition of the medieval era. This new way of thinking spread across Europe, inspiring a generation of artists, architects, and philosophers. Perhaps the most famous was Leonardo da Vinci, an ingenious scientist, artist, and inventor who represented the ideal humanist, or “Renaissance man.”

New artistic techniques
One of the techniques that Renaissance scholars rediscovered was perspective—a way to give depth to paintings and drawings. Objects that are further away look smaller and shorter than objects up close. The Romans used mathematical formulas to mimic this effect in drawings. Renaissance artists copied the Roman technique to make their paintings astonishingly lifelike.

Painting
Renaissance painters tried to show their subjects as realistically as possible. They wanted their paintings to look like a window onto another scene, rather than a flat plane filled with characters. They used techniques such as perspective to give their images depth, and they painted people in a lifelike manner. They also covered a greater variety of subjects: medieval art mostly showed religious scenes and portraits, but Renaissance artists also painted scenes from history, Greek and Roman myths, and everyday life.

Drawing distance
Artists using perspective show distant objects as smaller. The artist sets one or more “vanishing points,” where objects are too far away to see.

The School of Athens (1510)
This painting was created for the Pope by Raphael, one of the most admired artists of the Renaissance. It depicts Ancient Greek philosophers, painted to resemble Renaissance thinkers such as Leonardo da Vinci, Michelangelo, and Raphael himself.
Renaissance rulers

In the 15th century, Italy was made up of city-states ruled by wealthy merchant families. Their dukes and princes acted as patrons, paying for artists and thinkers to create artworks, monuments, and inventions to impress rival rulers. New political ideas arose. These were most famously summed up by a diplomat named Niccolò Machiavelli, who advised nobles to be unjust or even cruel in order to achieve noble ends.

Medici coat of arms

The Medici family ruled Florence from 1434. The balls on their coat of arms may represent coins, showing their origins as traders and bankers.

"MEN ARE DRIVEN BY TWO IMPULSES, LOVE AND FEAR... IT IS MUCH SAFER TO BE FEARED THAN LOVED."

NICCOLO MACHIABELLI, THE PRINCE, 1513

The Northern Renaissance

From Italy, the ideas of the Renaissance quickly spread to Northern Europe. Rich kings such as Francis I of France and wealthy merchants in Belgium and the Netherlands, were eager to benefit from the new ideas. Their artists followed the techniques of the Italian Renaissance, and developed new styles of their own. Scholars such as Dutchman Desiderius Erasmus translated Greek and Roman texts into versions that could be widely read.

The printing press

Around 1455, a German blacksmith named Johannes Gutenberg invented a printing press that used movable type (metal letters that could be swapped around and reused). By allowing copies of books to be printed easily, it sped up the spread of ideas.

Architecture

Many Italian cities contained ruins of Roman buildings, and the architects of the Renaissance were determined that their creations should be just as grand and beautiful. They studied Roman writings on architecture and geometry to make the shapes of their buildings more harmonious, and they copied Greek and Roman styles of columns and arches for decoration.

Florence Duomo (1436)
The rulers of the city of Florence wanted their new cathedral (duomo) to be the envy of all their rivals. By 1413, it was almost complete, but nobody had worked out how to build its huge dome. Architect Filippo Brunelleschi solved the problem, designing a dome with two layers using lightweight bricks.

Renaissance doctors and artists studied human anatomy by dissecting (cutting open) the bodies of dead criminals.

Michelangelo's David (1504)
Michelangelo was one of the greatest painters and sculptors of the Renaissance. His sculpture of David, biblical King of Israel, is regarded as one of the most perfect human figures ever carved in marble.

Sculpture

Like the painters of the era, Renaissance sculptors tried to make their works as lifelike as possible. Inspired by Greek and Roman sculptures, they showed their subjects in natural poses, and brought out details such as hairs and folds of cloth. Many artists studied human anatomy so that their works copied the shapes of limbs, muscles, and veins exactly as they appear in real life.
The age of discovery

Shakespeare's plays could be very gory. *Titus Andronicus* includes several murders, severed heads, and even cannibalism.

The stage

Three doors led from the tiring house onto the stage. Actors could also arrive through the audience, or through trapdoors in the stage floor. The roof was painted with stars, to represent the heavens.

The hut

A hidden space above the stage was used for special effects such as heavenly music.

Lords' boxes

Noble visitors to the theater sat here, away from the crowds.

Roof thatched with straw

A hidden space above the stage was used for special effects such as heavenly music.

Tiring house

These rooms were used for storage, and for the actors to change their clothes (or attire).

Back stage

Actors could wait here without being seen by the audience. Each actor might play several roles in a single play.

Stage door

Actors could enter through three doors in the back wall.

Groundlings

It cost only a penny to watch a performance if you didn't mind standing in the yard.
Stories on stage
For thousands of years, human beings have used theater to share stories and ideas. The Ancient Greeks built some of the earliest theaters. They divided plays into two types.

**Tragedy**
Serious stories in which the heroes and heroines suffer and often die at the end are called tragedies. They often explore the way honor, justice, or fate can force us to go against our personal feelings.

**Comedy**
These plays use humor to tell a story, although not always a happy one. Some versions, known as satire, use comedy to point out weakness or bad behavior, especially in those in power.

**Theater design**
Plays can be performed almost anywhere, from open streets to tiny studios. Most take place in buildings designed to allow the audience to see and hear the actors, and to make the scene seem as realistic as possible.

**Ancient Greek theater**
This design uses a curve of seats to reflect sound. Even a whisper from the stage can be heard by the whole audience.

**In the round**
Traveling actors in medieval Europe often set up a stage surrounded by the audience on three or even four sides.

**Proscenium arch**
Modern theaters often have an arch to frame the action on stage and keep the audience separate.

Shakespeare’s theater
Painting and sculpture were not the only arts to be revolutionized by the Renaissance. Theater also changed, not least with the arrival of the period’s most famous playwright, William Shakespeare.

In Europe, medieval theater was mostly morality plays and stories from the Bible, which followed a fixed formula. Around the middle of the 16th century, new plays began to present stories of romance, tragedy, and adventure based on Classical myths, history, and even current events. The new plays were extremely popular. Everyone from poor laborers to rich merchants and nobles flocked to the new theaters, and the most famous actors were even invited to court to perform for royalty.

“All the world’s a stage. And all the men and women merely players.”
As You Like It, by William Shakespeare

Shakespeare’s Globe Theater
The late 16th and early 17th centuries saw many great playwrights emerge. By far the most famous is English writer William Shakespeare. His plays were so successful that, in 1599, his theater company was able to build a permanent playhouse in London: the Globe Theater. A copy of his theater stands near the original site today.

The estimated number of new words invented by Shakespeare that are in common use today. 1,700

1613 The Globe Theater burned down in this year when a stage cannon set the thatched roof on fire.
The Great Wall
For centuries, China’s greatest threat came from the north, where warlike tribes mounted swift, fierce raids on unprotected settlements. To keep them out, the Chinese emperors built a series of walls stretching thousands of miles.

Signal tower
Often built on high points to be easily seen, these towers were used to send signals along the wall.

Garrison
Small numbers of troops were stationed at regular intervals along the wall to watch for invaders.

Brazier for sending smoke signals

Signal cannon
The noise of the cannon could be used to signal at night, when smoke could not be seen.

Bamboo supports

Rubble filling
The inside of the wall was filled with broken stones and mud.

Stone layers
The outsides of the wall were built of stone and fired bricks.
Imperial China

At its height, China was the most powerful empire in the world. Its emperors controlled wealth and influence beyond the wildest dreams of European monarchs.

China is one of the world’s oldest civilizations, with written records going back almost 3,500 years. Its history includes long periods of civil war and conflict with its neighbors. Despite all this, Chinese imperial society was generally extremely stable and well organized. From the 1st century BCE, the government was run by a civil service, which later on could only be entered by passing difficult exams. Chinese explorers established trade routes as far as Africa and Arabia, and Chinese craftsmen created some of the most important inventions in human history, including paper, gunpowder, and porcelain.

The path of the wall
The earliest parts of the wall were built in the 7th century BCE, to protect Chinese farmland from nomadic raiders to the north. They were first joined together in the 3rd century BCE under Qin Shi Huangdi. Successive Chinese emperors fortified and extended these walls, and they reached their greatest extent in the 16th century, under the rule of the Ming emperors.

Imperial families
Several different dynasties rose to power over the centuries. Some brought war and famine, while others saw incredible advances in philosophy, technology, and art. The first ruling dynasty began in the 16th century BCE under the Shang, but they controlled only a part of the vast empire that would follow.

Zhou dynasty
The Zhou conquered their neighbors to build an empire across China. Great sages lived under their rule: Laozi, founder of Tao philosophy, and Kong Fuzi (Confucius), whose code still influences Chinese culture today.

Warring States period
Rival states formed after the decline of the Zhou. Their rulers fought for land and power, using strict military organization to raise and control their armies.

China united
The Warring States period ended with victory by the Qin kingdom, reuniting China after centuries of war. Qin Shi Huangdi became emperor. He built new roads and canals, and introduced consistent weights and measures across the empire.

Death of an emperor
Qin Shi Huangdi died 11 years after becoming emperor. He was buried in a vast tomb complex guarded by an army of thousands of terra-cotta warriors, complete with weapons and armor.

Han dynasty
Qin Shi Huangdi’s son ruled for only four years, and died during a popular rebellion. Liu Bang, a peasant who had risen to become a powerful general, took control of the empire, founding the Han dynasty.

Tang and Song dynasties
After centuries of turmoil, China returned to peace under the Tang and Song dynasties. Art, literature, and invention flourished as the empire expanded and China became very wealthy.

Ming dynasty
After the fall of the Song, China was ruled by Mongols from the north for many years. They were overthrown by rebel Zhu Yuanzhang. His descendants, the Ming emperors, ruled from a huge palace called the Forbidden City.

The last emperor
By the 19th century, China had come into conflict with European powers. The emperors were weakened and, in 1912, a military revolt deposed the Qing rulers and founded the Republic of China.
Rulers of India

The Mughals were warrior horsemen from Central Asia who swept through northern India in the 16th century. Their rulers built a great empire in which Hindu and Muslim people lived side by side in relative peace.

The Mughals invaded India in 1526 under the command of the warrior Babur. They captured the important northern Indian city of Delhi, and Babur became the first Mughal emperor. Within 150 years, his descendants had expanded their empire to include most of India.

The Mughals ruled over 150 million people. A Muslim people, they were tolerant toward the religion of their Hindu subjects. The emperors were lavish patrons of the arts, and their craftsmen built many beautiful buildings. Yet only a century after reaching the height of its power, the Mughal Empire had lost most of its territory.

Finding an empire

Zahir-al-Din Babur, known as Babur, was the founder of the Mughal Empire. A descendant of Genghis Khan, he originally ruled a small state around Kabul in Afghanistan. He was known as a lover of poetry and gardens, and also as a fierce warrior. In 1526, he defeated the Sultan of Delhi and made the city his new capital. His son, Humayun, was expelled from India in 1540, but returned to continue Mughal rule.

Arms and armor

Mughal warriors mostly fought on horseback. They wore chain mail over their lower neck, arms, body, and upper legs, with an iron breastplate for extra protection. Their armies were also well equipped with guns and cannons.

Battle and conquest

The Mughal Empire was founded after a great battle at Panipat near Delhi in April 1526, where Babur’s army of just 12,000 defeated an enemy force of 100,000 men and 1,000 elephants. Babur’s men had the advantage of gunpowder weapons (cannons and handguns), which their opponents lacked. The Mughal army went on to conquer other Indian kingdoms, and absorbed their warriors into its ranks, gaining well-trained heavy cavalry and eventually amassing 100,000 men.
**The end of the empire**
Shah Jahan’s son, Aurangzeb, conquered new provinces in the south of India, expanding Mughal territory by a quarter. But the empire came under attack from a new power, the Maratha Confederacy. Constant wars drained the Mughal treasury and the empire began to crumble. Aurangzeb was also unpopular with Hindus and other non-Muslim subjects. After he died in 1707, the empire fell apart, with weak rulers unable to defend it from its enemies. In 1739, the Persian ruler Nadir Shah invaded, sacking the city of Delhi and carrying off many Mughal treasures. By 1857, the Mughals ruled only central Delhi. Emperor Bahadur Shah joined a rebellion against the British in 1857. He was deposed and the Mughal Empire came to an end.

**Mughal art**
Art and architecture flourished under the Mughals. Manuscripts with delicate paintings were especially prized. These now provide us with lots of information about the Mughal court. The emperors ordered new cities full of wonderful buildings to be constructed, such as Fatehpur Sikri and Shahjahanabad. Some of their buildings, such as the Taj Mahal at Agra, are world famous to this day.

**Tomb**
The central room holds the tombs of Mumtaz Mahal and Shah Jahan.

**Marble walls**
The mausoleum is built of pure white marble.

**Lotus design**
The top of the dome is decorated with a design representing a lotus flower.

**Minarets**
Four minarets frame the building. Each one is more than 130 ft (40 m) tall.

**The Taj Mahal**
Shah Jahan ordered the Taj Mahal to be built as a tomb for his wife, the Mughal empress Mumtaz Mahal. The white marble building took 17 years to complete and was designed to represent paradise.
THE MODERN WORLD

The years since 1750 have seen huge turbulence in every area of life. Globe-spanning empires arose in the 19th century, and fell apart as the balance of power shifted from nobles and emperors to everyday citizens. New technology transformed agriculture, industry, transport, and warfare, and a digital revolution changed communications and entertainment forever.

THE AGE OF REVOLUTION

From around 1750, new political movements called for kings and governments to grant more freedom to the people. At the same time, colonies began to seek independence from their ruling countries. When rulers and colonial powers refused these demands, the populace rose up in rebellion. The USA won their independence from Britain by force in 1783, inspiring other revolutions.

