used for feeding on small animals on the bottom. Sturgeons feed on aquatic **insects**, **snails**, **crayfish**, small clams, and small fish.

Sturgeons have a cartilaginous skeleton with bony plates instead of scales in their skin which cover the sides of the body, and which completely cover the head.

Sturgeons are distributed throughout **North America**, **Asia** and northern **Europe**. A few **species** are anadromous, living in the oceans but swimming up **rivers** to spawn, and other species live only in fresh **water**. Of the anadromous sturgeons, one of the two species on the Pacific coast, *Acipenser transmontanus*, may weigh over 1,000 lb (450 kg). The two anadromous species on the Atlantic coast have been recently greatly reduced in population.

Sturgeons are found both in the rivers and the eastern coasts of North America. The most common species in North America is the **lake** sturgeon, *Acipenser fulvescens*. In Europe they are found in the rivers and the coast line from Scandinavia to the Black Sea. From time to time trawlers fishing along the coasts of Britain and Ireland may catch sturgeons. **Pollution** and the presence of weirs have been instrumental in reducing the populations to the point of **extinction** in rivers where they were once plentiful.

Spawning occurs from May to July when the sturgeons enter the rivers of the United States and continental Europe. A female sturgeon may lay up to three million eggs, each about 0.08 in (2 mm) in diameter, and covered with **gelatin**. Eggs remain on the bottom of the river, hatch within 3–7 days, and release larvae that measure about 0.4 in (9 mm). At one month the young fish may measure 4-5.5 in (10-14 cm) long. The young may not start the seaward journey until they reach two or three years of age and are 3.3 ft (1 m) long.

The flesh of the sturgeon is edible but is not prized; it is the sturgeon's eggs used to make caviar that are in great demand. The swim bladders of sturgeons are used to make isinglass, a semi-transparent whitish gelatin used in jellies, glues, and as a clarifying agent.

Since the population of sturgeons has been greatly diminished, commercial fishing of these fish is now limited. Some sturgeons may provide considerable excitement because of the battle they provide when hooked on light tackle.

The sturgeon family has the distinction of providing the largest **freshwater** fish in North America. In the last century three fish were reported to exceed 1,500 lb (680 kg). At present some specimens may weigh over 1,000 lb (450 kg), and one fish caught by gill net weighed 1,285 lb (584 kg). Although the species extends from Alaska to the middle of California, the largest fish are found mainly in the Columbia and Fraser rivers in British Columbia, Washington, and Oregon.

A lake sturgeon (*Acipenser fulvescens*). *Photograph by Tom McHugh. Photo Researchers, Inc. Reproduced by permission.*

The white sturgeon is actually grayish brown with a white belly. When at 9 ft (2.7 m) long, it may be about 50 years of age. The 3,000,000 eggs laid by a 10–foot female may weigh almost 250 lb (113 kg). Laws protecting large sturgeons, which tend to be females with eggs, are now in effect.

The green sturgeon, *A. medirostris*, grows up to 7 ft (2.1 m) and weighs about 350 lb (159 kg). It has a greenish **color** and its barbells are located nearer to the end of the snout, and has fewer bony plates along the back.

