1.2 The Building Blocks of Matter

A 1-kg (≈ 2-lb) cube of solid gold has a length of about 3.73 cm (≈ 1.5 in.) on a side. If the cube is cut in half, the two resulting pieces retain their chemical identity. But what happens if the pieces of the cube are cut again and again, indefinitely? The Greek philosophers Leucippus and Democritus couldn't accept the idea that such cutting could go on forever. They speculated that the process ultimately would end when it produced a particle that could no longer be cut. In Greek, *atomos* means "not sliceable." From this term comes our English word *atom*, once believed to be the smallest particle of matter but since found to be a composite of more elementary particles.

The atom can be naively visualized as a miniature solar system, with a dense, positively charged nucleus occupying the position of the Sun and negatively charged electrons orbiting like planets. This model of the atom, first developed by the great Danish physicist Niels Bohr nearly a century ago, led to the understanding of certain properties of the simpler atoms such as hydrogen but failed to explain many fine details of atomic structure.

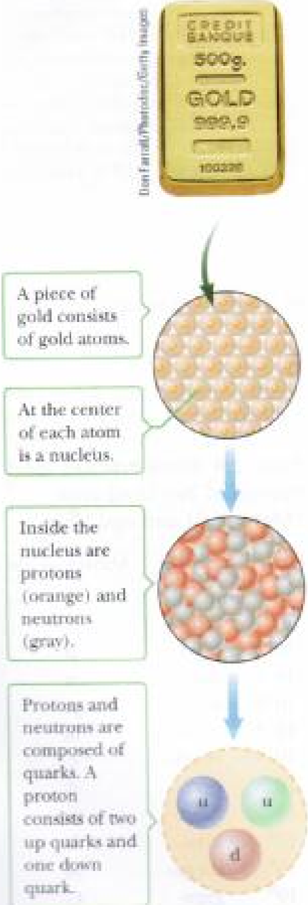


Figure 1.2 Levels of organization in matter.

Notice the size of a hydrogen atom, listed in Table 1.1, and the size of a proton—the nucleus of a hydrogen atom—one hundred thousand times smaller. If the proton were the size of a Ping Pong ball, the electron would be a tiny speck about the size of a bacterium, orbiting the proton a kilometer away! Other atoms are similarly constructed. So there is a surprising amount of empty space in ordinary matter.

After the discovery of the nucleus in the early 1900s, questions arose concerning its structure. Although the structure of the nucleus remains an area of active research even today, by the early 1930s scientists determined that two basic entities—protons and neutrons—occupy the nucleus. The *proton* is nature's most common carrier of positive charge, equal in magnitude but opposite in sign to the charge on the electron. The number of protons in a nucleus determines what the element is. For instance, a nucleus containing only one proton is the nucleus of an atom of hydrogen, regardless of how many neutrons may be present. Extra neutrons correspond to different isotopes of hydrogen—deuterium and tritium—which react chemically in exactly the same way as hydrogen, but are more massive. An atom having two protons in its nucleus, similarly, is always helium, although again, differing numbers of neutrons are possible.

The existence of *neutrons* was verified conclusively in 1932. A neutron has no charge and has a mass about equal to that of a proton. Except for hydrogen, all atomic nuclei contain neutrons, which, together with the protons, interact through the strong nuclear force. That force opposes the strongly repulsive electrical force of the protons, which otherwise would cause the nucleus to disintegrate.

The division doesn't stop here; strong evidence over many years indicates that protons, neutrons, and a zoo of other exotic particles are composed of six particles called **quarks** (rhymes with "sharks" though some rhyme it with "forks"). These particles have been given the names *up, down, strange, charm, bottom*, and *top*. The up, charm, and top quarks each carry a charge equal to $+\frac{2}{3}$ that of the proton, whereas the down, strange, and bottom quarks each carry a charge equal to $-\frac{1}{3}$ the proton charge. The proton consists of two up quarks and one down quark (see Fig. 1.2), giving the correct charge for the proton, +1. The neutron is composed of two down quarks and one up quark and has a net charge of zero.