The French Revolution

In 1789, the French people rebelled. King Louis XVI was deposed and executed. The Revolution became a bloodbath, as the new leaders turned on each other in an era of violence known as the Terror.

Napoleon Bonaparte

After the French Revolution, a popular general named Napoleon became Emperor of France, and began a long and bloody war of conquest across Europe.

Imperial rivals

Wars in this period became ever larger and more bloody as rival empires threw their full might against each other.

- Seven Years War (1756–63)
  The world’s first global war was fought mainly between the empires of Britain and France over colonies in India and North America.

- Napoleonic Wars (1803–15)
  Napoleon Bonaparte proclaimed himself Emperor of France and waged a war of conquest, but was defeated at Waterloo by an alliance of European powers.

- Crimean War (1853–56)
  Russia’s attempts to capture land from the Ottoman Empire were halted when Britain and France allied against them.

- Opium wars (1839–60)
  The Chinese tried to stop British merchants from trading in opium, sparking two wars with Britain. The fighting ended with the Chinese forced to open 14 ports to European trade.

- Russo-Japanese War (1904–05)
  Japan’s powerful, modernized army and navy inflicted a shock defeat on Russia in a war over territory in China and Korea.

A postcolonial world

European colonies in Asia and Africa found it harder to win independence than those in America. However, two World Wars greatly weakened the European empires. India and Pakistan won their independence from Britain in 1947, after mass popular protests led by a lawyer named Gandhi. In Africa, Ghana was the first colony to win independence in 1957, and many others soon followed.

YOU CAN CHAIN ME, YOU CAN TORTURE ME, YOU CAN EVEN DESTROY THIS BODY, BUT YOU WILL NEVER IMPRISON MY MIND.

GANDHI, CAMPAIGNER FOR INDIAN INDEPENDENCE
A CENTURY OF CONFLICT

The first half of the 20th century saw two of the bloodiest wars in human history. Each started with conflicts in Europe, then spread to countries all across the world. World War I (1914–18) saw millions of fighting men killed in bitter trench warfare. World War II (1939–45) brought battles between armies of tanks and aircraft, and the development of the atomic bomb. When the dust had settled, the world's most powerful nations were the US and the communist USSR. They fought a Cold War, backed by vast nuclear arsenals.

The Cold War

Although the US and USSR had been allies in World War II, they became enemies once it was over. They did not fight directly, but fought a "Cold War" by other means, such as overthrowing governments friendly to the other side. The Cold War was especially dangerous since both sides had nuclear weapons that could have killed many millions of people.

World War I

In 1914, the killing of Archduke Franz Ferdinand of Austria in Sarajevo caused a war between the German-led Central Powers and the Allies (led by the French and British). Much of the fighting happened on the Western Front in France and Belgium, where attempts to capture heavily defended trench systems caused massive casualties. Only in 1918 did the Allies break through and defeat Germany.

World War I cemetery

Nearly 10 million soldiers died during World War I. Many of them were buried in graveyards near where they fell.

World War II

In 1933, Adolf Hitler became leader of Germany. His campaign to conquer neighboring countries set off a new global conflict in 1939. German armies were victorious at first, but were defeated in 1945 by their Allied enemies. Japan joined the war in 1941, but was forced to surrender after the US attacked with atomic bombs in 1945.

A TRANSFORMED WORLD

While wars and revolutions brought political changes, advances in science and technology transformed society. Developments in medicine created cures for diseases that had killed millions. The Industrial Revolution brought new machines that could do the work of dozens of workers. These new societies brought much greater equality, and the old order was overturned, as women and nonwhite people fought to win equal rights.

Equal rights

Before the 20th century, women, African-Americans, and nonwhites in European colonies were often denied basic freedoms. It took the determination of many brave campaigners to ensure that basic rights such as voting and education were available to all.

1893 New Zealand becomes first country to grant women the right to vote in national elections.

1920 19th Amendment to the United States Constitution grants women the vote.

1948 South Africa begins passing legislation discriminating against nonwhites. This policy is called apartheid.

1964 The Civil Rights Act makes it illegal in the USA to deny black people equal access to education and housing.

1965 Voting Rights Act (US) removes obstacles to African-Americans voting.

1994 South Africa holds first elections in which adults of all racial groups can vote, ending apartheid.

Science and medicines

The 20th century saw scientific advances beyond anything in human history. Antibiotics cured untreatable diseases, and cars and airplanes reduced journeys that would have taken days or weeks to a few hours. Human beings discovered ever more about the universe, their history, and themselves.

Environmental challenges

The 19th and 20th centuries saw a rapid rise in the world's population, and a huge increase in the resources human beings use. Supplies such as coal, oil, and even fresh water may become scarce. Many natural habitats have been damaged by pollution or human exploitation. Rising global temperatures threaten to disrupt vast areas of farmland and human living space across the world.

“ANYONE WHO HAS NEVER MADE A MISTAKE HAS NEVER TRIED ANYTHING NEW.”

ALBERT EINSTEIN

Ozone hole

In the 1990s, air pollution led to a breakdown in the ozone layer, a part of the atmosphere that protects the Earth from harmful radiation. At its biggest, the hole, situated above Antarctica, was twice the area of Europe.

1982, the USSR and US between them had more than 20,000 nuclear warheads with a combined explosive power estimated at more than 12,000 megatons, or 1 million times the energy released by the bomb that destroyed Hiroshima.
The slave trade

European settlers in America needed laborers to work on plantations. Between 1500 and 1900, this led to 12 million African slaves being taken to the Americas.

The slave trade is often called the “Triangular Trade” because it had three stages. Goods from Europe were traded in Africa for slaves, who crossed the Atlantic in a journey known as the Middle Passage. These slaves were then exchanged for crops to be sold in Europe. Many slaves died on the journey to the Americas, and those who survived faced appalling working conditions on the plantations. An international campaign banned the Atlantic slave trade in the 19th century.
Terrible conditions

On the voyage across the Atlantic, which could last from six weeks to six months, slaves were crammed together below deck in the ship’s hold, with little fresh food or water. Male slaves were chained together to prevent them from attacking the crew.

Slave ship

To make the most profit possible, the traders packed slaves into very small spaces, sometimes less than 12 in (30 cm) high. One infamous slave ship, the Brooke, carried as many as 600 slaves, shackled together in pairs.

A deadly voyage

Crammed conditions and lack of food and water meant that 1.8 million slaves died of disease or starvation while voyaging to the Americas on the Middle Passage. Their bodies were thrown overboard.

Death toll

The death rate for slaves reached as high as one in four on the worst Atlantic voyages.

Calling for an end

Calls to put an end to the inhumanity of the slave trade led to its abolition in Britain in 1807. Other countries soon followed, until the final country to end the trade, Brazil, did so in 1831.

“NEVER, NEVER WILL WE DESIST TILL WE HAVE WIPED AWAY THIS SCANDAL FROM THE CHRISTIAN NAME, RELEASED OURSELVES FROM THE LOAD OF GUILT, UNDER WHICH WE AT PRESENT LABOR, AND EXTINGUISHED EVERY TRACE OF THIS BLOODY TRAFFIC.”

WILLIAM WILBERFORCE
(ANTISLAVERY CAMPAIGNER)
The Enlightenment

The 18th century was a time of revolution. The power of governments, religious beliefs, and scientific principles were all challenged by a wave of new thinkers determined to replace outdated traditions.

The Renaissance had brought new ways of thinking about science and philosophy, but they were still based on old traditions: the teachings of the Church and writings of the Ancient Greeks and Romans. The thinkers of the Enlightenment wanted to replace these sources of wisdom with individual observation, experiment, and logic—the rule of reason. Their radical ideas would bring wars, revolutions, and the beginnings of modern science.

**Revolution of ideas**

In the 18th century, people who wanted to know about the world studied natural philosophy, which included all the sciences and maths. At the time, a flood of new information was spreading across Europe, helped by new discoveries of explorers in Asia, Africa, and the Americas, and by the printing press. A group of natural philosophers in Paris, led by Denis Diderot and Jean d’Alembert, compiled an *Encyclopédie*, a giant, 28-volume work summing up everything they knew about art, science, and crafts. Their message was that reason and science could be applied to almost any subject, and their ideas spread across Europe and America. German philosopher Immanuel Kant summed up the new way of thinking as: “Dare to know. Have courage to use your own understanding.”

**Isaac Newton**

One of the founding figures of the Enlightenment was the English scientist Isaac Newton (1642–1727). He is most famous for working out the laws of gravity and motion, which showed how the movements of the Moon and stars follow the same laws as the movements of objects on Earth. He also made vital discoveries about the nature of light and heat, and was one of the first to formulate a mathematical process called calculus. His curiosity about the world sometimes led him to do strange things. For example, he pushed a blunt needle into his eye socket to see how changing the shape of his eyeball affected his vision, as part of his studies into how light moves.

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**Rights of Man—and Woman**

As well as scientific advances, the Enlightenment was marked by new ideas about society. From around 1750, a group of radical philosophers in France began to spread ideas that questioned traditional thinking. They argued that kings, nobles, and clergymen did not deserve special rights and privileges over other people. Other thinkers such as Jean-Jacques Rousseau and Mary Wollstonecraft produced powerful arguments calling for all human beings to be treated equally, while writers such as Voltaire and Montesquieu wrote satires (mocking imitations) of corrupt institutions and outdated opinions.

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**The Encyclopédie**

Diderot’s great work covered not only art and science but everyday professions, such as music, cooking, and even farming.

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**Celestial sphere**

From the early 17th century, astronomers had known that the Earth and other planets orbit the Sun. Isaac Newton’s theory of gravity explained why.

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**1748**

A French thinker named Charles-Louis de Secondat, known as Montesquieu, published *Spirit of the Laws*, which called for political power to be divided between the monarchy, parliament, and the courts of law—a system known as the “separation of powers.”

**1762**

Swiss philosopher Jean-Jacques Rousseau proposed that governments should only rule with the consent of the people. In *The Social Contract*, he wrote, “Man is born free, and everywhere he is in chains.”

**1759**

*Candide*, a satirical novel by French philosopher Voltaire, highlighted the hardships and injustices suffered by many people around the world. Voltaire wrote that, for people to be truly free, they had to be able to use the power of reason, and they had to know and defend the basic rights of all human beings.
Revolution of wealth
Among the new concepts to develop at this time was the science of economics, or the study of wealth and money. Great empires grew rich by trading goods across the world. Banks offered a safe place for the wealthy to deposit their money, and gave loans to people who needed funds to start new businesses. Ordinary people were also encouraged to invest in money-making projects. Financial projects sometimes went disastrously wrong: for example, in 1720, when the British South Sea Company collapsed, taking with it millions of pounds (dollars) of investors’ money.

Financial centers
With the rise of capitalism, cities such as London and Amsterdam became banking centers, home to great wealth.

Revolution of wealth
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Financial centers
With the rise of capitalism, cities such as London and Amsterdam became banking centers, home to great wealth.

Romantic rebellion
The ideals of the Enlightenment spread quickly, but by the late 18th century they had already inspired a backlash, especially among artists, musicians, and poets. A new movement, Romanticism, arose, arguing that total reliance on reason ignored the values of emotion and natural beauty. Famous Romantics include the composer Beethoven, writers such as John Keats and Edgar Allan Poe, and painters such as Eugène Delacroix.

Romantic values
Nature
Nature was seen as intense and genuine, where logic and reason were artificial and could deceive.

Gothic
The Romantics were inspired by medieval fairy tales, especially fantasies and gruesome tales.

Emotion
Instinct and emotion were seen as the sources of truth, which could be distorted by logic.

Romantic hero
The passionate, solitary genius was seen as a hero, rising above the ideas of ordinary people.

Supernatural
The spiritual world was seen as an answer to the dull, scientific world of the Enlightenment.

Individuality
The Romantics thought being alone put you more closely in touch with nature and your true self.

Imagination
The creative power of imagination could build wonders that logic found impossible.

Symbols and myths
Mysterious meanings could be found in symbols from nature and ancient languages.

Burning of the Houses of Lords and Commons
Romantic artists such as Englishman Joseph Turner painted images depicting the power of natural forces. This painting shows a fire that swept through the British Houses of Parliament in 1834.

1776
English-American Thomas Paine published a pamphlet, Common Sense, which supported America’s independence from Britain. His later work, Rights of Man, argued that people should overthrow the government if it abuses their rights.

1792
Englishwoman Mary Wollstonecraft called for women to receive the same education and opportunities as men in A Vindication of the Rights of Women. She imagined a society based on the rule of reason, which respects all human beings.
The American Revolutionary War

In the 18th century, Britain ruled 13 colonies along the east coast of North America. From 1770, these colonies began to rebel against British control and, 13 years later, they won their independence.

Britain's colonies in North America were governed from London. Their inhabitants were British citizens, but were not given full rights: they could not vote and had no one representing their views in parliament. The colonists were angry about this unfair treatment, but the British ignored their concerns, passing unpopular laws and putting high taxes on everyday goods such as sugar, tea, and paper.

In 1775, tensions erupted into war. A large, well-trained British army invaded from Canada in 1777, to support British troops stationed in the colonies, but they were outmaneuvered by skillful American commanders led by George Washington. The war ended with the British defeated, and the creation of a new independent country: the United States of America.

Lead-up to the war

Britain had run up huge debts during the Seven Years War (1756–63), and urgently needed money to pay them off. The government planned to raise the money by taxing its American colonies. The colonists protested against this taxation without representation, and the revolutionary idea of becoming free of British rule spread. In 1773, the British imposed a harsh new tax on tea, and colonists in Boston took action. They boarded a ship in the harbor and threw chests of British tea into the sea. This event, famous as the Boston Tea Party, lit the fuse for the war. The British responded by imposing restrictive new laws on the colonies, and especially on Boston. The Continental Congress—a group of representatives of the 13 colonies—called these laws intolerable acts and sent messages of protest to the king.

AT THE BOSTON TEA PARTY, COLONISTS DESTROYED 342 CHESTS OF TEA WITH A VALUE OF ABOUT $15,000.

