present at this time and this ratio will continue about the same to the present day. There are no atoms formed yet because the temperature is still too high. What is present is called a *plasma.*

6. *From 30 min to 1 Billion Years*
Further expansion and cooling now allows the hydrogen and helium nuclei to capture electrons and the first chemical elements are born. Large clouds of hydrogen and helium are formed.

7. *From 1 Billion Years to 10 Billion Years*
The large rotating clouds of hydrogen and helium matter begin to concentrate due to the gravitational force. As the radius of the cloud decreases, the angular velocity of the cloud increases in order to conserve angular momentum. (Similar to the spinning ice skater discussed in section 9.7.) These condensing, rotating masses are the beginning of galaxies.

Within the galaxies, gravitation causes more and more matter to be compressed into spherical objects, the beginning of stars. More and more matter gets compressed until the increased pressure of that matter causes a high enough temperature to initiate the fusion process of converting hydrogen to helium and the first stars are formed. Through the fusion process, more and more chemical elements are formed. The higher chemical elements are formed by neutron absorption until all the chemical elements are formed.

These first massive stars did not live very long and died in an explosion—a supernova—spewing the matter of all these heavier elements out into space. The fragments of these early stars would become the nuclei of new stars and planets.

8. *From 10 Billion Years to the Present*
The remnants of dead stars along with hydrogen and helium gases again formed new clouds, which were again compressed by gravity until our own star, the sun, and the planets were formed. All the matter on earth is the left over ashes of those early stars. Thus, even we ourselves are made up of the ashes of these early stars. As somebody once said, there is a little bit of star dust in each of us.

The Language of Physics

Leptons
Particles that are not affected by the strong nuclear force (p. 1036).

Hadrons
Particles that are affected by the strong nuclear force (p. 1036).

Baryons
A group of hadrons that have half-integral spin and are composed of three quarks (p. 1036).

Mesons
A group of hadrons that have integral spin, that are composed of quark-antiquark pairs (p. 1036).

Antiparticles
To each elementary particle in nature there corresponds another particle that has the characteristics of the original particle but opposite charge. Some neutral particles have antiparticles that have opposite spin, whereas the photon is its own antiparticle. The antiparticle of the proton is the antiproton. The antiparticle of the electron is the antielectron or positron. If a particle collides with its antiparticle both are annihilated with the emission of radiation or other particles. Conversely, photons can be converted to particles and antiparticles (p. 1037).

Antimatter
Matter consists of protons, neutrons, and electrons, whereas antimatter consists of antiprotons, antineutrons, and antielectrons (p. 1037).

Quarks
Elementary particles that are the building blocks of matter. There are six quarks and six antiquarks. The six quarks are: up, down, strange, charmed, bottom, and top. Each quark and antiquark also comes in three colors, red, green, and blue. Each color quark also has an anticolor quark. Baryons are composed of red, green, and blue quarks and mesons are made up of a linear combination of colored quark-antiquark pairs (p. 1038).

Quantum electrodynamics (QED)
The merger of electromagnetic theory with quantum mechanics. In QED, the electric force is transmitted by the exchange of a virtual photon (p. 1042).

Weak nuclear force
The weak nuclear force does not exert the traditional push or pull type of force known in classical physics. Rather, it is responsible for the transmutation of the subatomic particles. The weak force is independent of electric charge and acts between leptons and hadrons and also between hadrons and hadrons. The weak force is the weakest force after gravity (p. 1043).

Electroweak force
A unification of the electromagnetic force with the weak nuclear force. The force is mediated by four particles: the photon and three intermediate vector bosons called W^+, W^-, and Z^0 (p. 1043).

The strong nuclear force
The force that holds the nucleons together in the nucleus. The force is the result of the color forces between the quarks within the nucleons. At relatively large separation distances within the nucleus, the quark-antiquark pair (meson), which is created by the gluons, is exchanged between the nucleons. At shorter distances within the nucleus, the strong force can be explained either as an exchange between the quarks of one proton and the quarks of another proton, or perhaps as a direct exchange of the gluons themselves, which give rise to the quark-quark force within the nucleon (p. 1044).

Quantum chromodynamics (QCD)
In QCD, the force holding quarks together is caused by the exchange of a new particle, called a gluon. A gluon interacting with a quark changes the color of a quark (p. 1044).