The up and down quarks are sufficient to describe all normal matter, so the existence of the other four quarks, indirectly observed in high-energy experiments, is something of a mystery. Despite strong indirect evidence, no isolated quark has ever been observed. Consequently, the possible existence of yet more fundamental particles remains purely speculative.

1. Isotopes of one element differ in a number of
a) protons
b) electrons
c) neutrons
d) they differ just in the chemical properties
]
2. According to Demokritos, atom was:
a) similar to solar system
b) made up of protons, neutrons and electrons
c) not divisible particle
d) point-like particle

3. Which particle has the lowest known charge?
a) electron
b) up quark
c) strange quark

4.The nucleus could be stable, because of:
a) strong nuclear force
b) negative electrons in shell
c) electrical force between protons

5. There is a lot of empty space in ordinary matter, because of
a) the atom shell have very low density
b) atoms are usually very far from each other
c) atomic nucleus have very low density

26.8 General Relativity

Special relativity relates observations of inertial observers. Einstein sought a more general theory that would address accelerating systems. His search was motivated in part by the following curious fact: mass determines the inertia of an object and also the strength of the gravitational field. The mass involved in inertia is called inertial mass, m_i, whereas the mass responsible for the gravitational field is called the gravitational mass, m_g. These masses appear in Newton's law of gravitation and in the second law of motion:

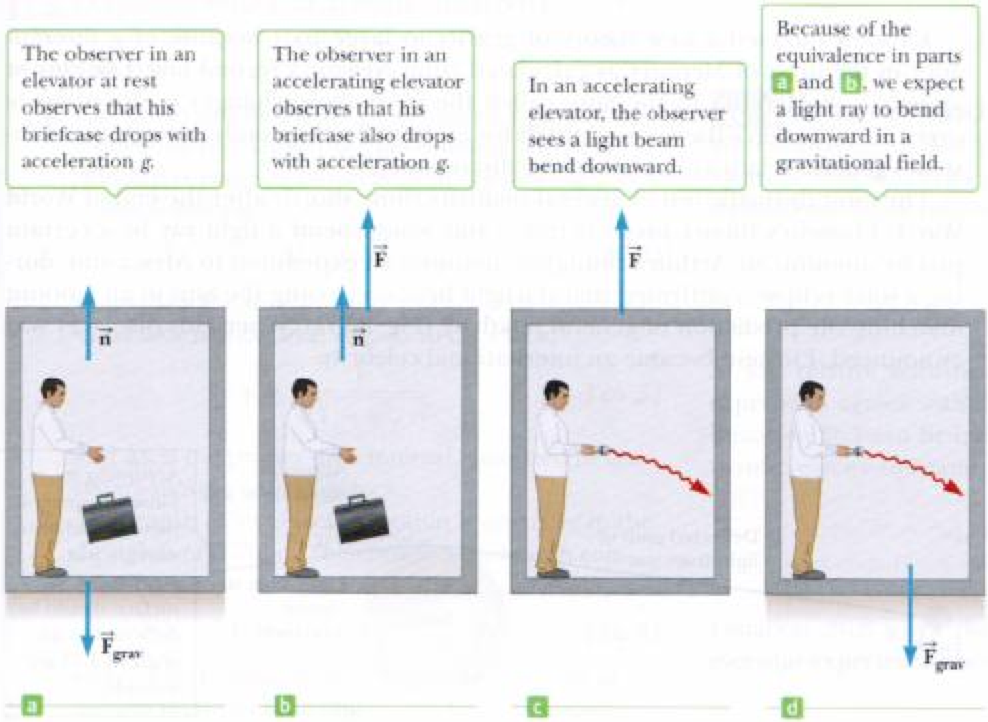
$$\text{Gravitational property} \qquad F_g = G\frac{m_g m'_g}{r^2}$$

$$\text{Inertial property} \qquad F_i = m_i a$$

The value for the gravitational constant G was chosen to make the magnitudes of m_g and m_i numerically equal. Regardless of how G is chosen, however, the strict proportionality of m_g and m_i has been established experimentally to an extremely high degree: a few parts in 10^{12}. It appears that gravitational mass and inertial mass may indeed be exactly equal: $m_i = m_g$.