The new nation

At the end of the war, the 13 colonies that had fought for independence became the first states of the US. They signed a peace treaty with Britain in 1783, which also granted them ownership of substantial territory to the west.
The Declaration of Independence
The 13 rebel colonies formed their own government, the Continental Congress, which soon decided to seek complete independence from Britain. A lawyer from Virginia named Thomas Jefferson was given the task of drafting a Declaration of Independence to formalize their position. The argument of the Declaration was based on four key points, listed below. On July 4, 1776, representatives of the 13 colonies signed the Declaration to form a new nation: the United States of America.

1 Right to rebel
That colonies must be allowed to sever their connection with their rulers as long as they have good reasons and can explain them.

2 Legitimate government
That the only acceptable form of government is one that tries to do the best for its people and respects their rights.

3 Crimes of the king
That the British king had ruled the colonies without respecting the rights and interests of the people who lived there.

4 Declaration of independence
That, therefore, the colonies had a right to throw off the government of the British and rule themselves, and were no longer part of the British Empire.

"WE HOLD THESE TRUTHS TO BE SELF-EVIDENT, THAT ALL MEN ARE CREATED EQUAL, THAT THEY ARE ENDOWED BY THEIR CREATOR WITH CERTAIN UNALIENABLE RIGHTS, THAT AMONG THESE ARE LIFE, LIBERTY AND THE PURSUIT OF HAPPINESS."
DECLARATION OF INDEPENDENCE

Commander-in-chief
George Washington was a tobacco farmer and trained surveyor from Virginia who gained military experience fighting against the French in North America during the Seven Years War. His opposition to Britain’s treatment of its American colonies led to his appointment as commander-in-chief of the rebel American army. Washington turned his men into a professional fighting force. He held them together during tough times and lost battles, and led them to victory. In 1789, he was elected as the first President of the United States of America.

The march to independence
Nearly all of the early battles of the American Revolutionary War ended in a draw. The British forces were too powerful for the Americans to defeat outright, while the colonial forces used local support and knowledge of the land to escape attacks by the British. As the war went on, however, stronger leadership and assistance from foreign allies tipped the balance in favor of the Americans, and the British suffered crushing defeat.

The road to rebellion
After the colonists destroyed shiploads of British tea in Boston harbor, the British tightened their control on the colonies by passing laws to limit their freedoms. It was the final straw, and two years later, the first shots of the Revolutionary War were fired.

Statue of Washington
Washington is often referred to as the father of the nation because of his leadership and influence in the founding of the United States.

The two sides
The American forces relied heavily on militia—local groups who organized themselves into fighting units. The Continental Army was also supported by French and Spanish troops, and some Native Americans. The “redcoats” of the British army were assisted by Loyalists—colonists who wanted to remain part of the British Empire, German mercenaries, and Native Americans, who wanted to protect trading and territory agreements with the British. The British navy controlled the coast, but could not affect the war inland.

Boys as young as 10 fought in the American army, and women served as nurses, cooks, and even spies.

The first battle
British troops marched to Concord, Massachusetts, to raid the colonists’ store of weapons. The colonists sent a force to resist them. Although they were forced to withdraw, the Americans succeeded in blocking the British and protecting their supplies.

Battle of Saratoga
More than 6,000 British soldiers were surrounded and forced to surrender by the Continental Army. This resounding American victory encouraged the French to join the war on the American side, followed by the Spanish and the Dutch.

Valley Forge
With foreign support on the way, the American army sought shelter in a defensive camp at Valley Forge, near Philadelphia. Although safe from British attack, they suffered from harsh conditions and lack of supplies throughout the winter months. An estimated 2,000 men died of disease and starvation.

Victory for the colonists
After several further defeats, the British were forced to retreat to the east coast. As the American army and the French navy closed in, the British were trapped at Yorktown, Virginia, and surrendered. The war was over and the Americans had won.

Peace treaty
After long negotiations, a peace treaty was finally agreed in Paris in September 1783. Britain handed over large areas of territory to the US, and also signed separate treaties with the Americans’ European allies, France, Spain, and the Netherlands.
French Revolution

In 1789, the French monarchy was overthrown in a bloody revolution. The rebels created a government run by the citizens rather than the nobility, but rivalry between its members brought chaos and bloodshed.

At the end of the 18th century, France was nearly bankrupt after a series of costly wars. To make matters worse, a bad harvest in 1788 left much of the population short of food. While the country faced starvation, King Louis XVI and the nobility lived in luxury, and rumors spread that they were hoarding grain that the poor desperately needed. The French people had heard how the Americans overthrew the rule of the British king in 1776, and as the poor grew more dissatisfied, they demanded change. In 1789, a sharp rise in the price of bread caused riots on the streets of Paris, and when the king demanded a rise in taxes that same year, the people took action and the French Revolution began.

The end of the monarchy

The new National Assembly promised to give power to the people, leaving the king as only a figurehead. When rumors spread that the king had ordered the army to close down the new government, the citizens formed a National Guard to fight back. Their first target was the Bastille, a prison where enemies of the old government were held, which they stormed on July 14, 1789. Many of the king’s supporters fled or joined the revolution, and the king himself was imprisoned in the Tuileries Palace in Paris. He tried to regain favor with the people by agreeing to their demands for reform, but remained a hated figure. On August 10, 1792, his palace was stormed by the mob and the king was sent to prison. In 1793, he was found guilty of plotting against the French people and sentenced to death by beheading.

The Bastille

was nearly empty when it was stormed. Only seven prisoners were rescued, but 98 revolutionaries died in the attack.

Timeline

The French Revolution saw France change from a monarchy, ruled by the king, to a Republic, in which power was held by the people, although suspicion and brutality left many living in fear. The end of the Revolution saw the rise of a new emperor.

June 14, 1789

The King of France, Louis XVI, asked the government to approve an increase in taxes. Already angered by a national food shortage and unfair taxes, representatives of the Third Estate (the working people) broke away from the other two Estates. They announced their intention to govern the country themselves, and formed a National Assembly.

July 14, 1789

Rumors spread that the king had called for the army to shut down the new National Assembly. Angry mobs began to riot throughout Paris, bringing chaos to the city. A crowd stormed the Bastille prison, liberating seven inmates. This date came to be known as the beginning of the Revolution, and July 14 is celebrated as a national holiday in France to this day.

October 5, 1789

A crowd of about 7,000 women marched on the royal palace at Versailles, outside Paris, to protest over the shortage of bread. According to later rumor, when she heard the people lacked bread, the French queen, Marie Antoinette, said “Let them eat cake.” This was taken as a symbol of how little the monarchy understood the sufferings of the people.
The number of days in a week in the new revolutionary French calendar. 10

1.6 million—the number of soldiers in Napoleon’s army at its height.

The Terror
After the death of the king in 1793, the National Assembly was headed by a group called the Jacobins, a political club led by Maximilien de Robespierre. They believed that France was full of spies sent by foreign powers who wanted to bring back the monarchy. The Jacobins began to execute anyone they suspected of working against them. Around 40,000 people were killed in Paris alone during this bloody period, known as The Terror, which only ended when Robespierre himself was sent to the guillotine in 1794.

The guillotine
This gruesome machine was used during the French Revolution to execute people as quickly and efficiently as possible.

The Guillotine was nicknamed the “National Razor” and was used to execute up to 20 people a day.

The Napoleonic Wars
After the Revolution, France was left without a strong leader and surrounded by enemies. In 1800, Napoleon Bonaparte (1769–1821), a young general, became a hero to the people after a series of stunning military victories. In 1804, he made himself Emperor of France, and began a campaign of conquest across Europe. From 1805–1807, his armies defeated Austria, Russia, and Prussia until his empire covered most of Europe. He was finally defeated in 1815 at the Battle of Waterloo by an alliance of the nations of Europe.

The ideals of the Revolution
The new Republic of France was influenced by the United States, which had won independence from Britain in 1776. Like the Americans, the French Revolutionaries wrote out a document, the “Declaration of the Rights of Man and the Citizen,” which would underpin the new government. It proclaimed that all men and women are born equal, so kings and nobles have no right to rule over those of common birth, and that people should be allowed to govern themselves by democratic vote. These ideas remain important to theories of democracy and human rights to this day.

Maximilien de Robespierre
French lawyer Maximilien de Robespierre was at the forefront of the Revolution. He believed passionately in equal rights and government by the people. However, he betrayed his own beliefs by deciding the only way for the Revolution to succeed was by the deaths of those who opposed it. Tens of thousands of so-called “enemies of the Revolution” were executed on the orders of Robespierre and his allies.

French infantryman’s uniform
Napoleon’s soldiers were the most feared in Europe. They were superbly trained and operated in tight formations. Their uniform consisted of white breeches, dark blue jacket, and a hat, or shako, decorated with a red plume. Each man was armed with a large, heavy gun called a musket.

June 25, 1791
The king and queen attempted to flee the country in disguise. They were spotted and taken back to Paris, where they were held under guard in the Tuileries Palace. They were moved to prison in 1792 and, in 1793, they were executed by guillotine after being accused of helping Austria, the queen’s homeland, which was at war with Revolutionary France.

1792–1801
France’s neighbors were outraged by the overthrow and death of King Louis. They also hoped to gain control of French lands in the confusion of the Revolution. Wars broke out between France and other European countries such as Austria, Italy, and Britain, and in French overseas territories such as Haiti. The French armies emerged victorious.

Spring 1793
A Committee of Public Safety was founded by Maximilien de Robespierre to fight back against agents of the old government, thought to be secretly undermining the Revolution. The Committee ran out of control, accusing many innocent people of betraying the Republic. As many as 40,000 people were executed during this Reign of Terror.

December 2, 1804
Napoleon Bonaparte proclaimed himself Emperor of France and was crowned in Paris. A military genius, he had become enormously popular among the French people after winning a stunning series of victories during the wars of 1792–1801. After his coronation, Napoleon’s armies begin a war of conquest across Europe, winning great success at first.
The Industrial Revolution

Between 1760 and 1860, an age-old way of life based on farming and crafting by hand was transformed, as people moved to towns and goods were produced by machines in factories.

This transformation began in Britain, where ingenious inventors and engineers applied new scientific ideas to the old methods of farming, mining, and manufacturing. Britain also had a ready supply of raw materials, such as coal and iron ore, to power the new inventions, and a rapidly growing population eager to work in the factories and buy the new goods they produced. The Industrial Revolution transformed our way of life, bringing incredible wealth to some, but crushing poverty to many others.

New machines
The backbone of the Industrial Revolution came from new machines. Cotton making, for example, had been a lengthy process involving hours of hard work. Inventions such as the Spinning Jenny (1764), and the Spinning Mule (1779) could do the work automatically in a fraction of the time. At first, these bulky machines were powered by water wheels, and so were built-in factories next to rivers. The first water-powered cotton mill was built by entrepreneur Richard Arkwright in 1771 in Derbyshire, England. Over time, water wheels were replaced by steam engines, and factories moved into towns.

Water-powered cotton mill
Cotton is made by combing out fluffy fibers and spinning them into thread. Before the Industrial Revolution, this was done by workers in their own homes. Cotton mills could process much larger amounts of cotton far more quickly.

Reeling and winding
These machines wind the cotton on to tapered rods called bobbins.

Carding machines
These machines comb and untangle the raw cotton to separate out the fibers.

Water frames
Water-driven spinning frames are used to spin the cotton into thread.

Faster travel
Industrial factories depended on being able to bring in large quantities of raw materials (such as coal and cotton fiber) and send out large quantities of finished products. The old methods of transportation—such as wagon trains and sailing ships—could not move materials quickly enough or in large enough amounts. Industrial countries built huge networks of canals, where barges carrying up to 33 tons were pulled along by horses. Rail networks and steam engines allowed people and goods to travel quickly over long distances. Steam ships made ocean journeys far quicker and more reliable.

Steam locomotives
The railway became one of the greatest symbols of the Industrial Revolution. From around 1840, the US led the world in producing fast, reliable steam locomotives, such as this one built in 1863 by the Baltimore and Ohio Railroad.
Poverty in towns
Industrial progress brought great wealth to factory owners and entrepreneurs, and made basic goods such as food and clothing cheaper than ever before. However, it also created a new kind of poverty. Large numbers of people moved to the cities in search of work, where they were packed into crowded, dirty housing. Many were unemployed and ended up in prison for debt, or forced to move into harsh lodgings called workhouses, where they performed hard labor for no pay. Those who did have jobs worked in unsafe conditions. They were often paid poorly, and many families struggled to afford basic essentials.

Rise of the machines
The changes brought by industry quickly gathered momentum across Europe and North America. New factories created cheap goods and jobs for poor laborers. At the same time, mechanized farming left many rural workers unemployed, and forced them to move to cities to work in factories. With so many people looking for work, factory owners offered low wages, which meant laborers looked for even cheaper goods. Scientists and entrepreneurs used their profits to build new machines and factories, bringing prices down and creating more jobs.

Science
New discoveries give scientists ideas about better ways to do things. They develop new technologies such as steam power and cheap steel.

Invention
Engineers and inventors experiment with new scientific ideas, using them to develop machines that make farming and manufacturing easier.

Mechanization
Business owners invest money in the new inventions. Farms and workshops use machines instead of human workers, and factories are built.

Demand for low prices
Poor workers need food and goods to be cheap. This encourages business owners to build more factories and find cheaper ways of working.

Lower wages
In crowded cities, many people compete for jobs. Business owners pay low wages, since it is hard for their employees to find work elsewhere.

Migration to cities
Machines replace many jobs on farms. At the same time, new factories create jobs in cities. Laborers move from the country into cities to find work.

An island of ideas
The many inventions of the 18th century were made possible by scientists and engineers, funded by rich entrepreneurs. Together they developed new machines, such as the steam engine, new ways of working, such as factory mass production, and new industrial processes, such as the Bessemer process for producing steel.