Grand unified theory
A theory that merges the electroweak force with the strong nuclear force. This force should be able to transform quarks into leptons and vice versa. The theory predicts the existence of 12 new particles, called X particles that are capable of converting hadrons into leptons by changing quarks to leptons. This theory also predicts that an isolated proton should decay. However, no such decays have ever been found, so the theory may have to be modified (p. 1045).

Gravitons
The quanta of the gravitational field. Since gravitation is a warping of spacetime, the graviton must be a quantum of spacetime (p. 1047).

Superforce
An attempt to unify all the forces under a single force. The theories go under the names of supersymmetry, super gravity, and superstrings (p. 1050).

The Big Bang theory
The theory of the creation of the universe that says that the universe began as a great bundle of energy that exploded outward about 15 billion years ago. It was not an explosion of matter into an already existing space and time, rather it was the very creation of spacetime and matter (p. 1052).

Questions for Chapter 34

†**1.** Discuss the statement, "A graviton is a quantum of gravity. But gravity is a result of the warping of spacetime. Therefore, the graviton should be a quantum of spacetime. But just as a quantum of the electromagnetic field, the photon, has energy, the graviton should also have energy. In fact, we can estimate the energy of a graviton. Therefore, is spacetime another aspect of energy? Is there only one fundamental quantity, energy?"

†**2.** Does antimatter occur naturally in the universe? How could you detect it? Where might it be located?

3. When an electron and positron annihilate, why are there two photons formed instead of just one?

4. Murray Gell-Mann first introduced three quarks to simplify the number of truly elementary particles present in nature. Now there are six quarks and six antiquarks, and each can come in three colors and three anticolors. Are we losing some of the simplicity? Discuss.

5. Discuss the experimental evidence for the existence of structure within the proton and the neutron.

6. How did the Pauli exclusion principle necessitate the introduction of colors into the quark model?

†**7.** If the universe is expanding from the Big Bang, will the gravitational force of attraction of all the masses in the universe eventually cause a slowing of the expansion, a complete stop to the expansion, and finally a contraction of the entire universe?

†**8.** Just as there are electromagnetic waves associated with a disturbance in the electromagnetic field, should there be gravitational waves associated with a disturbance in a gravitational field? How might such gravitational waves be detected?

†**9.** Einstein's picture of gravitational attraction is a warping of spacetime by matter. This has been pictured as the rubber sheet analogy in chapter 30. What might antimatter do to spacetime? Would it warp spacetime in the same way or might it warp spacetime to cause a gravitational repulsion? Would this be antigravity? Would the antiparticle of the graviton then be an antigraviton? Instead of a black hole, would there be a white hill?

10. Discuss the similarities and differences between the photon and the neutrino.

Problems for Chapter 34

Section 34.2 Particles and Antiparticles

1. How much energy is released when an electron and a positron annihilate? What is the frequency and wavelength of the two photons that are created?

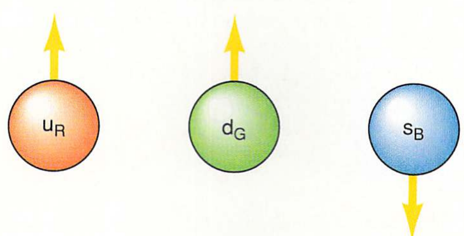
2. How much energy is released when a proton and antiproton annihilate?

3. How much energy is released if 1.00 kg of matter annihilates with 1.00 kg of antimatter? Find the wavelength and frequency of the resulting two photons.

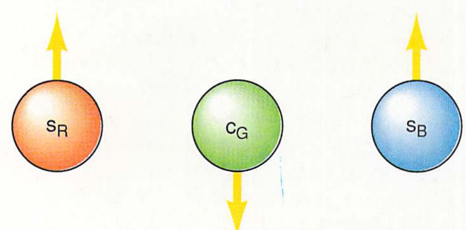
4. A photon "disintegrates," creating an electron-positron pair. If the frequency of the photon is 5.00×10^{24} Hz, determine the linear momentum and the energy of each product particle.