In Einstein's view the remarkable coincidence that m_g and m_i were exactly equal was evidence for an intimate connection between the two concepts. He pointed out that no mechanical experiment (such as releasing a mass) could distinguish between the two situations illustrated in Figures 26.10a and 26.10b. In each case a mass released by the observer undergoes a downward acceleration of g relative to the floor.

Einstein carried this idea further and proposed that *no* experiment, mechanical or otherwise, could distinguish between the two cases. This extension to include all phenomena (not just mechanical ones) has interesting consequences. For



example, suppose a light pulse is sent horizontally across the box, as in Figure 26.10c. The trajectory of the light pulse bends downward as the box accelerates upward to meet it. Einstein proposed that a beam of light should also be bent downward by a gravitational field (Fig. 26.10d).

The two postulates of Einstein's **general relativity** are as follows:

1. All the laws of nature have the same form for observers in any frame of reference, accelerated or not.
2. In the vicinity of any given point, a gravitational field is equivalent to an accelerated frame of reference without a gravitational field. (This is the *principle of equivalence*.)

The second postulate implies that gravitational mass and inertial mass are completely equivalent, not just proportional. What were thought to be two different types of mass are actually identical.

One interesting effect predicted by general relativity is that time scales are altered by gravity. A clock in the presence of gravity runs more slowly than one in which gravity is negligible. As a consequence, light emitted from atoms in a strong gravity field, such as the Sun's, is observed to have a lower frequency than the same light emitted by atoms in the laboratory. This gravitational shift has been detected in spectral lines emitted by atoms in massive stars. It has also been verified on Earth by comparing the frequencies of gamma rays emitted from nuclei separated vertically by about 20 m.

The second postulate suggests a gravitational field may be "transformed away" at any point if we choose an appropriate accelerated frame of reference: a freely falling one. Einstein developed an ingenious method of describing the acceleration necessary to make the gravitational field "disappear." He specified a certain quantity, the *curvature of spacetime*, that describes the gravitational effect at every point. In fact, the curvature of spacetime completely replaces Newton's gravitational theory. According to Einstein, there is no such thing as a gravitational force. Rather, the presence of a mass causes a curvature of spacetime in the vicinity of the mass. Planets going around the Sun follow the natural contours of the spacetime, much as marbles roll around inside a bowl. The fundamental equation of general relativity can be roughly stated as a proportion as follows:

$$\text{Average curvature of spacetime} \propto \text{energy density}$$

Einstein pursued a new theory of gravity in large part because of a discrepancy in the orbit of Mercury as calculated from Newton's second law. The closest approach of Mercury to the Sun, called the perihelion, changes position slowly over time. Newton's theory accounted for all but 43 arc seconds per century; Einstein's general relativity explained the discrepancy.

The most dramatic test of general relativity came shortly after the end of World War I. Einstein's theory predicts that a star would bend a light ray by a certain precise amount. Sir Arthur Eddington mounted an expedition to Africa and, during a solar eclipse, confirmed that starlight bent on passing the Sun in an amount matching the prediction of general relativity (Fig. 26.11). When this discovery was announced, Einstein became an international celebrity.

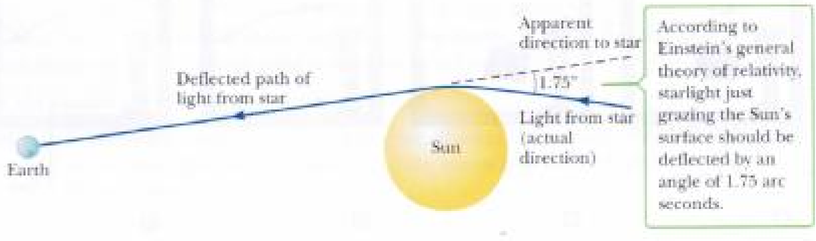


Figure 26.11 Deflection of starlight passing near the Sun. Because of this effect, the Sun and other remote objects can act as a *gravitational lens*.