Farming with machines
A growing population called for more food and more efficient ways to grow it. In 1701, English inventor Jethro Tull created a seed drill that automatically sowed crops. Steam-powered plows appeared in the 1820s, and the American engineer Cyrus McCormick designed a mechanical harvester in 1831.

The first factories
Richard Arkwright built the first water-powered mill in Derbyshire, England. Fast-flowing water created enough power to run his spinning machines. This allowed cotton to be mass-produced, since more thread could be made much faster. Arkwright became a pioneer of modern factories.

Watt’s steam engine
Inventors across the world had experimented with using steam to power machinery for hundreds of years, with little success. In 1776, Scottish inventor James Watt built a much more efficient engine, which could provide an up-down movement for pumping and a circular movement for operating machines.

Bridges of iron
The era of modern bridge-building started in 1779 with the construction of the Ironbridge in Shropshire, England, the first bridge to be made entirely of solid cast iron. With stronger bridges and better-quality iron and steel, bridges could be built over longer distances, opening up new routes for roads and railways.

Gas lighting
Gas from coal mines was burned in lamps to provide lighting in streets and homes. It was pumped through a network of pipes across major cities. The large-scale introduction of gas lighting in the 1790s was the work of William Murdoch, a Scottish engineer who also built steam engines. Gas lighting was brighter and more reliable than candles and oil lamps, allowing factories to remain open all night.

Brunel and the railways
Isambard Kingdom Brunel was a bridge and railway engineer who oversaw the creation of much of Britain’s rail network. At age 27 he became engineer to the Great Western Railway, where he constructed over 1,000 miles (1,600 km) of track. He was famous for his innovative designs for bridges, viaducts, and tunnels.

The steel revolution
In 1855, an Englishman named Henry Bessemer discovered a new, cheap way of making steel, using a machine called a “Bessemer converter” to burn impurities out of iron. Steel was essential for building railways, machinery, factories, and vehicles. By making it cheap and widely available, Bessemer’s new process opened the way for a huge increase in the rate of industrialization.
How a steam engine works

The engine is powered by heat from coal burning in the firebox. Hot air from the fire passes along copper pipes through a water tank or boiler. This heats the water to boiling point, producing steam. The steam expands as it is heated, creating pressure inside the boiler.

1. **Piston moves down**
   - An opening at the top of the boiler allows steam into sealed tubes called cylinders, one for each wheel. The pressure from the steam pushes down a piston inside the cylinder, which moves a control rod to turn the wheel. The turning of the wheel moves a valve inside the cylinder that controls the flow of steam.

2. **Piston moves up**
   - When the piston reaches the bottom, the valve inside the cylinder switches the flow of steam from the top to the bottom of the cylinder. The steam now pushes the piston up, pulling on the wheel control rod to turn the wheel back to where it started. Steam and smoke from the firebox escape through the chimney.

Water barrel

Water from this barrel kept the boiler topped off. The driver controlled the flow of water through pipes from the barrel to the boiler.

Tender (supply cart)

The engine required a constant supply of coal and water, kept on a cart pulled behind.

Stephenson's Rocket

The first steam locomotives were unreliable and very heavy. In 1829, a competition was held to design an engine to run on the newly built Liverpool to Manchester Railway. The winner was the Rocket, built by Robert Stephenson and his father, George.

The Age of Steam

For thousands of years, humans had relied on animal and people power to move heavy loads and drive machinery. This all changed in the late 18th century with the arrival of a bold new invention: the steam engine.

Steam engines operate by burning fuel to heat water until it boils. Hot steam from the boiling water is trapped to create pressure, which is used to drive machinery. This simple principle opened the way to powerful new engines. Steam engines were more flexible than windmills or waterwheels, which had to be built in specific places, and more powerful than humans or animals. They could drive factory and farm equipment, and pull plows across fields or trains along tracks. Larger models pumped vast amounts of water to drain mines and supply canal systems, and hauled blocks of stone and ore from quarries and mines. They were the driving force behind many of the innovations of the Industrial Revolution.
Inside the engine

Early steam engines used a single large cylinder to power all the wheels at once. The Rocket had two angled cylinders, each connected directly to a single wheel with a control rod. This and other innovations, such as the blast pipe and a boiler with multiple tubes for hot air, made the Rocket faster and more efficient than any steam engine built before.

Safety valve
This valve would allow steam to escape if the pressure rose too high, preventing explosions.

Control valves
These levers allowed the driver to control the flow of water and steam through the engine.

Steam dome
Steam from the boiler collected under this dome and was funneled into pipes leading to the cylinders.

Boiler
Water in this tank was heated by pipes, which ran through it carrying hot air from the furnace.

Control rod
This rod transferred the in-out movement of the piston to the circular movement of the wheels.

Wooden wheels with steel rims

George Stephenson
Stephenson himself controlled the Rocket on its first demonstration.

Firebox
Inside the engine

Stoker
Coal

Cylinder
This sealed tube captured steam from the boiler and used it to push a piston, driving the wheels.

Piston

Smokestack (chimney)
A blast pipe sucked air up through the chimney. The air was drawn in through the firebox, fanning the flames.

Cylindrical boiler

4.7 tons—the weight of the Rocket steam locomotive.

27 mph (47 kph)—the Rocket's top speed.

75 miles (120 km)—the distance the Rocket traveled on its first day of trials.

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The course of the war

The war pitted 23 Union states of the North and West against 11 Confederate states of the South. The North had superior numbers, wealth, and weaponry, and despite some brilliant military successes, the South was eventually forced to surrender.

1. **April 12, 1861**
   Tensions between the North and South were running high. The war began when the Confederate army shot at Union soldiers stationed at Fort Sumter, South Carolina, and forced them to lower the American flag in surrender.

2. **July 21, 1861**
   The Confederates won their first battle near a small stream in Virginia called Bull Run. The Union answered by blockading the ports and borders of southern states, trying to wreck their economy.

3. **September 16-18, 1862**
   The Battle of Antietam, one of the bloodiest of the war, left 23,000 soldiers dead, wounded, or missing. The Confederates were beaten back in a turning point of the war.

4. **May 18-July 4, 1863**
   The city of Vicksburg beside the Mississippi River, held by the Confederates, was taken by Union troops. Control of the Mississippi was vital, since the South was using it to transport food and soldiers.

5. **July 1-3, 1863**
   In Gettysburg, Pennsylvania, the Union won the largest battle of the war after three days of fighting. Confederate leader General Lee lost 20,000 men, who were killed or wounded.

6. **April 9, 1865**
   With his troops surrounded, General Lee surrendered to General Ulysses S. Grant in a house in the village of Appomattox, Virginia.

Abraham Lincoln

The 16th president of the United States, Abraham Lincoln was a brilliant orator. He was determined to keep the states of America together at all costs. After the war, he hoped to heal the divide between North and South, but was killed by a supporter of the South while at the theater in 1865.

“GOVERNMENT OF THE PEOPLE, BY THE PEOPLE, SHALL NOT PERISH FROM THE EARTH.”
ABRAHAM LINCOLN, SPEECH TO UNION FORCES AT GETTYSBURG, 1863

The Confederacy

Eleven Southern states broke away from the Union to form the Confederacy: North Carolina, South Carolina, Georgia, Alabama, Mississippi, Louisiana, Florida, Texas, Tennessee, Arkansas, and Virginia. They fought for states' rights and the right to own slaves. The Confederates had their own capital in Richmond, Virginia, and their own currency, flag (see left), and president—Jefferson Davis.

A nation divided

Battles were fought across America, but most of the fighting occurred in the states of Virginia and Tennessee, and along the border states—slave states that did not declare independence. Much of the conflict was near the Confederacy’s capital, Richmond, Virginia, and the Union capital in Washington, DC.
The number of Americans killed in the Civil War is nearly equal to the number who died in every other foreign war fought by the US since.

The election of Abraham Lincoln as president in 1860 tore the US in half, and the Civil War broke out between the North and South over the rights of individual states and the issue of slavery.

The US had been one country made up of many states, but in the mid-19th century it became a divided nation. The northern states, made strong by industry and immigrants from Europe, had little sympathy for the old-fashioned farm culture of the South, which depended on slavery. The people of the South suspected that the North was seeking to destroy their way of life. When Abraham Lincoln became president, 11 Southern states feared he would abolish slavery and left the Union. The war that followed divided families and friends. More than 620,000 soldiers died, and even though the country was finally reunited, bitterness remained for decades.
World War I

Half a century of power struggles, in which Germany and Austria-Hungary were set against France and Russia, ended with four years of bloody conflict that involved nearly every country in the world.

The war that followed was fought mainly in Europe, but fighting also spread to the Middle East, Africa, and Asia. Nations took part in bombing raids and chemical warfare, as well as experimenting with tanks, military aircraft, and submarines. However, most of the war was fought using ordinary artillery, machine guns, rifles, and horses. What was different about this war was the vast numbers of those involved: soldiers fought and died in the millions, and entire populations were expected to help make weapons and support the war.

Causes of the war
On June 28, 1914, the Archduke of Austria-Hungary was shot by a nationalist from Serbia in the Balkans. Austria-Hungary blamed Serbia for the killing and declared war. Russia offered to support Serbia. Germany declared war on Russia, then on France. Country after country rushed to defend their allies or declare war on their rivals until armies were on the move across the world. Most people believed the war would be over very quickly, but they were tragically mistaken.

RIVALRY
Tensions rose as giant European empires with colonies all across the world competed for power by trying to control trade and gain more land.

ARMS RACE
European powers raced to build the largest armies and most powerful warships, setting the scene for war on a scale never seen before.

TWO SIDES
Neighboring countries sought alliances for protection against their rivals, so that when war started all the major powers were soon dragged in.

TENSIONS
Southeast Europe (the Balkans) fought for independence from the Ottoman Empire. Violence in this region heightened tensions across Europe.

Road to war
In the early 1900s, powerful European nations competed for trade and land, and built up large armies. Nations made agreements to support one another (alliances), but these were often fragile. Two groups of countries on opposite sides emerged: the Central Powers and the Triple Entente (Allies).

Europe at war
World War I was fought largely in Europe between the Central Powers—Germany, Austria-Hungary, and Turkey—and the Allies—Britain, France, Italy, Russia, Japan, and later the United States.

Course of the war
For four long years bloody battles were fought. The Western Front, running across eastern France, saw some of the heaviest fighting. Until 1917, Germany and the Central Powers seemed to be winning, but that changed when the US came to fight for the Allies.

The fronts
The areas, or fronts, in which the war was fought went right across Europe. The two main zones, or theaters, of war were the Western Front and the Eastern Front. The Western Front stretched from the North Sea to the Swiss border and was made up of a continuous line of trenches. The Eastern Front, on the other side of Europe, saw the great armies of Germany and Austria-Hungary battle against Russia.

The war at home
World War I was the first “total” war, meaning not just soldiers but the whole civilian population were involved. The entire nation was expected to help keep the war effort going, by helping on the “Home Front.” Civilians only received fixed rations of food to make sure enough could be sent out to the troops, and women took over many of the jobs of men sent to fight. Bombing raids on German, French, and some British cities brought the war into ordinary homes.

Everyone must play their part
This Russian poster reads: “All for the war.” In wartime, women took men’s places on farms, in factories, and in offices. Every man was expected to fight: military leader Lord Kitchener (far right) calls on British men to join the army.

The number of enemy planes shot down by the German Red Baron fighter pilot.
On Christmas Day 1914, British and German soldiers on the Western Front stopped fighting to exchange gifts, sing carols, and even play soccer.

**600** The number of rounds that a World War I machine gun could fire in one minute.

**A new kind of warfare**
At the start of the war, armies on both sides were still using outdated tactics, such as cavalry and bayonet charges. However, with deadly weapons like machine guns widely available, these old tactics failed, resulting in huge numbers of deaths. By the end of the war, both sides had developed new strategies, as well as new weaponry, such as aircraft. Both sides used poison gas to kill off enemy soldiers. Horses, shown to be unsuited to the modern battlefield, were replaced by the first tanks.

**The cost of the war**
There had never before been a human conflict on this scale, and with it came huge cost to human life. More than half of the 65 million men who fought across the world were killed or wounded, and many died of disease. More than six million ordinary citizens died, from illness or starvation. Europe was left in ruins, and its systems of government, and the way people worked and lived, changed forever.

**Military deaths**
It is estimated that 15 million people died in World War I. Most of them were soldiers, especially in the armies of Russia and Germany.

**Poison gas**
At first there was no protection against poison gas, but by the middle of the war both sides carried gas masks. Around 30 types of gas were used, causing more than 1.2 million casualties.

**The number of soldiers that perished each hour throughout the four-and-a-quarter years of the war.**

**Key**
- 1 million soldiers killed
- 2 million soldiers killed

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**Russian revolution**
A communist revolution swept across Russia in 1917, overthrowing the Tsar (emperor). Russian soldiers continued to fight until March 1918.

**Eastern Front**
Russia fought against Germany and Austria-Hungary all across Eastern Europe.

**Balkan front**
Serbia fought against Germany, Austria-Hungary, and Bulgaria.

**Arab revolt**
The Arabs of North Africa and the Middle East rose up against the Ottoman Turks who ruled the region.

**Verdun**
Continuous fighting across the trenches produced a stalemate on the Western Front. Trying to break the deadlock, Germany launched an attack on the French fortifications at Verdun. After months of brutal fighting, the exhausted French army forced the Germans to retreat.

**Somme**
The British and French, after little progress for two years, began the Big Push—a large-scale attack to break through German lines at the Somme in France. Thousands were mown down by German machine guns. More than 600,000 Allied troops were killed or wounded, for little gain.

**Hundred Days Offensive**
Provoked by German submarine attacks on American ships, the US entered the war in 1917. In 1918, American, British, and French soldiers mounted a series of successful attacks, known as the Hundred Days Offensive, forcing the Central Powers to surrender.