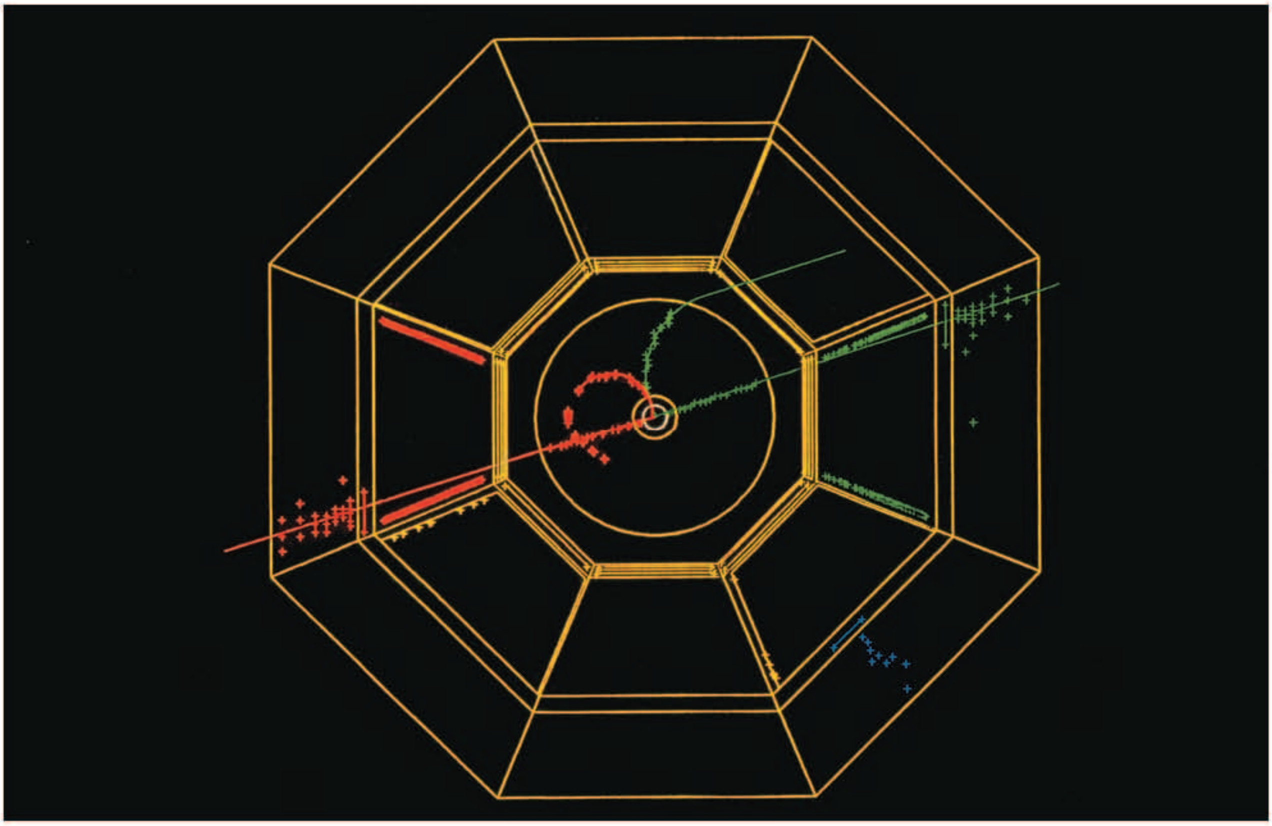
The largest fish caught in fresh water along the Atlantic coast is the Atlantic sturgeon, *A. oxyrhynchus*. It has been verified that a 14–ft (4.3–m) fish weighing 611 lb (278 kg) has been caught. As is the case with the Pacific sturgeon, the Atlantic sturgeon populations are being depleted because of pollution and **dams**, which prevent them from reaching their breeding grounds.

Nathan Lavenda

Style *see* **Flower**

Subatomic particles

Subatomic particles are particles that are smaller than an atom. Early in the twentieth century, electrons, protons, and neutrons were thought to be the only subatomic particles; these were also thought to be elementary (i.e., inca-



An electronic display of the decay of an upsilon, a particle made of a bottom quark and an antiquark, in the CLEO detector at the CESR collider at Cornell University. An electron and a positron have met and annihilated (center); their energy produces an excited upsilon, which lives too briefly to show. It decays into a lower energy state by emitting a photon which converts into a positron (curves away tightly to the left) and an electron (curves to the right). The lower-energy upsilon then decays to its ground state by emitting another photon (detected in the bottom right sector of the grid). The ground-state upsilon finally decays into a high energy electron-positron pair (seen as the two long paths that cut diagonally across the grid in opposite directions from the center). *Newman Laboratory of Nuclear Science, Cornell University, National Audubon Society Collection/Photo Researchers, Inc. Reproduced by permission.*

pable of being broken down into yet smaller particles). However, the list of subatomic particles has now been expanded to include a large number of elementary particles and the particles they can be combined to make.

There are two types of elementary particles. One type of makes up **matter**. Examples of these particles include **quarks** (which make up protons and neutrons) and electrons. Baryons and mesons are combinations of quarks and are considered subatomic particles. The most famous baryons are protons and neutrons.

The other elementary particles are mediators of the fundamental forces. These mediator particles enable the matter particles to interact with each other. That is, when two electrons collide, they do not simply bounce off of each other like two billiard balls: they exchange a **photon** (one of the mediator particles). All forces, including gravity, are thought to be mediated by particle exchanges.