General relativity also predicts that a large star can exhaust its nuclear fuel and collapse to a very small volume, turning into a **black hole**. Here the curvature of spacetime is so extreme that all matter and light within a certain radius becomes trapped. This radius, called the *Schwarzschild radius* or *event horizon*, is about 3 km for a black hole with the mass of our Sun. At the black hole's center may lurk a *singularity*, a point of infinite density and curvature where spacetime comes to an end.

There is strong evidence for the existence of a black hole having a mass of millions of Suns at the center of our galaxy.

APPLYING PHYSICS 26.1 Faster Clocks in a "Mile-High City"

Atomic clocks are extremely accurate; in fact, an error of 1 s in 3 million years is typical. This error can be described as about one part in 10^{14}. On the other hand, the atomic clock in Boulder, Colorado, is often 15 ns faster than the atomic clock in Washington, D.C., after only one day. This error is about one part in 6×10^{12}, which is about 17 times larger than the typical error. If atomic clocks are so accurate, why does a clock in Boulder not remain synchronous with one in Washington, D.C.?

EXPLANATION According to the general theory of relativity, the passage of time depends on gravity; clocks run more slowly in strong gravitational fields. Washington, D.C., is at an elevation very close to sea level, whereas Boulder is about a mile higher in altitude, so the gravitational field at Boulder is weaker than at Washington, D.C. As a result, an atomic clock runs more rapidly in Boulder than in Washington, D.C. (This effect has been verified by experiment.) ■

1. You are standing on the weight in an elevator. How many kilograms will it shows, if the elevator starts to fall freely?
a) less than before
b) more than before
c) zero
d) the same than before

2. If the gravitational mass would be lower, than inertial mass, the gravitation acceleration wouldn't be constant for object with different masses.
a) true
b) false

3. The experiment of releasing an object in an elevator will be same for two cases:
a) the elevator is at rest in a gravitation field – the elevator is moving without a gravitation field
b) the elevator is accelerating in a gravitation field – the elevator is at rest
c) the elevator is at rest without gravitation field – the elevator is moving
d) the elevator is accelerating without a gravitation field – the elevator is at rest in a gravitation field

4. A clock on the Moon would run
a) faster
b) more slowly
c) the same

5. Black hole is a place
a) of no volume
b) of no light
d) of big gravity
c) where everything disappear

30.11 Unanswered Questions in Cosmology

In the past decade new data have raised questions that many consider to be the most important in science today. At issue is the composition of the Universe, which is closely tied to its ultimate fate. One of these questions concerns the rate at which stars orbit the galaxy, explained by a postulated material called **dark matter**. Although evidence for its existence was noticed by Fritz Zwicky in 1933, only relatively recently has it become a dominant field of inquiry. The other question involves the accelerating expansion of the Universe discovered in 1998, attributed to an equally mysterious material called **dark energy**.

Dark Matter

When the velocities of stars in our galaxy are measured, it is found they are traveling too fast to remain bound by gravity to the Milky Way, if the mass of the galaxy is due to that found in luminous stars. Figure 30.14a shows the velocity versus radial distance curve for bodies circling the Sun. As the distance from the Sun increases, the velocity of planetary bodies decreases, a consequence of the inverse square law of gravitation. Figure 30.14b, on the other hand, shows the velocity curve of stars in the Milky Way galaxy. The curve increases and flattens out but doesn't decline,

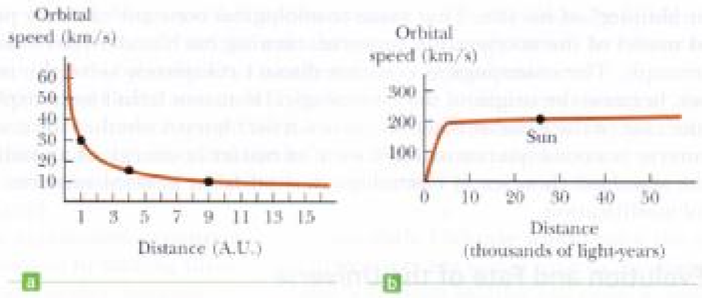


Figure 30.14 (a) Velocity versus radial distance curve for bodies circling the Sun. (b) Velocity curve of stars in the Milky Way galaxy.

meaning the stars are traveling much faster than expected if primarily under the influence of gravitation from visible stars. Traveling at higher than the expected galactic escape speed, the stars should leave the galaxy, yet remain in their orbits. Similar observations have been made of stars in other galaxies.