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**1915-16**

**Gallipoli**
British Empire forces, including many troops from Australia and New Zealand, launched an attack on the Ottoman Empire at Gallipoli, on the west coast of Turkey. They landed in April 1915, but suffered heavy casualties and were forced to withdraw.

**1916**

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Trench warfare

Soldiers on both sides in World War I faced a lethal bombardment of bullets, shells, and poison gas. They lived and fought in deep trenches stretching great distances across the battlefields.

Both sides suffered horrific losses in the first few months of the war, as armies of massed infantry charged toward deadly machine guns. It became clear that neither side could break through the other’s defenses. Instead they dug down into long lines of fortified trenches, which stretched all across Europe. The war became a stalemate that lasted for years, with soldiers camped in lines of trenches, facing each other across a strip of no man’s land.

New weapons
World War I saw some of the highest rates of death and injury to frontline soldiers of any war in history. This was partly due to the development of powerful new weapons such as machine guns and high-explosive artillery shells, which could cause mass casualties in a very short space of time.

Artillery
The largest guns could bombard trench positions from miles away. A direct hit from an artillery shell would create a large crater, and could kill a dozen men in an instant.

Life in the trenches
The trenches were a harsh place to live. In winter they filled with mud and ice, and they were infested with huge rats all year round. The soldiers were often cold and wet, hungry and exhausted, and to make matters worse, they knew an attack could come any moment.

Deadly enemies
Life in the trenches was extremely dangerous. Around 9.7 million soldiers were killed in combat, and many more were horribly wounded under a nearly constant barrage of bullets, shells, and poison gas.

What a bloodbath, what horrid images, what slaughter…
Hell cannot be this dreadful.”
Albert Joubaire, a French soldier at Verdun in 1916

Gas warfare
Both sides used poison gas as a weapon, and gas masks were essential.

Shell explosion
Artillery shells could be loaded with explosives, poison gas, or pieces of metal called shrapnel.

No man’s land
The land between the trenches was a sea of mud blasted by artillery shells. The bodies of dead soldiers often lay here for days because it was too dangerous to retrieve them.

Underground war
As well as attacking above ground, both sides tried to tunnel into enemy trenches, to place explosives. Fierce battles were fought when enemy diggers met underground.
Firing bay
The bottom of the trench was dug to be deep enough that soldiers could walk along it without being exposed to enemy fire. Steps enabled soldiers to see out over no man's land, and snipers to fire on the enemy.

Reconnaissance
During quiet times, small groups might be sent into no man's land to spy on enemy movement.

Shell hole
Craters left by shell explosions filled with rainwater and mud, and could drown the unwary.

Firing bay
Soldiers standing here could look and fire out over no man's land. They had to beware of gunfire from enemy snipers.

Pillbox
Concrete boxes were built to shelter machine guns and lookout posts.

Latrines
Under constant threat from enemy fire, even toilets and washrooms had to be built in trenches.

Soldiers' shelter

Officers' dugout
Special rooms for officers were dug below ground.
World War II

In September 1939, Germany, led by brutal dictator Adolf Hitler, stormed into Poland. This was the beginning of World War II. Lasting six long years, it was the deadliest conflict in history.

World War I was supposed to be “the war to end all wars,” but defeated countries believed they had been treated badly by harsh peace terms. In the 1930s, a catastrophic global recession broke out, which left many people poor and destitute. Disillusioned, they began to turn to new, forceful leaders for solutions.

In Germany, the Nazi Party rose to power under Adolf Hitler. He launched mass invasions west into Europe and east into the USSR in search of more “living space” for the German people. At the same time, the Japanese fought to take control of Asia and the Pacific Ocean. The battle to defeat Germany, Japan, and their allies would spread across the globe, and cost the lives of millions.

Codes, spies, and propaganda

World War II was one of the first wars fought with modern technology and electronics. Both sides became very good at spying, and they used codes to pass on secret information. Spies and double agents did their best to outwit the enemy. In their own countries, they used posters, movies, and radio broadcasts to spread propaganda—powerful messages designed to stir national pride, loyalty, and hatred of the enemy.

Enigma

The Enigma machine was a German device used to send coded messages. It could only be read by another Enigma machine. The British cracked the codes in 1941 using an early form of computer.

Rotator cylinder

Letters are coded by a set of rotating wheels. They can only be decoded using the same settings.

Keyboard

When a letter is pressed, it sends an electrical signal to the rotator for coding.

Plugboard

The plugboard hugely increases the number of coding combinations.

Rise of Fascism

Fascism, a new form of nationalism, rose out of the ashes of World War I. As people struggled with mass unemployment and poverty, they were drawn to strong leaders such as Benito Mussolini (Italy) and Francisco Franco (Spain) who promised national unity and prosperity. In Germany, Adolf Hitler declared himself Führer (leader) and led the country to war.

Theaters of war

Battles raged on land, sea, and in the air across Western Europe, the Eastern Front, the Mediterranean, North Africa, and the Pacific and Atlantic oceans. Few nations remained neutral, supporting either the Allies (Britain, France, the US, and Russia) or the Axis (Germany, Italy, and Japan).

United States of America

Neutral at the start of the war, the US helped the Allies with loans of money and materials. A surprise attack by Japan brought the US into the war in 1941.

Key

- Allied nations
- Axis nations
- Countries conquered by the Axis

Battle of the Atlantic

The Allies needed to keep shipping lanes open, so essential supplies from the US could reach Britain and the USSR. German U-boats (submarines) sank many convoys, but the Allies eventually defeated the German navy.

North Africa

The Axis and the Allies fought in North Africa from 1940 to 1943. British General Bernard Montgomery defeated German Field Marshal Erwin Rommel in tank battles across the desert.
The Pacific theater of war included Japan, China, and Korea, and many small islands in Southeast Asia. The Japanese won early victories, but their advance was halted by the US Navy at the Battle of Midway in 1942.

The Holocaust
Adolf Hitler was convinced that the German people were the “master race” and that other people, such as Jews, were inferior. Under German occupation, Jews were herded into ghettos where many starved to death. In 1942, Hitler instigated the Final Solution—the murder of all Jews. He set up concentration camps where “inferior” people such as Jews, homosexuals, gypsies, and Soviet prisoners of war were gassed to death in one of the most horrific campaigns in human history.

“I STILL BELIEVE, IN SPITE OF EVERYTHING, THAT PEOPLE ARE TRULY GOOD AT HEART.”
ANNE FRANK, JEWISH VICTIM OF THE HOLOCAUST

The yellow star
Jews were forced to wear this yellow badge to identify them as Jewish. It became a symbol of Nazi persecution.

The course of the war
Hitler’s forces quickly conquered large areas of Europe. He then attacked his former allies, the USSR, but was halted by fierce resistance. When the US joined the Allies in 1941, the tide began to turn. German forces were pushed back, and the Japanese were defeated in brutal fighting across Asia and the Pacific.

German invasion of Europe
Hitler’s lightning invasion swiftly conquered Poland. The following year, German troops took Denmark, Norway, Belgium, the Netherlands, and most of France. The British were forced to evacuate 340,000 Allied troops at Dunkirk, France, in May 1940.

Battle of Britain
During the Battle of Britain, German and British aircraft fought for control of the skies. Germany’s defeat prevented a land invasion of Britain, but bombers began deadly air raids on British cities.

Operation Barbarossa
The Germans turned on their former allies, the USSR, reaching Moscow and Leningrad. But they were driven back by Soviet counterattacks and the harsh winter. Both sides suffered huge losses, and the Germans suffered their first defeat of the war.

Pearl Harbor
Japan, Germany’s allies, mounted a surprise attack on American ships at Pearl Harbor, Hawaii, bringing the USA into the war. In June 1942, the US fleet defeated the Japanese Navy at the Battle of Midway in the Pacific Ocean, halting the Japanese advance.

El Alamein
The Allies won a major victory when the British drove the Germans out of Egypt at the Battle of El Alamein.

Stalingrad
The focus of the war on the Eastern Front, the brutal Battle of Stalingrad, USSR, involved unimaginable hardship as two armies fought for control of the city. The Soviet Red Army destroyed superior German forces, and soon began to march on Germany.

D-Day
After two years of planning, the Allies invaded Europe in Operation Overlord. To liberate France, 4,000 landing craft, 600 warships, and thousands of Allied aircraft hit five beaches in Normandy. Germany was forced to surrender just 11 months later.

Hiroshima
In the last act of the war, the Americans used a new weapon, the atomic bomb, to force the Japanese to surrender. They dropped bombs on the cities of Hiroshima and Nagasaki. The two explosions killed more than 300,000 people.
Modern warfare

World War II was the most destructive conflict in history, since modern technology created new and deadly weapons. The war saw the introduction of guided missiles, mass tank battles, jet engines, atomic weapons, and powerful bomber planes.

Hitler’s armies planned to shock the Allies into surrender using surprise bomb attacks and rapid tank invasions—a strategy he called Blitzkrieg (lightning warfare). As the war went on, both sides built tanks, planes, and ships in huge numbers, and these weapons caused mass casualties and pulverized vast areas of land. Toward the end of the war, fleets of bombers numbering more than 1,000 pummeled cities for days and nights on end.

During World War II, both sides used bombers to attack enemy cities: to destroy factories and damage enemy morale. German planes pounded British cities in 1940–41 in a series of attacks called the Blitz, while Allied aircraft leveled German cities such as Dresden in 1945.

Bomber plane

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2.9 million tons—the total weight of bombs dropped by the Allies on Europe.
Mechanized warfare

In World War II, mechanized warfare came of age. Hitler’s Blitzkrieg proved that speed and mobility were crucial. Armies of tanks were supported by airpower and artillery. Vehicles transported troops and weapons quickly to the front line. Submarines disrupted supplies, and aircraft carriers became a prime offensive weapon. Engineers worked furiously to design machines that were faster, lighter, and deadlier.

**Soviet T34 tank**
This speedy, versatile tank was key to the Soviet defeat of the German invasion.

**British Spitfire fighter plane**
British Spitfires defeated the German airforce, preventing an invasion.

**USS Yorktown class aircraft carrier**
These great ships allowed planes to operate across the Pacific Ocean.

**German U-boat**
U-boats sank hundreds of ships carrying supplies from the US to its allies.

**German V-2 rocket**
This long-range rocket flew on its own power to explode in enemy cities.

**B-17 bomber**
The American Boeing B-17 was the first mass-produced, four-engine heavy bomber. Designed for long-range, high-altitude flight, it flew 294,875 missions to targets all over Europe, and dropped 716,800 tons of bombs, mostly on German factories.
A world divided
The Cold War saw two superpowers face off, backed by global alliances. The communist nations (marked in red), led by the USSR, were opposed by NATO (marked in blue), an alliance led by the US, and other allied countries around the world.

The Cuban Missile Crisis
The island of Cuba was a communist state and an ally of the USSR. In 1962, the Soviets began to build missile launch sites in Cuba, within striking distance of major US cities. The Americans demanded the missiles be removed. Military conflict seemed inevitable, but at the last minute, the Soviets withdrew.

The Space Race
Both sides raced to send people into space. The Soviets took the first victory when Russian pilot Yuri Gagarin orbited the Earth in 1961. But the Americans won the race when, in 1969, the crew of spacecraft Apollo 11 became the first human beings to walk on the Moon.

Global conflict
The battle between NATO and the USSR spread across the world. An “Iron Curtain” divided Europe between communist east and democratic west. Violent struggles broke out in Africa, Latin America, and Asia. In the end it was economic more than military force that brought the war to an end.

“FROM EACH ACCORDING TO HIS ABILITY, TO EACH ACCORDING TO HIS NEEDS.”
COMMUNIST MOTTO
The Cold War

After World War II, the world was divided between two immensely powerful rivals: the communist USSR and the democratic US. Bitter enemies, these two superpowers faced off, backed by massive arsenals of nuclear weapons.

The people of the USSR (the Soviets) believed in communism, a system that shares all wealth equally. However, their government was often corrupt and oppressive. The US was a capitalist democracy, and its people enjoyed much greater freedom than those in communist countries. Both sides had vast stores of nuclear weaponry, enough to wipe each other out if they ever went to war. This threat of “mutually assured destruction” forced them to fight by other means, using spies and economic warfare to weaken the other’s position. Most of their battles were fought in smaller countries such as Vietnam and Nicaragua, with the USSR trying to spread communism and the US fighting to prevent them from succeeding.
The 1960s

Filled with political revolutions, struggles for independence, and teenage rebellion, the 1960s was a decade of change, in which old values and traditions were challenged by a new generation.

In Europe and the USA, the 1960s were a time of social change. A new generation, growing up after the horrors of World War II, looked forward with optimism and the belief they could change the world. They rejected their parents’ values and challenged all forms of authority, embracing outrageous new styles of fashion, psychedelic art, and politically motivated music. At the same time, protest movements called for peace across the world, for the end to racial discrimination, and for equal rights for women.

The 1960s also saw wars in Vietnam, Nigeria, and Cyprus, and between Arabs and Israelis in the Middle East. Mao’s Cultural Revolution turned Chinese society upside down. African countries achieved independence from their old colonial rulers, some becoming bright new democracies, while others slipped into civil war. Despite the turmoil, the decade ended with an astounding triumph for human science, technology, and bravery, when the first people set foot on the Moon.

Peace and love

Many people were shocked by the violence they saw on their new television screens, especially in news reports from the Vietnam War. Influenced by Eastern philosophies such as Hinduism and Buddhism, they formed protest movements calling for violence to be rejected in favor of peace and universal love. The Campaign for Nuclear Disarmament (CND) called for both sides in the Cold War to abandon nuclear weapons. The hippie movement, born in San Francisco, CA, called for a laid-back lifestyle promoting peace, love, and understanding.

War and peace

Despite numerous protests for peace, the 1960s became increasingly violent. Tensions grew between the US and the USSR, in a Cold War between East and West, and both sides built up massive arsenals of nuclear weapons. However, the 1960s also saw huge strides in the quest for equal rights. Discrimination against black people was outlawed in the US, and women gained greater control over their lives and choices.