Discovery of particles

Electrons

The first subatomic particle to be discovered was the **electron**. While others had deduced the existence of a negatively charged particle in what were called **cathode** rays (and which are now known to be beams of electrons), it was English physicist J. J. Thomson (1856–1940), who in 1897 measured the **velocity** and charge-to-mass **ratio** of these particles. The charge-to-mass ratio was found to be relatively large, and independent of the gas used in his experiments, which indicated to him that he had found a true particle. Thomson gave it the name “corpuscle,” which was later changed to “electron.”

The charges of all particles are traditionally measured in terms of the size of the charge of the electron. The electron has a charge, e, of 1.6×10^{-19} Coulombs.

Photons

The first mediator particle to be discovered was the photon. In 1900, German physicist Max Planck (1858–1947) reported that **light** came in little packages of **energy**, which he called "quanta." In 1905, German physicist Albert Einstein (1879–1955) studied the **photoelectric effect** and proposed that **radiation** is quantized by its nature—that is, transfers energy in minimal packets termed quanta. A photon (the name was coined by U.S. chemist Gilbert Lewis [1875–1946] in 1926) is one of these quanta, the smallest possible piece of energy in a light wave. (The word "wave" is applied by physicists to describe some observable aspects of the behavior of light, while the particle terminology of the "photon" is applied to describe others. Both words convey mental pictures that are useful in some physical applications, but neither picture is sufficient: a photon is not a "particle" in the sense of a perfectly round, hard, self-contained **sphere**, nor is light a "wave" in the sense of being a smooth undulation in some medium.)

Protons

The **proton** was one of the earliest particles known. (The word proton is Greek for "the first one.") In 1906 the first clues to the nature of the proton were seen. J. J. Thomson reported detecting positively charged **hydrogen** "atoms." These were in fact, hydrogen nuclei (protons), but atomic structure was not understood at the time. Thomson thought that protons and electrons were randomly scattered throughout the atom, the so-called "plum-pudding model." In 1909–1911, English physicist Ernest Rutherford (1871–1937) and his colleagues, German physicist Hans Wilhelm Geiger (1882–1947) and New Zealand physicist Ernest Marsden (1888–1970) did their famous scattering experiments involving alpha particles (two protons and two neutrons; a helium-atom nucleus) shot through gold foil. From their observations of the angles at which alpha particles were deflected, they deduced that **atoms** had relatively hard and small centers, thus proving the existence of the atomic nucleus and disproving the plum-pudding model.

In 1913, the **Bohr model** of the atom was introduced (named after Danish physicist Neils Bohr, 1885–1962). In this model, the hydrogen atom consists of an electron orbiting the nucleus (a single proton), much as the **Earth** orbits the **Sun**. The Bohr model also requires that the angular **momentum** (**mass** times velocity times distance from the orbital center) of the electron be limited to certain values (that is, be "quantized") in order that the electron not fall into the nucleus. Though known to have serious defects, the Bohr model still supplies the standard graphic representation of the atom: a solid nucleus around which electrons **orbit** like tiny planets.

When the principles of **quantum mechanics** were developed, the **Heisenberg uncertainty principle**, discovered by German physicist Werner Heisenberg (1901–1976) meant the Bohr atom had to be modified. The Heisenberg uncertainty principle states that it is impossible to accurately determine both the position and the momentum (mass times velocity) of a subatomic particle at the same time. Indeed, a subatomic particle cannot be thought of as *having* precise values of these quantities simultaneously, measured or not. This means that the electrons in an atom can still be thought of as orbiting, the nucleus, but their position is smeared throughout a wide region or "cloud" rather than confined to well-defined orbits.

Neutrinos

In 1930, scientists started to suspect the existence of another subatomic particle that came to be known as the **neutrino**. Neutrinos are considered matter particles, but they do not make up normal matter by themselves. In fact, neutrinos are very common–about 60 billion neutrinos from the Sun pass through every square centimeter of the Earth's surface every second–but we do not observe them because they interact only rarely with other particles.