Section 34.4 Quarks

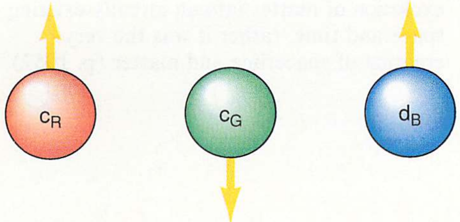
5. If the three quarks shown in the diagram combine to form a baryon, find the charge and spin of the resulting particle.



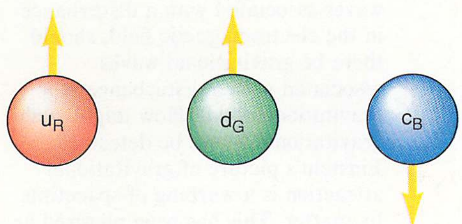
6. If the three quarks shown in the diagram combine to form a baryon, find the charge and spin of the resulting particle.



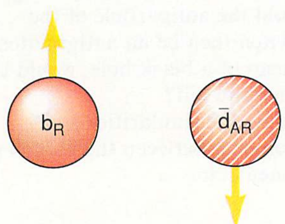
7. If the three quarks shown in the diagram combine to form a baryon, find the charge and spin of the resulting particle.



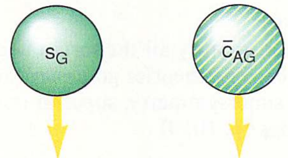
8. Find the charge and spin of the baryon that consists of the three quarks shown in the diagram.



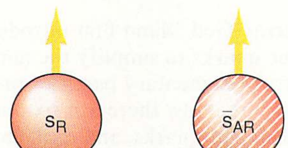
9. If the two quarks shown in the diagram combine to form a meson, find the charge and spin of the resulting particle.



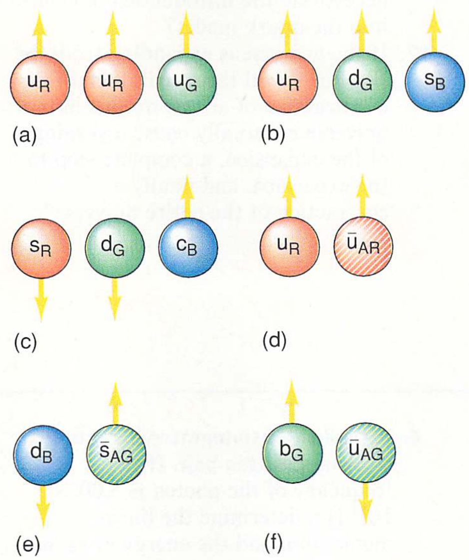
10. If the two quarks shown in the diagram combine to form a meson, find the charge and spin of the resulting particle.



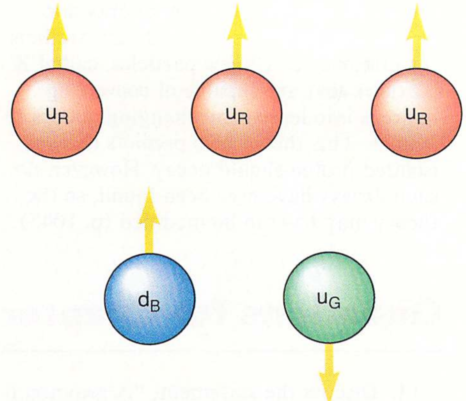
11. Find the charge and spin of the meson that consists of the two quarks shown in the diagram.



12. Which of the combinations of particles in the diagram are possible and which are not. If the combination is not possible, state the reason.



13. Why are the two particles in the diagram impossible?



14. A baryon is composed of three quarks. It can be made from a total of six possible quarks, each in three possible colors, and each with either a spin-up or spin-down. From this information, how many possible baryons can be made?

15. A meson is composed of a quark-antiquark pair. It can be made from a total of six possible quarks, each in three possible colors, and each with either a spin-up or spin-down, and six possible antiquarks each in three possible colors, and each with either a spin-up or spin-down. Neglecting linear combinations of these quarks, how many possible mesons can be made?

16. From problems 14 and 15 determine the total number of possible hadrons, ignoring possible mesons made from linear combinations of quarks and antiquarks. Could you make a "periodic table" from this number? Discuss the attempt to attain simplicity in nature.

17. Determine all possible quark combinations that could form a baryon of charge +1 and spin ½.