Campaign for civil rights

At the beginning of the decade, many Southern states encouraged separation between white and black people (or segregation). In February 1960, four black students in South Carolina protested by sitting down at a “whites-only” lunch counter and refusing to leave. Their example sparked similar protests across segregated states.

Death of a president

President John F. Kennedy was shot and killed as he drove through the streets of Dallas, Texas. His murder shocked not just America, but the entire world, coming at a time of uncertainty and tension between Russia and the United States.

The first man in space

On April 12 1961, the Russian Yuri Gagarin became the first person to journey to outer space. His spaceship, the Vostok I, just large enough for one person, made a single orbit of the Earth. His flight lasted a total of 108 minutes from launch to landing.


Independence across Africa

Up to World War II, much of Africa was ruled by European empires. These empires were greatly weakened by the war, and in 1960, 17 African countries gained independence, including Nigeria, Chad, Somalia, and Madagascar. The process of decolonization (giving power back to local people) would continue for many years.

Martin Luther King

The campaign for civil rights in the US was led by Dr. Martin Luther King, Jr. In August 1963, he gave a powerful speech to a crowd of campaigners in Washington, DC, calling for an end to racism. He was murdered five years later, but new laws in 1964 and 1965 banned racial discrimination.

The British invasion

Pop music became a powerful cultural force. British bands such as The Beatles and The Rolling Stones became world famous, storming the American charts in 1964.
The number of troops that entered Czechoslovakia during the Prague Spring.

The number of people who attended the Woodstock Festival.

Volkswagen camper van
An icon of 1960s counterculture, these vans were perfect for people who wanted to drop out of mainstream society, travel the world, and try new things.

New art and fashion
Many parts of Europe and the US became very wealthy in the 1960s. Teenagers suddenly had buying power, and their shopping habits created new cultural trends. Artists such as Andy Warhol created Pop Art, using images from advertising, comic books, and movies. Young people didn’t have to dress like their parents anymore, and fashion was transformed by designers such as Mary Quant. Carnaby Street in London became the center of this creative energy. In France, a New Wave of directors experimented with films focusing on realistic situations and the important social issues of the day.

“The young today are less materialistic and more intelligent than they’ve ever been.”
Mary Quant, designer of the miniskirt, 1967

Fashion revolution
The miniskirt, by Mary Quant, is an icon of 1960s fashion. The older generation thought it was vulgar and indecent. The younger generation adored it. The new designs made models such as Twiggy (Lesley Hornby) overnight celebrities.

Vietnam War
In the bloodiest conflict of the Cold War, the US army supported South Vietnam against communist North Vietnam, who were allied with the USSR and China. The war was a disaster for the US, who were forced to withdraw after years of brutal fighting.

China’s Cultural Revolution
Communist China was led by Mao Zedong. He was loved by farmers and workers, but he suspected the educated middle class of trying to undermine him. In 1966, to strengthen his hold on power, he called for a Cultural Revolution to rebuild Chinese society. Schools and colleges were closed down. Millions of young people were taken out of education and sent to work on farms. Scientists, teachers, scholars, writers, and business managers were beaten and humiliated by mobs in the streets. The turbulence continued until Mao’s death in 1976.

Equality in Australia
The indigenous people of Australia—the Aborigines—campaigned for equality throughout the 1960s. Their lands had been taken by white settlers, they were denied access to education and healthcare, and many were not permitted to vote. In 1967, Australia finally granted citizenship to Aborigines, but the struggle for equality continued for many years.

Woodstock
The Woodstock Music and Art Fair was held in August 1969 on farmland near Bethel, NY. It summed up the youthful optimism of the decade as hundreds of thousands came to watch their heroes perform live. The festival featured performances by the decade’s greatest musicians, such as Joan Baez, Janis Joplin, and Jimi Hendrix.

1965
1966
1967
1968
1969

The Six Day War
Israel had long been in dispute with its Arab neighbors. In 1967, fearing an attack led by Egypt, Israel struck first, capturing large areas of land in Egypt and Palestine in a war lasting just six days.

Prague Spring
Czechoslovakia had lived under communist rule since 1948, with the Czech government strongly influenced by the Soviet Union. In 1968, Czech leader Alexander Dubček tried to give the people new freedoms. The Soviets would not allow this and sent tanks into Prague, the Czech capital. Despite protests by the people of Prague, Dubček was removed from power and communist rule continued.

Moon landings
The 21st century

At the end of the 20th century, the world got ready to party. Huge celebrations took place across the globe to greet the year 2000, the start of the new millennium. The new century brought grave new challenges, but also amazing opportunities.

With the world’s population expanding, humanity’s demands on the planet are growing rapidly. As the 21st century goes on, scientists have become increasingly concerned that we may run out of some natural resources, and that human activity is causing dangerous changes to our environment. Many countries have also had to contend with devastating natural disasters. Terrorist attacks brought fear and conflict to many cities, and a global financial collapse increased the hardship for millions.

At the same time, the 21st century has seen astonishing new advances in technology. Smartphones and tablets have transformed the way we communicate, and the Internet has expanded hugely to give voices to users across the globe.

Digital revolution

The digital revolution began in the 1980s, when computers became cheap enough for people to buy and use at home. At first computers were big metal boxes, but today they are hidden in everyday objects, such as smartphones, tablets, MP3 players, and cameras. The Internet is rapidly evolving to play a central role in society, transforming cultural, economic, and political landscapes. There are thought to be more than 2 billion Internet users worldwide, all of whom can exchange information in an instant.

The War on Terror

In 2001, a group of Islamist terrorists named al-Qaeda launched a series of attacks on targets in the US. A decade of conflict followed. The US and its allies launched a “War on Terror,” invading Afghanistan to capture the terrorists and prevent further attacks. Meanwhile, al-Qaeda and their allies plotted to cause more deaths and destruction in other countries across the world.

The War in Iraq

In 1991, Saddam Hussein, leader of Iraq, ordered an invasion of neighboring Kuwait. His armies were driven out by an international force led by the US, but tensions remained high. In 2001, the international community suspected that Saddam Hussein possessed weapons of mass destruction capable of causing huge civilian casualties. As the War on Terror heightened tensions across the Middle East, the US and UK led an invasion of Iraq in 2003, toppling Saddam Hussein from power. Although the invasion lasted only a few weeks, violence would continue in Iraq for many years.

Saddam Hussein’s statue is toppled

US tanks rolled into the Iraqi capital, Baghdad, in April 2003, signaling the end of the dictatorship of Saddam Hussein. Jubilant Iraqis toppled a massive statue of the former leader in a symbolic gesture of contempt.

Natural disasters

The first years of the 21st century were beset by natural disasters and extreme weather. In 2003, more than 40,000 people died in heat waves across Europe. In 2004, a huge tsunami caused devastation around the Indian Ocean, killing almost 230,000 people in 14 countries. The following year, a powerful storm, Hurricane Katrina, laid waste to the city of New Orleans, with wind speeds of 125 mph (200 kph). A massive earthquake devastated the island of Haiti in the Caribbean in 2010, killing more than 300,000 people and leaving millions homeless. In 2011, another earthquake triggered a tsunami in Japan, destroying homes and causing radioactive material to leak from the Fukushima nuclear power plant.

Global dangers

Countries all across the world experienced devastating natural disasters in the early years of the 21st century. Some were freak chance events, while others have been linked to changes in the world’s climate.
Invasion of Afghanistan
The US and its NATO allies launched Operation Enduring Freedom after the 9/11 attacks, in an effort to track down Osama bin Laden. The terrorist leader was thought to be in Afghanistan, where the Taliban government was allied with al-Qaeda. The invasion succeeded in overthrowing the Taliban, but violence continued in Afghanistan for years.

Madrid bombings
On the eve of Spanish political elections, members of al-Qaeda exploded bombs on four trains in Madrid, killing 191 people and wounding 1,841. The Spanish government had supported the 2003 US-led invasion of Iraq. The Spanish public promptly voted that political party out of office and installed a party that withdrew Spanish troops from Iraq.

London bombings
Britain experienced attacks on July 7, 2005, when terrorists carried out a series of suicide bombings on London’s transport system. Three bombs exploded on underground trains, and one on a double-decker bus. An al-Qaeda website claimed that they had launched these attacks in retaliation for Britain’s involvement in the wars in Iraq and Afghanistan.

Death of Bin Laden
US President Barack Obama received intelligence that Osama bin Laden, the head of al-Qaeda, was hiding out in a compound in Abbottabad, Pakistan. In a daring night raid named Operation Neptune Spear, a US Navy Seal team shot dead bin Laden and four others. It was an important milestone in the War on Terror, but not an end to Islamist extremist terrorist attacks.

The Arab Spring
In 2010, a Tunisian man set fire to himself in protest to poor treatment by the Tunisian police. His rebellion sparked a wave of unrest that spread across the Arab world, in countries ruled by dictators or corrupt and oppressive governments. First, the Tunisian leader, Zine al-Abidine Ben Ali, was forced from power. Then dissent spread to Egypt, where President Hosni Mubarak resigned after massive popular protests. In 2011, there were uprisings in Yemen, Bahrain, Libya, and Syria. Libya’s leader, Colonel Muammar Gaddafi, was overthrown by rebel fighters. Free elections took place in some Arab countries, but others such as Syria were thrown into civil war.

Global financial crisis
In 2007, US banks realized that they had lent money for home mortgages to hundreds of thousands of customers who could not afford to pay them back. To make matters worse, the banks had bundled up the mortgages with other investments, worth billions of dollars. These suddenly lost value, threatening financial systems across the world. The value of investments plummed, and huge banks collapsed in the US and Europe. The crisis brought poverty and unemployment to many countries across the globe.

2009 financial statistics
- Value of world’s companies wiped out
- GDP (annual production) of US
- Money spent by European governments to prop up banks in debt
REFERENCE
Find out all about stars, wars, flags, empires, inventions, wonders of the world, record-breaking animals, and history’s looniest leaders in the reference section. A useful glossary explains many of the terms used in this book.
Sky maps

These six maps fit together to form a map of the whole night sky. Together, the shape they create is known as the celestial sphere, and includes every star that can be seen from Earth. The stars can also be linked together into shapes called constellations—there are 88 constellations in total. Some have smaller shapes within them, which are called asterisms. The red lines on these maps divide the celestial sphere into different regions, each with a single constellation as its focus. The dots show stars—the bigger the dot, the brighter the star it represents.

THE NORTH POLAR SKY

The main feature of the north polar sky is Polaris, also known as the North Star or Pole Star. Although not a particularly bright star, it is important, because it lets navigators on land or sea find which way north is, and set their direction of travel accordingly. As the Earth’s axis points to a spot very close to Polaris, the star appears to stay in virtually the same place, while the sky rotates around it.
THE SOUTH POLAR SKY

While the northern hemisphere has Polaris to guide travelers, there is no equivalent south star. Here, observers must use a fairly complicated method to find the south celestial pole, since it lies in a faint and barren part of the night sky. However, the constellations nearby contain some wonderful stars, and there is a good view of our galaxy, the Milky Way.
EQUATORIAL SKY CHART 1

This section of the night sky is best observed in the evenings of September, October, and November. It mainly consists of empty areas of space and faint stars, but there are some objects worth looking out for. In the Andromeda constellation you can see the Andromeda Galaxy, which is our largest neighboring galaxy. Just north of the celestial equator (shown as a yellow line here) is the Great Square of Pegasus, an asterism (part of a larger constellation). In Piscis Austrinus is Fomalhaut, the brightest star in this region.

EQUATORIAL SKY CHART 2

This part of the night sky is filled with interesting star patterns and is best observed in the evenings of June, July, August, and September. The northern area is dominated by the Summer Triangle asterism, made up of three stars: Deneb, in the Cygnus constellation; Vega, in Lyra; and Altair, in Aquila. To the south is a curving arrangement of stars that forms the constellation Scorpius, and the constellation Sagittarius is also nearby.
**EQUATORIAL SKY CHART 3**
This part of the night sky is best observed in evenings in March, April, and May. It contains two of the brightest stars of the whole celestial sphere: reddish Arcturus, in Boötes, and bluish Spica, in Virgo. Virgo is the second-biggest constellation, and just to its south is the largest, Hydra, which weaves its way across—and beyond—the entire region. Just above the center and to the right are the stars that make up Leo, the Lion. One of the few constellations with an easily recognizable pattern, its head forms a distinctive backward question mark of six stars.

**EQUATORIAL SKY CHART 4**
This section of the night sky is best observed in the evenings of December, January, and February. It is one of the most stunning areas of the night sky as it contains more bright stars than any other. A good constellation to try to identify is Orion, which has an easily recognizable line of three bright stars across its center, known as Orion’s Belt. Adjacent to Orion is Taurus, containing the star Aldebaran, as well as one of the celestial sphere’s finest star clusters—the Pleiades or the Seven Sisters.
The world

The Earth's surface is divided into seven large land masses called continents: Antarctica, North America, South America, Europe, Asia, Africa, and Australasia and Oceania. Most of this land is further divided into countries—194 in total. The only major exception is Antarctica, where there are no countries, although many nations claim ownership of parts of the land there.

Dividing the world

This political map of the world, shows the continents and countries. An imaginary line known as the equator runs horizontally around the center of the Earth. The region either side of the equator—within the Tropic of Cancer to the north and the Tropic of Capricorn to the south—is known as the Tropics. This is the world’s hottest region, where the Sun’s rays strike the Earth directly.

Time zones

The Earth is also divided by imaginary vertical lines known as lines of longitude. For every 15° you head east or west, you either gain an hour or lose an hour. The world is divided into 24 of these time zones.