In 1930 a problem with a process called nuclear beta decay had developed. Nuclear beta decay is when an unstable, or radioactive, nucleus decays into a lighter nucleus and an electron. Scientists observed that the energy before the beta decay was greater than the energy after the beta decay. This was puzzling because one of the most basic laws of **physics**, the law of **conservation** of energy, states that the amount of energy in any process must remain the same. To keep the idea of energy conservation intact, Austrian physicist Wolfgang Pauli (1900–1958) proposed that a hitherto-unidentified particle carried off the missing energy. In 1933 Italian physicist Enrico Fermi (1901–1954) named this hard-to-detect particle the neutrino, and used it to successfully explain the theory of beta decay.

One type of neutrino, the electron neutrino, was finally detected in 1956. Later, a second type of neutrino, the muon neutrino, was found, and a third type, called the tau neutrino, was discovered in the late 1990s. For decades physicists debated the question of whether the neutrino is a massless particle, like the photon, or has a finite mass. In 1998 physicists discovered that at least one of these types of neutrinos must have mass. Though it would have to be very tiny, it must at least be greater than 20-billionths of the mass of the electron—extremely small, but not zero.

Positrons

In 1931–1932, U.S. physicist Carl Anderson (1905–) experimentally observed the anti-electron, which he called the positron, after its positive charge. The positron is an **antiparticle** which had been predicted by English physicist Paul Dirac (1902–1984) in 1927–1930. Every particle has a corresponding antiparticle that has the same properties except for an opposite electrical properties (charge and magnetic moment). Antiparticles make up what is called **antimatter**. Matter is much more common in our universe than antimatter, though it is unknown why this is so.

Neutrons

In 1932 English physicist James Chadwick (1891–1974) discovered another matter particle, the **neutron**. The neutron is very similar to the proton except that it is electrically neutral (i.e., has no charge). Chadwick found the neutron by hitting a chemical called beryllium with alpha particles. When this occurred, highly penetrating radiation was emitted. This “radiation” turned out to be a stream of neutrons. After Chadwick’s experiment, Werner Heisenberg proposed that the nucleus is made up of protons and neutrons, which was later found to be true.

Pion, muons, and kaons

The second mediator particle discovered (after the photon) was the pion. In 1935, Japanese physicist Hideki Yukawa (1907–1981) formulated the idea that protons and neutrons were held together by a nuclear **force** that was mediated by a particle called the pion. Yukawa described it in detail. In 1937 the first evidence for the pion was obtained by studying cosmic rays (high-energy particles from **space**). By 1947 it became clear that cosmic rays did contain Yukawa’s pions, but also contained another particle, a heavy electron-like particle, which was given the name muon. In 1947 yet another particle was detected from cosmic rays, the kaon. The kaon is like a heavy pion, and decays into two lighter pions. The kaons are considered strange particles because they can be made fairly quickly, but it takes a long time for them to decay. Usually the time to make a particle and the time for it to decay to be about the same, but this is not true for the kaon.

Quarks

In 1980, Maurice Jacob (1933–) and Peter Lanshoff detected small, hard, objects inside the proton by firing high-energy electrons and protons at it. Most of the high-energy particles seemed to pass right through the proton. However, a few of these high-energy particles were reflected back, as if they had hit something. These and other experiments indicated that the proton contains three small, hard, solid objects. Thus protons are not elementary, but the objects inside them may be. These objects are now called quarks.

Quark model

Quarks had been postulated much earlier, in 1964, by American physicist Murray Gell-Mann (1929–) and, independently, by American physicist George Zweig (1937–). The theory describing quarks was called the quark model. In 1964 it was thought that there should be three different quarks. These different quarks each have a unique property called flavor. These first three quarks had flavors that were whimsically named up, down, and strange. Up-flavored quarks have an **electric charge** of $(2/3)e$, where e is the fundamental quantum of charge such as that of the negatively-charged electron. Down- and strange-flavored quarks have an electric charge of $(-1/3)e$. The quark model also says that quarks must remain bound inside their particles—in nature, quarks cannot exist by themselves. This idea is called quark confinement, and is based on the experimental observation that a free quark has never been seen. Since we cannot isolate quarks, it is very difficult to determine their masses.