Two general theories have been advanced to account for the behavior of too-rapidly moving stars: either there is a new form of dark matter that has not been directly observed, or the law of gravitation must become stronger than an inverse square at long range. From the velocity profile of stars, 90% of the matter in the galaxy would consist of the hypothetical dark matter. Among the candidates for dark matter are neutrinos, which due to "neutrino oscillation," the spontaneous changing from one type of neutrino into another, are now thought to have mass. All stars emit enormous numbers of neutrinos every second, so if neutrinos had even a small mass, they could account for the dark matter. Another hypothetical candidate is a WIMP, a weakly interacting massive particle left over from the Big Bang. Because other galaxies have rotation curves similar to the Milky Way's, it may well be that dark matter predominates over ordinary matter in the Universe at large.

The leading alternate explanation for the galactic rotation curves is that Newton's law of gravitation doesn't hold over large distances. That theory, called MOND (Modified Newtonian Dynamics), has received a great deal of attention but thus far has not worked well enough to gain widespread acceptance. Some researchers have also tried to account for the rotation curves of galaxies by using Einstein's theory of gravity, general relativity. Finally, it is entirely possible that the correct theory may require both new kinds of matter and a modification of gravity theory.

Dark Energy and the Accelerating Universe

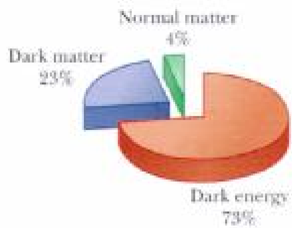


Figure 30.15 The theorized composition of the Universe. Normal matter, as found on Earth and in the Sun, comprises only about 4% of the material in the Universe. The unknown material causing increased gravitational attraction on the galactic scale is called dark matter, whereas the similarly unknown material causing the accelerated expansion of the Universe is called dark energy.

By 1998 two groups of astronomers, one led by Brian Schmidt and Adam Riess and the other by Saul Perlmutter, had made highly accurate new measurements of the distances to other galaxies using Type 1a supernovae. Those observations showed that the Universe is both expanding and accelerating! The accelerated expansion can't be caused by normal matter nor by dark matter because they exert an attractive gravitational force. Instead, it is thought that a new kind of matter, called **dark energy**, exerts a repulsive force that causes the Universe to expand more rapidly than is predicted by Einstein's theory of general relativity. Figure 30.15 shows the theorized proportions of matter, dark matter, and dark energy. Normal atoms, the kind we're made of, comprise only about 4% of the Universe, whereas approximately 23% is dark matter and 73% is dark energy.

Einstein introduced a cosmological constant into his theory of general relativity in order to explain why the Universe appeared not to change with time. The cosmological constant provided a repulsive force sufficient to prevent the matter of the Universe from collapsing under the attractive influence of gravity. When Edwin Hubble's observations of the red shift of galaxies led to the notion of a dynamically expanding universe, Einstein called the cosmological constant "the biggest blunder" of his life. That same cosmological constant can now produce a good model of the accelerating universe, turning his blunder into something of a triumph. The cosmological constant doesn't completely solve the mystery, however, because the origin of the cosmological constant hasn't been explained. As in the case of the galactic rotation curves, it isn't known whether the accelerating universe is a consequence of a new form of matter or energy, or an indication that the standard theories of cosmology derived from general relativity are in need of modification.

The Evolution and Fate of the Universe

Unsolved questions remain about the origin and early evolution of the Universe. Although the Big Bang model explains why galaxies seem to be flying away from us, several observational problems have emerged that can't be fully explained by the Big Bang hypothesis alone.