Continental populations

There are now more than 7 billion people in the world. Asia is the most densely populated continent, with around 60 percent of the world’s population, including the world’s two most populous nations: China (1.3 billion people) and India (1.2 billion people). By contrast, there are never more than a few thousand people living the harsh climate of Antarctica at any one time—and these are mostly scientists doing research.
**Continent size**

The largest continent in the world is Asia. Australia and Oceania is the smallest continent, at only about a sixth of the size of Asia. The biggest country in the world is Russia, which crosses the border between Europe and Asia, at 6,601,668 miles² (17,098,242 km²). The second and third largest countries are Canada and the US, both in North America. Canada has a total area of 3,855,102 miles² (9,984,670 km²) and the US is 3,794,100 miles² (9,826,675 km²).

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With an area of 0.2 miles² (0.5 km²), Vatican City is the world’s smallest country.
World flags

Every country has a national flag with a unique design that identifies it to other countries. There are no international rules for flag design—each country can choose any pattern, though they are usually based on the country’s history or culture. Most flags are rectangular in shape, but the proportions of the rectangle are not always the same. This is not always the case, however—Nepal, for example, has a distinctive, nonrectangular flag, which looks like two triangles on top of each other. National flags first became widespread in the 19th century, but Denmark has the oldest national flag still in use, dating back as far as the 13th century.
Tree of life

Life has evolved into an amazing variety of forms, but they are all related to the first living things that appeared on Earth more than 3.8 billion years ago. This tree of life shows how the simplest single-celled organisms—prokaryotes such as bacteria—developed into the more complex single-celled eukaryotes and the multicelled plants, fungi, and animals.

The main groups of the diversity of life are shown in this diagram, including all the vertebrates or animals with backbones. Humans are part of the primate group of mammals, so we are also linked through billions of years of evolution to the simplest living organisms on the planet.
Nature’s record breakers

Some animals are capable of the most amazing feats, moving at extraordinary speeds or producing incredibly loud noises. Others are remarkable for their size—either weighty giants or so small that it is difficult to imagine how their bodies function. Some live to advanced ages, while others survive for just a few days.

**WEIGHTY WILDLIFE**

Most of the heaviest animals, such as whales and giant sharks, live in the sea, where the ocean water supports their bodies.

![Diagram showing heaviest animals](image)

**NOISIEST ANIMALS**

The snapping shrimp stuns its prey with the loudest noise made by any animal, but luckily it only lasts for a split-second.

![Diagram showing loudest animals](image)

**GETTING AROUND**

Some predators achieve astonishing speeds as they attack their prey. By contrast, the sloth seems to live its life in slow motion.

![Speed chart](image)

**JUMPING CREATURES**

Craggy mountain terrain allows the snow leopard to leap huge distances to attack prey. Other animals jump to escape danger.

![Jumping creatures chart](image)
ANIMAL LIFESPANS

Big animals tend to live longer than small ones, and some insects, such as mayflies, survive for just a few hours as flying adults.

**Longest Lives (YEARS)**

- Bowhead whale 211
- Ocean Quahog Mollusc 400
- Aldabra Giant Tortoise 255
- Rougheye Rockfish 140
- Giant barrel sponge 2,300
- 500
- 1,000
- 2,000
- 2,500

**Shortest Lives (DAYS)**

- Mayfly 1
- Gastrotrich 3
- Drone ant 14
- Bee 31
- Dragonfly 121
- 0
- 30
- 60
- 90
- 120
- 150

TALL AND SMALL

The smallest animals are microscopic, such as the rotifers that live mainly in ponds and streams. Other creatures are giants that tower over all the other animals living alongside them.

**Tallest**

- Giraffe 20 ft (6 m)
- African elephant 13 ft (4 m)
- Moose 7½ ft (2.3 m)
- Ostrich 9½ ft (2.8 m)
- Man 5½ ft (1.7 m)

**Smallest**

- Paper clip 1½ in (3.2 cm)
- Bumblebee bat 1½ in (4 cm)
- Moss rotifer 0.001 in (0.005 cm)
- Dwarf sphaero gecko ½ in (1.6 cm)
- Amau frog ¼ in (0.8 cm)
- Paedocypris fish ¼ in (1 cm)
Conversion Tables

Measurements are important because they help people agree on things. Without accurate measurements, there would be no world records, cooking would be guesswork, and it would be hard to find clothes that fit. Ancient measurements were often based on body parts, which is why we still measure in units such as feet to this day. However, everyone’s body is a different size, so now we use more standard measures.

UNITS OF MEASUREMENT

There are two common systems for measuring most things. The traditional way is called imperial and it is still popular in the United States. The metric system is more suited to scientific work and is widely used in Europe. In metric, each measurement is linked to others by powers of 10.

### AREA

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### TIME

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### MAKING CONVERSIONS

You can convert imperial measurements to metric ones or vice versa, by multiplying or dividing by a fixed number called a conversion factor. The only thing that cannot be converted in this way is temperature, which has its own unique method.

**To convert from Fahrenheit (˚F) to Celsius (˚C)**

\[ C = \frac{F - 32}{9} \times 5 \]

**To convert from Celsius (˚C) to Fahrenheit (˚F)**

\[ F = \left( \frac{C \times 9}{5} \right) + 32 \]
### HOW TO CONVERT METRIC AND IMPERIAL MEASURES

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INCREDIBLE HISTORY

Throughout the ages, in every corner of the globe, history has been happening. From crazy rulers and child prodigies to huge empires and life-changing inventions, history is filled with people and events that often seem too incredible to be true. Here are some of the amazing events, inventions, and people that have gone down in history.

BIGGEST EMPIRES

The greatest empires in history ruled over large areas of land, often spanning many continents. Empires are ruled by a single monarch or an oligarchy (a small group of people, such as a powerful family). They rule over vast territories, and must maintain control of their lands as well as conquering new places if they want to expand. Here are the five biggest empires the world has ever seen.

- **British Empire**
  - At its peak in the late 19th century, the British empire covered about a quarter of Earth’s land area. It was said that the “Sun never sets” on its lands.
  - **20.9 Million miles**
  - **33.7 Million km**

- **Mongol Empire**
  - Under the Genghis Khan, the empire of the Mongols (a group of eastern nomadic tribes) grew rapidly in the 13th and 14th centuries. It expanded across Asia, including China and Russia.
  - **20.5 Million miles**
  - **33 Million km**

- **Russian Empire**
  - The Russian Empire existed from 1721 until the Russian Revolution in 1917. At its peak in the middle of the 19th century, it stretched across Eastern Europe, Asia, and North America.
  - **14.7 Million miles**
  - **23 Million km**

- **Spanish Empire**
  - Under the rule of the Habsburg dynasty, the Spanish Empire became the major global power in the 16th and 17th centuries. Territories included North and South America and parts of Europe.
  - **12.4 Million miles**
  - **20 Million km**

- **Qing Empire**
  - Ruling for 267 years from the mid-17th century to the beginning of the 20th century, the Qing (Manchu) dynasty was the last imperial dynasty of China.
  - **9.1 Million miles**
  - **14.7 Million km**

LONGEST WARS

Conflicts have been fought throughout history, all around the world. While some wars are resolved quickly, others continue for decades, or even a century, until the last battle is fought and won.

- **The Hundred Years’ War, 1337–1453**
  - The longest in recorded history, this war was fought between the English and French. Despite the name, it lasted 116 years.
  - **116 Years**

- **The Punic Wars, 264–146 BCE**
  - This was a series of three wars between Carthage (the major maritime power) and Rome (which controlled the Italian peninsula). Rome defeated Carthage, and destroyed the city in 146 BCE.
  - **43 Years**

- **The Thirty Years’ War, 1618–1648**
  - Although there were many reasons for this war, it was mainly a religious conflict between Catholics and Protestants. Mostly fought in Germany, it became a political war and changed Europe forever.
  - **30 Years**

- **The Wars of the Roses, 1455–1485**
  - The fight for the crown of England lasted 30 years and was fought between the Houses of York and Lancaster. The Tudor king, Henry VII, led the House of Lancaster to victory over Richard III’s House of York.
  - **30 Years**

- **The Peloponnesian War, 431–404 BCE**
  - This war was fought between rival alliances of Greek city-states led by Athens and Sparta. Athens was strongest at sea, but Sparta was more powerful on land and eventually crushed the Athenian forces.
  - **27 Years**

- **Napoleonic Wars, 1796–1815**
  - Napoleon Bonaparte was a skilled general who declared himself Emperor of France in 1804. He led France in a series of wars against other European powers, until his defeat at the Battle of Waterloo.
  - **23 Years**

SHORTEST WARS

Not all conflicts are long and drawn out—some are over in just a few days. The shortest war ever began when the Zanzibar sultan’s successor took control without gaining the permission of the British consul first. He fled from the palace almost immediately.

- **Anglo-Zanzibar, 1896**
  - Between Britain and the Zanzibar Sultanate.
  - **38 MINUTES**

- **Six Day War, 1967**
  - Between Israel and neighboring states Egypt, Jordan, and Syria.
  - **6 DAYS**

- **Indo-Pakistan War, 1971**
  - Between India and Pakistan.
  - **13 DAYS**

- **Serbo-Bulgarian War, 1885**
  - Between Serbia and Bulgaria.
  - **14 DAYS**

- **Georgian-Armenian War, 1918**
  - Between Georgia and Armenia.
  - **24 DAYS**
AMAZING INVENTIONS

Our everyday lives would be very different if these inventions had never happened. From simple household objects to complex modern technology, these incredible discoveries have transformed the way we live and think, and changed the course of history.

- 1440: Printing press
  Johannes Gutenberg’s press let people make copies of writings quickly and cheaply.

- 1776: Steam engine
  James Watt added a separate condensing chamber to the early steam engine, making it more efficient.

- 1876: Telephone
  Alexander Graham Bell is famous for this invention, but many others claimed to have beaten him to it.

- 1879: Light bulb
  This bright idea for electric light in the home was the invention of Thomas Edison and Joseph Swan.

- 1886: Car
  German engineer Karl Benz took to the road in a three-wheeled car, powered by an internal combustion engine.

- 1903: Airplane
  The Wright brothers invented a flying machine, which would revolutionize travel across the world.

- 1928: Penicillin
  The accidental discovery of mold growing on bacteria led Alexander Fleming to discover the first antibiotic.

- 1941: Modern computer
  The first electronic, programmable computer was invented by Konrad Zuse. It was called the Z3.

- 1969: Internet
  The first network was set up by the Pentagon. Twenty years later, Tim Berners-Lee invented the World Wide Web.

LOONY LEADERS

Throughout history there have been many eccentric leaders. Some were just victims of bad publicity, while others were cruel or actually insane. Here is a selection of just a few of history’s loony leaders.

- Hatshepsut (1470s BCE)
  This Egyptian ruler knew her people did not like the idea of a female pharaoh, so she put on a fake beard and called herself king instead of queen.

- Ashurnasirpal II (ruled 884–859 BCE)
  This Assyrian general enjoyed boasting about his conquests. An inscription at the entrance to his palace described the tortures inflicted on those who rebelled against him.

- Nebuchadnezzar II (ruled 605–562 BCE)
  A Babylonian king who believed that he was a cow, Nebuchadnezzar II spent seven years in a field, chewing his cud.

- Peisistratus (560s BCE)
  This Athenian citizen claimed he had been attacked, so the city let him have bodyguards. He then used his bodyguards to take over the city, becoming its ruler.

- Nero (37–68)
  This Roman emperor had his mother and adoptive brother killed. It is said that he captured Christians and had them burned in his garden at night, to provide light.

- Caligula (12–41)
  The Roman emperor Caligula was known for his cruelty and extravagance. He proclaimed himself a god, and expected people to worship him. He replaced the heads on many statues of gods so that they looked like him.

- Irene of Athens (752–803)
  Mother of Emperor Constantine VI, Irene of Athens had her son’s eyes gouged out so that she could rule the Byzantine Empire on her own.

- Basil II (958–1025)
  After victory in battle with the Bulgarians in 1014, Emperor Basil of Byzantium ordered his troops to punish 15,000 Bulgarian prisoners by scooping out their eyes. A single man was allowed to keep one eye so that he could lead the others home.

- Timur the Lame (1336–1404)
  A nomadic warlord from modern-day Uzbekistan, this leader killed anyone who got in his way. On one occasion this meant all 30,000 inhabitants of a city.

- Vlad III (1431–76)
  Nicknamed Vlad the Impaler, this Transylvanian ruler marched into neighboring Bulgaria, where he captured 20,000 people and impaled them on stakes.

- Farouk of Egypt (1920–65)
  This Egyptian leader was a thief who enjoyed picking pockets while on state visits. He once stole an expensive pocket watch from Winston Churchill.

- Lighthouse of Alexandria
  Built by the Nile River in the third century BCE, this was the world’s first lighthouse. It used mirrors to reflect sunlight out to sea.

- Great Pyramids of Giza
  These three pyramids near Cairo are called Khufu, Khafra, and Menkaura. They were built as royal tombs for Egyptian pharaohs.

- Statue of Zeus at Olympia
  This statue of Zeus, the Greek god of thunder, was 40 ft (12 m) high. It was placed at Olympia, the site of the Ancient Olympic games.

- Temple of Artemis at Ephesus
  This large temple was built in honor of Artemis, the Greek goddess of the hunt and childbirth. It was made of marble, and had 127 columns.

- Colossus of Rhodes
  Made of bronze, this statue of Greek sun god Helios was 110 ft (33.5 m) tall. It stood for 60 years before falling during an earthquake.

- Mausoleum at Halicarnassus
  This enormous marble tomb was for Mausolus, the King of Caria. It was built by his grieving wife Artemisia.

- Hanging Gardens of Babylon
  Built on a huge brick terrace, these gardens were said to be 75 ft (22 m) in the air. Many experts believe they may not have existed at all.

CHILD PRODIGIES

Some people are born brilliant, and achieve great things from a very young age. From musicians to mathematicians, these clever children made their mark on the world with their amazing achievements and impressive talents.

- Avicenna (980–1037)
  At 10, this Persian polymath (expert in many subjects) had memorized the Qur’an. He was a qualified physician at 18.

- Blaise Pascal (1623–62)
  This talented mathematician wrote a significant treatise on geometry at 16.