In 1964 physicist Oscar W. Greenberg (1932–) suggested each quark has a quality he termed **color**. The label “color” for this quark property does not refer to the usual definition of color, but is just a way to keep track of quarks. Using this idea of color, the improved quark model says only overall-colorless particles can exist in nature. There are only three different kinds of color in the quark model, usually designated red, blue, and green. Color had to be introduced when a particle called the Δ++ (pronounced delta-plus-plus) baryon was discovered to avoid violating the **Pauli exclusion principle**. The Pauli exclusion principle says that each particle in a system of matter particles must have unique properties like electric charge, mass, and spin. The Δ++ baryon is made of three up quarks. Without color, each of its three up quarks cannot have its own properties. Color has been proven experimentally, and a theory called the **standard model** of elementary particles has updated the quark model.

Subatomic particle classifications

Elementary matter particles

There are two kinds of elementary (indivisible) matter particles, the quarks and the leptons. The two lowest-mass leptons are the electron (e^-) and its partner the neutrino, usually called the electron-neutrino (ν_e). For unknown reasons, this lepton pairing is repeated two more times, each time with increasing mass. These leptons are called the muon (μ^-) and muon neutrino (ν_μ) and the tau (τ^-) and tau neutrino (ν_τ). There are said to be three families, or generations, of leptons.

Like the leptons, the quarks have three families. The first family of quarks are the up and down quarks, the second contains the strange and “charmed” quarks, and the third the “bottom” and “top” quarks. Though all matter we see around us contains only up, down, and strange quarks, physicists have proven the existence of all six

TABLE 1. ELEMENTARY MATTER PARTICLES

1st family			*2nd family*			*3rd family*		
particle	*charge*	*mass*	*particle*	*charge*	*mass*	*particle*	*charge*	*mass*
leptons								
ν_e	0 e	0	ν_μ	0 e	0	ν_τ	0 e	0
e-	-1 e	.511	μ-	-1 e	106	τ^-	-1 e	1777
quarks								
u	2/3 e	2-8	c	2/3 e	1000-1600	t	2/3 e	176000
d	-1/3 e	5-15	s	-1/3 e	100-300	b	-1/3 e	4100-4500

TABLE 2. ELEMENTARY MEDIATOR PARTICLES

particle	*charge*	*mass*	*force*
γ	0 e	0	Electromagnetic
g	0 e	0	Strong
$W^{\pm}$	±1 e	80200	Weak
Z^0	0 e	91200	Weak

flavors of quarks, culminating with the discovery of the top quark in 1995.

Another property of elementary particles is termed “spin.” Spin is akin to the **rotation** of a particle on its axis, as the earth spins on its axis to give us day and night. (In actuality elementary particles do not rotate like spheres; it is only that the particle property termed spin obeys rules that mathematically are similar to those used to describe the rotation of macroscopic bodies.) The spin of elementary particles is measured in special units called “h-bar” (h-bar is **Planck’s constant** divided by 2π), and $= 1.1 \times 10^{-34}$ Joule-seconds. Using the property called spin, all matter particles are fermions which have spin one-half h-bar or three-halves h-bar. All quarks and leptons have spins of one-half h-bar. The matter particles and some of their properties are summarized in Table 1.

Masses are given in units of MeV/c^2, where c is the speed of light (three-hundred-million meters per second). The quark masses are approximate.

Elementary mediator particles

Bosons are particles defined to have spin of zero h-bar, one h-bar, or two h-bar. The elementary mediator particles are bosons with spins of one h-bar. The force we are most familiar with is the electromagnetic force. The electromagnetic force is responsible for keeping electrons and nuclei together to form atoms. The electromagnetic force is mediated by photons, which are massless. The mediators of the strong force are called gluons, because they glue quarks together to form mesons and baryons. Like the quarks, the gluons carry the color property, and as a result there are eight different types of gluons.

The weak force is more uncommon. It is responsible for radioactive decays like nuclear beta decay. The mediators of the weak force are the electrically charged W-bosons ($W\pm$), and the electrically neutral Z-bosons (Z^0), both discovered in 1983. Some properties of the mediator particles are given in Table 2.