First of all, the Universe, as measured by the temperature of the microwave background, is altogether too uniform. It's as if the entire Universe were in equilibrium. For a system to be in equilibrium, its constituents must be able to exchange energy, arriving after a certain passage of time to a uniform temperature. How could this equilibrium be achieved, however, when different parts of the Universe are so far apart from each other that they could not possibly exchange energy? That mystery is called the horizon problem.

Second, the measurements of the cosmic microwave background strongly suggest that the Universe has a flat geometry. Figure 30.16 shows the standard three fates of the Universe, derived with Einstein's theory of general relativity by graphing the expansion factor, R, versus cosmic time. The expansion factor may be thought of as giving a measure of the size of the Universe, like a cosmic radius. A flat universe is expected to expand forever, although in the limit as time goes to infinity the expansion rate gradually slows to zero. A flat universe, however, is a state of unstable equilibrium, like a pencil standing on its point. With a small deviation one way or the other, either the Universe would collapse again as on the lower curve in Figure 30.16, or expand forever as in the upper curve in Figure 30.16. To be flat now, the Universe had to be flat also at the beginning of the Universe to extremely high accuracy. It is extremely improbable that the Universe was so finely tuned early in its evolution. That fine-tuning is called the flatness problem.

A third problem arises when particle theories are combined with cosmology. Studies of the standard model of particle physics in the early Universe show that large numbers of magnetic monopoles should have been created in the early Universe, so many that hundreds of thousands of them would pass through our bod-

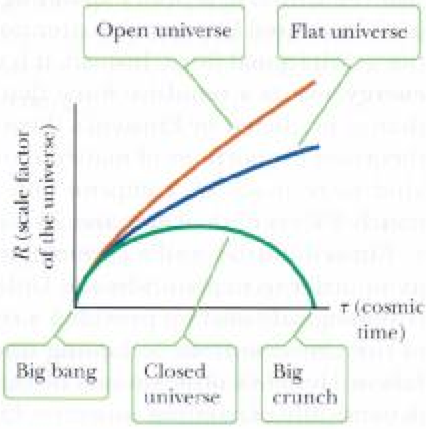


Figure 30.16 The three fates of the Universe, according to Einstein's theory of general relativity. With a sufficient quantity of attractive matter, the universe would initially expand but eventually collapse back into a "big crunch." A flat universe would expand forever, with the expansion slowing to zero in the limit as cosmic time τ goes to infinity. A hyperbolic (or open) universe would accelerate forever. A dark energy universe, or equivalently, one due to a positive cosmological constant, would be similar to the hyperbolic universe but curve upward.

ies every second. Magnetic monopoles are tiny magnets consisting of an isolated north or south pole, and despite calculations predicting them to be common, they have never been observed. That is called the monopole problem.

In 1981 Alan Guth, now at MIT, proposed the inflationary model of the Universe to resolve these three problems with a single mechanism. In this model, an as yet unidentified field called the **inflaton field** caused the Universe to enter into a very rapid exponential inflation, expanding 10^{32} times in size in a tiny fraction of a second.

That accelerated expansion in the very early Universe would solve the monopole problem by making them so dilute that very few would exist in the observable Universe. Further, because the Universe was much smaller just prior to inflation, it would be in thermal equilibrium and, consequently, after the expansion would remain similar in all places and in all directions, solving the horizon problem. Finally, the rapid inflation would cause the curvature of spacetime to appear to flatten out, just as the Earth appears flat to those on its surface because only a very small portion of the entire Earth is visible in a given locality. That solves the flatness problem.

After the brief inflationary epoch the Universe could continue to expand normally. Whereas there is no definitive evidence that the inflationary Universe is correct, it is currently the most accepted working hypothesis for how the early Universe evolved. Some researchers have attempted to combine inflation and dark energy into a single theory called "quintessence." To date, however, no single theory explaining the origins of either early inflation or later universal acceleration has found general support among cosmologists.

only MATECO: Think of 4 questions, about this article.