- Maria Gaetana Agnesi (1718–99)
  By 13, Agnesi could speak at least seven languages. She became a mathematician, linguist, and philosopher.

- W. Amadeus Mozart (1756–91)
  Mozart was playing keyboard and violin at the age of four, and composing music at five.

- Pablo Picasso (1881–1973)
  Trained by his father, Picasso was painting incredible works of art from a very early age.

ANCIENT WONDERS

Admired and marveled by Ancient Greek travelers, the Seven Wonders of the Ancient World were amazing landmarks around the eastern Mediterranean rim. Only one, the Great Pyramids of Giza, still remains today.

- Lighthouse of Alexandria
- Great Pyramids of Giza
- Statue of Zeus at Olympia
- Temple of Artemis at Ephesus
- Colossus of Rhodes
- Mausoleum at Halicarnassus
- Hanging Gardens of Babylon
Glossary

ACCELERATION
In physics, a term meaning the rate of change in velocity.

ADAPTATION
The way in which a living species, such as an animal or a plant, has developed in appearance or behavior to fit in with its environment.

AGRICULTURE
Using the land to grow food crops or raise domestic animals.

ALGAE
Simple, often single-celled, organisms, some of which look like plants; algae are found in a variety of habitats but occur most commonly in water.

AMPHIBIAN
A cold-blooded animal, such as a frog or newt, that can live both in water and on land.

ANARCHY
Disorder in society, especially when there is no leader or government in control.

ANTENNA
A sensitive feeler on the head of an insect or a crustacean (for example, a lobster, crab, or housefly).

APARtheid
An official policy of keeping people apart because of their racial origins. It was used to separate black Africans from white in South Africa.

ARCHAEA
A biological group of microscopic, single-celled organisms that look like bacteria but have different genes.

ARCHAEOLOGY
Study of the ancient past through looking at the remains of buildings and objects that people once used.

ARTHOSTOD
An invertebrate (animal lacking a backbone) that has a jointed, outer body case. Arthropods include insects, spiders, crustaceans such as crabs and lobsters, and scorpions.

BRONZE Age
A period of ancient history, between about 2500–1200 BCE, when people mostly used bronze for making tools and weapons.

CAMOUFLAGE
The way animals blend in with their environment or use disguises to escape notice by predators; this includes seasonal changes of coat color and mimicry of a more dangerous animal.

CAPITALISM
A system for organizing society that is in favor of capitalists: people or private organizations that make a profit and accumulate wealth (capital) by producing goods and services.

CARNIVORE
A meat-eating animal with teeth especially shaped for tearing flesh.

CITIZEN
A person who belongs to a city or a bigger community such as a state or country.

CIVIL WAR
War between different political groups or regions within the same country.

CNIDARIA
A large group of marine animals, including jellyfish and many types of coral, which carry stinging cells in their tentacles.

COELACANTH
A deep-sea fish with a distinctive shape, long thought to be extinct. It has features very similar to those seen in fossil fish from the age of dinosaurs.

COLD-BLOODED
Describing an animal whose body heat depends on the temperature of its surroundings; reptiles, for example, are cold-blooded.
**COLONY**
A group of people who leave their native country to settle elsewhere but keep links with their homeland. Also: a group of animals, usually of one species, that live and work together.

**DETRITIVORE**
An animal that feeds on dead plant or animal matter.

**COMBUSTION**
A chemical reaction in which a substance, for example, a fuel oil, mixes and burns with oxygen.

**COMET**
Small astronomical body of ice and dust that orbits the Sun.

**COMMUNISM**
A political system based on the belief that property should not be owned by individual people but shared by all.

**COMPOUND**
A chemical substance in which two or more elements have bonded together.

**COMPOUND EYE**
The eyes of adult insects and some crustaceans consist of many sections. Each section has its own lens, and together they create a mosaic image.

**CONSTELLATION**
A group of stars that form a pattern in the sky; many constellations are named after animals or mythical characters.

**CORE**
The innermost and hottest part of Earth, consisting of a liquid outer layer around a solid center, both thought to be made of iron and nickel.

**CRUST**
Earth’s hard, rocky, outermost layer.

**CULTURE**
The customs, beliefs, and behavior shared by a society.

**DEMOCRACY**
A political system in which people have power to control their government, usually by electing politicians to represent their views.

**DNA**
Abbreviation for deoxyribonucleic acid, the material packed inside chromosomes that holds all the instructions for making and maintaining a living body.

**DYNASTY**
A family or group that rules over a country for several generations.

**ECHINODERM**
A spiny-skinned marine animal with a radially symmetrical body: if it is divided through the middle in any direction the halves look exactly alike. This group includes starfish and sea urchins.

**ECOSYSTEM**
A community of animals and plants that share, and interact with, the same habitat.

**ELECTRON**
One of the tiny particles inside an atom; electrons have a negative electric charge.

**ELEMENT**
In chemistry, a simple substance made of atoms that are all of the same kind.

**EMBRYO**
The earliest stage in the development of an animal or plant. A human embryo forms when sex cells join.

**EMPEROR**
A group of countries or states united under one ruling power.

**ENZYME**
A substance in animals and plants that speeds up a chemical reaction.

**ERUPTION**
A violent discharge of lava, hot ashes, and gases from a volcano. Eruptions are the result of molten rock, or magma, working its way from the inside of Earth to the surface.

**EXOMUSCLE**
A group of people who leave their native country to settle elsewhere but keep links with their homeland. Also: a group of animals, usually of one species, that live and work together.

**FUSION**
A joining together; nuclear fusion is the joining of two atomic nuclei.

**FROG**
A cold-blooded animal with moist skin, webbed feet, and an ability to reproduce both sexually and asexually.

**GLACIER**
A moving mass of ice, formed from accumulated snow. Some glaciers flow like rivers, while others are vast ice sheets such as those covering Antarctica and much of Greenland.

**GRAVITY**
The force that attracts one object to another and prevents things from floating off into space.

**GUERRILLARA**
A member of a small, independent fighting force that operates by making surprise attacks on an enemy.

**HABITAT**
The area where an animal naturally makes its home.

**HERBIVORE**
An animal that feeds on plants.

**HOMINID**
A word meaning humanlike, which refers to humans and all our extinct ancestors. It can also include the great apes (chimpanzee, bonobo, gorilla, and orangutan).

**HORMONE**
Natural chemicals that are produced by glands and circulate in the bloodstream to have an effect on particular parts of the body.
**HURRICANE**
A violent tropical storm with torrential rain and high winds that reach more than 74 miles (119 kilometers) per hour.

**IGNEOUS ROCK**
Rock formed from magma—hot, liquid material inside Earth—that has come to the surface then cooled and hardened.

**INDIGENOUS**
Occurring naturally in a particular environment or country.

**INERTIA**
The tendency of an object to either stay still or to move in a straight line at an unchanging speed until a force acts upon it.

**INFINITY**
The part of an army made up of soldiers who fight on foot.

**INVERTEBRATE**
An animal without a backbone: for example, an insect, a worm, or a crustacean.

**ION**
An atom that has lost or gained one or more electrons and as a result has either a positive or negative electrical charge.

**IONOSPHERE**
The area of Earth’s atmosphere through which radio waves can be transmitted.

**IRON AGE**
The historical period characterized by the use of iron for making weapons and tools. The earliest known iron implements were found in the Middle East and southern Europe, and date to about 1200 BCE.

**ISOTOPE**
One of two or more atoms of a chemical element that have different numbers of neutrons (particles with no electric charge) compared to other atoms of the element.

**KARST**
A type of landscape formed from limestone rocks. Karst country includes steep cliffs and, below the surface, caves and tunnels where underground streams have slowly dissolved the soft limestone.

**KERATIN**
A tough protein found in the top layer of skin and also in hair, nails, horns, and hooves.

**LAVA**
Hot, liquid rock forced out of a volcano during an eruption.

**LIGHT YEAR**
A measurement used by astronomers, based on the distance that light travels in one year.

**MAGMA**
Hot, liquid rock that is found beneath Earth’s surface.

**MAMMAL**
A warm-blooded animal that has a backbone, feeds its young on milk, and usually has a covering of fur.

**MANTLE**
The rocks that lie beneath Earth’s crust (surface), extending almost to the innermost core, and making up most of our planet’s weight.

**MARSUPIAL**
A mammal that carries its developing young in a pouch, usually on its stomach.

**METAMORPHIC ROCK**
Rock that has been changed from one type to another through immense heat or pressure underground.

**METAMORPHOSIS**
A change from one form to another, sometimes very different, form; metamorphosis is seen in animals such as insects and amphibians as they develop into adults.

**MELANIN**
Dark pigment that gives skin its color; it is also found in hair and the colored part of the eye (iris).

**METEORITE**
A small body of rock or debris that falls to Earth from space.

**MIGRATION**
Seasonal mass movement of animals from one place to another in search of food and places to breed.

**MINERAL**
A solid, inorganic (nonliving) material occurring naturally in Earth; different minerals are classified according to their elements and crystal structure.

**MINERALS**
A chemical process by which plants use the energy from sunlight to make their own food.

**MORAINES**
Rocks and soil carried downhill by a glacier and deposited as heaps or mounds.

**MORIAH**
A cloud of gas and dust in outer space; some nebulae are the debris from dead stars, others are where new stars form.

**MONARCHY**
A type of government in which a king or queen is recognized as the head of a country, even though he or she may have no real power.

**MONARCHY**
The control center of a body cell, where information about a living organism is held in the form of genes. Also: the central core of an atom.

**NUTRIENTS**
Food substances that are necessary for life and growth.

**ORBIT**
The path taken by an object—for example, a planet—that is circling around another.

**ORGANISM**
Any living thing, including an animal, a plant, or a microscopic lifeform such as a bacterium.

**ORE**
Ground that remains permanently frozen beneath the topsoil.

**PHARAOH**
Title given to a king in ancient Egypt. People believed that the pharaohs had sacred powers.

**PHOTOSYNTHESIS**
A chemical process by which plants use the energy from sunlight to make their own food.

**PHYLUM**
One of the major scientific divisions that group together living things according to what their ancestors were like and the way their bodies are made.
**PLACENTA**
In mammals, an organ that develops inside the womb during pregnancy. This acts as a supply line, providing the developing young with nourishing food and oxygen from the mother’s bloodstream.

**PLASMA**
A gaslike cloud of electrically charged matter.

**PLATE BOUNDARY**
An area where the edges of the vast moving plates that make up Earth’s crust come together.

**POLYP**
A form taken by some marine animals, such as jellyfish, sea anemones, and corals. Usually tube-shaped, polyps have a mouth at one end, and are attached firmly at the base to a rock or the seabed.

**PREDATOR**
An animal that hunts other animals for food.

**PREHISTORY**
The time before the development of civilizations, when people did not write things down.

**PREY**
An animal hunted by other animals for food.

**PROPAGANDA**
Information spread publicly to put forward ideas or political views; propaganda is sometimes used to cause deliberate harm to a person or group.

**PROTISTS**
Simple, single-celled life forms, most of which can be seen only under a microscope. Protists live in watery environments and include algae and mobile, animal-like protozoa.

**PROTON**
One of the tiny particles inside an atom; protons have a positive electric charge.

**PUPA**
The hard, protective case, also called a chrysalis, that encloses the larva of an insect as it develops into an adult.

**QUARK**
One of the particles that make up the other particles in the nucleus of an atom (neutrons and protons).

**REACTANT**
One of the ingredients that join together to cause a chemical reaction.

**REPTILE**
A cold-blooded, scaly-skinned vertebrate (animal with a backbone); reptiles include snakes and lizards.

**REPUBLIC**
A country without a royal family that is headed, usually, by a president who may or may not have been freely chosen by the people.

**RETINA**
A layer of light-sensitive cells lining the inside of the eyeball.

**SEDIMENTARY ROCK**
Rock formed from particles of older rocks that have settled in layers and hardened under compression.

**SEISMIC ACTIVITY**
The shock waves that can be felt after an earthquake.

**SHALE**
Rock formed from layers of clay deposited over millions of years.

**SOLAR SYSTEM**
The Sun together with its orbiting groups of planets, including Earth, and other smaller bodies such as asteroids.

**SOLARIS**
A method that uses sound waves to detect objects and measure distances underwater.

**STALACTITE**
A natural structure, found hanging from the ceilings of caves and underground passages. Stalactites form slowly from deposits of lime carried in trickling water.

**STALAGMITE**
A natural structure found on the floors of caves and underground passages. Stalagmites slowly build up from deposits of lime carried in water dripping from stalactites in the ceiling.

**STOMATA**
Tiny openings on the undersides of leaves that control the amount of gas and moisture passing into and out of a plant.

**STONE AGE**
The period of prehistory, lasting more than two million years, when humans and their ancestors made most of their tools out of stone.

**SUBDUCTION**
A geological process in which one of the vast plates that make up Earth’s crust is pushed beneath another.

**SULTAN**
In some Islamic countries, the traditional title given to the ruler.

**SUNSPOT**
A dark, cooler patch on the surface of the Sun.

**SUPERNOVA**
An exploding giant star.

**TENTACLES**
Long, elastic structures, like arms, that some animals use for feeling, moving around, and picking up food.

**TOXIN**
A poisonous substance produced by a living organism such as an animal or a plant.

**TURNOVER**
The speed at which something moves in a particular direction.

**VERTEBRATE**
An animal with a backbone.

**VIRUS**
Tiny lifeform that is a collection of genes inside a protective shell. Viruses can invade body cells, where they multiply, causing illnesses.

**VISCOSITY**
The measure of a liquid’s ability to flow.

**VIZIER**
Title once given to a chief official in some Muslim countries.

**VOLCANO**
An opening in Earth’s crust that provides an outlet for magma (hot, liquefied rock) when it rises to the surface.

**WARM-BLOODED**
Describing an animal that can keep its body heat at an almost constant level, regardless of whether the outside temperature is hot or cold.
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