TABLE 3. BARYONS

baryon	*quark content*	*spin*	*charge*	*mass*
p	u u d	1/2	+1 e	938
n	u d d	1/2	0 e	939
Λ	u d s	1/2	0 e	1116
Σ^+	u u s	1/2	1 e	1189
Σ^0	u d s	1/2	0 e	1192
Σ^-	d d s	1/2	-1 e	1197
Ξ^0	u s s	1/2	0 e	1315
Ξ^-	d s s	1/2	-1 e	1321
Λ_e^+	u d c	1/2	1 e	2281
Δ^{++}	u u u	3/2	2 e	1232
Δ^+	u u d	3/2	1 e	1232
Δ^0	u d d	3/2	0 e	1232
Δ^-	d d d	3/2	-1 e	1232
Σ^{*+}	u u s	3/2	1 e	1383
Σ^{*0}	u d s	3/2	0 e	1384
Σ^{*-}	d d s	3/2	-1 e	1387
Ξ^{*0}	u s s	3/2	0 e	1532
Ξ^{*-}	d s s	3/2	-1 e	1535
Ω^-	s s s	3/2	-1 e	1672

Baryons

One of the main rules of the standard quark model is that combinations of three quarks are called baryons. Protons and neutrons are the most important baryons. Protons are made of two up quarks and one down quark. Neutrons are made of two down quarks and one up quark. Since the quark model requires that naturally-occurring particles be colorless, a baryon must be made of a red, a blue, and a green quark. These combine to make a white, or colorless particle. Spin is also important in classifying baryons. Baryons are fermions and so have spins of one-half h-bar or three-halves h-bar. Table 3 summarizes several kinds of baryons, with masses in MeV/c^2 (millions of electron-volts divided by the speed of light squared) and spin in terms of h-bar.

Mesons

The second main idea of the standard quark model is that combinations of one quark and one antiquark form mesons. Pions (π) and kaons (K) are examples of mesons. Thus now we see Yukawa's nuclear force mediator particle, the pion, is really a matter particle made of a quark and an antiquark. There are several kinds of pions. For example, the positively charged pion, π^+, is made of an up quark and a down antiquark. Similarly there are several kinds of kaons. One kind of kaon, K^+, is made of an up quark and a strange antiquark. The colorless rule requires that mesons must be made of quarks with opposite color, red and anti-red for example. All mesons are bosons and so have spins of zero h-bar or one h-bar.

Current and future research

Subatomic particles are important in all electronic, optical, and nuclear technologies. Cathode-ray tubes, for example, use beams of electrons to create the pictures. A **television antenna** first picks up the television signal—a series of radio-frequency photons—which is then processed electronically and used to control an electron gun. An electron gun shoots a beam of electrons which is steered by magnets and hits the coated inner surface of the picture tube. When electrons hit this surface, it lights up, creating the picture as the electron beam is steered rapidly across it. A common type of smoke detector that uses subatomic particles is an ionization smoke detector; in an ionization smoke detector, alpha particles ionize (strip electrons from) air molecules. These ionized air molecules cause **electric current** to flow in the detector. If there is a fire, other particles enter the detector and interfere with the flow of the electric current, and this makes the alarm go off. Proton beams are used to treat **cancer**; all technologies involving **optics** or **radio** manipulate photons; all electronic devices manipulate electrons; **nuclear weapons** and **nuclear power** depend on controlling neutrons so as to produce either an explosive or a controlled nuclear chain reaction, respectively; positron-emitting isotopes are used to image metabolic activity in the human **brain** in real time; and so on.

In recent years, particle physics has been particularly exciting, with several important experimental developments. Besides the discovery of the W and Z bosons and the top quark, scientists working in Japan in 1998 found evidence that at least some of the three types of neutrinos have a small but nonzero mass. Their experiment did not allow them to determine the exact value for the mass, but subsequent work has shown that the mass of the neutrino is too small to account for the "dark matter" which astronomers have shown must account for a significant fraction of the mass of the Universe. Previously, it seemed that the unknown mass of the neutrino might explain the "dark matter" mystery; today, suspicion centers on "dark energy" rather than on "dark matter" as an explanation of the Universe's nonvisible mass.

See also Spin of subatomic particles.

KEY TERMS

Coulomb—The standard unit of electric charge, defined as the amount of charge flowing past a point in a wire in one second, when the current in the wire is one ampere.

Fundamental force—A basic force, which has its own elementary mediator particle(s). There are four fundamental forces: the strong force, the electromagnetic force, the weak force, and gravity.

Mega electron volt (MeV)—A unit of energy. One MeV is one million Electron Volts. An Electron Volt is the amount of energy an electron gains as it passes through one Volt of potential difference.

Quarks—Believed to be the most fundamental units of protons and neutrons.

Resources

Books

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