Section 30.3

Objectives

- **Distinguish** the different models of the universe.
- **Compare and contrast** how expansion is relative to each of the models.
- **Explain** the importance of the Hubble constant.

Review Vocabulary

radiation: the process of emitting radiant energy in the form of waves or particles

New Vocabulary

cosmology
Big Bang theory
cosmic background radiation

Cosmology

MAIN Idea The Big Bang theory was formulated by comparing evidence and models to describe the beginning of the universe.

Real-World Reading Link Manipulating a magnet and iron filings can help you model Earth's magnetic field. Cosmologists use particle accelerators to help create models of the early universe.

Big Bang Model

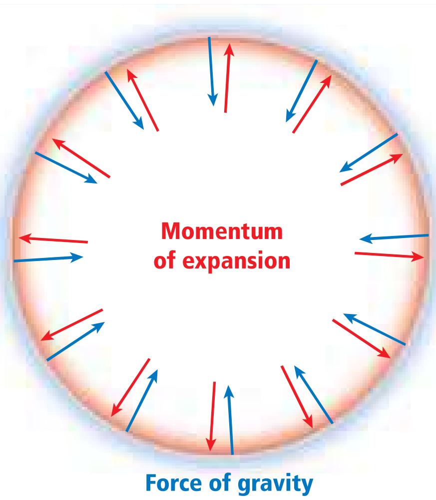
The study of the universe—its nature, origin, and evolution—is called **cosmology.** The mathematical basis for cosmology is general relativity, from which equations were derived that describe both the energy and matter content of the universe. These equations, combined with observations of density and acceleration, led to the most accurate model so far—the Big Bang model. The fact that the universe is expanding implies that it had a beginning. The theory that the universe began as a point and has been expanding since is called the **Big Bang theory.** Although the name might seem to imply explosion into space, the theory describes an expansion of space itself while gravity holds matter in check. Review the effects of expansion by checking results from the MiniLab in Section 30.2.

Outward expansion Similar to a star's internal fusion pressure opposing the effort of a gravitational force to collapse the star, the universe has two opposing forces. In the Big Bang model, the momentum of the outward expansion of the universe is opposed by the inward force of gravity acting on the matter of the universe to slow that expansion, as illustrated in **Figure 30.21.** What ultimately will happen depends on which of these two forces is stronger.

When the rate of expansion of the universe is known, it is possible to calculate the time since the expansion started and determine the age of the universe. When the distance to a galaxy and the rate at which it is moving away from Earth are known, it is simple to calculate how long ago that galaxy and the Milky Way were together. In astronomical terms, if the value of H, the expansion (Hubble) constant, is known, then the age of the universe can be determined. Corrections are needed to allow for the fact that the expansion has not been constant—it has slowed since the beginning and is now accelerating.

Based on the best value for H that has been calculated from *Hubble Space Telescope* data and the data on the cosmic background radiation, the age of the universe can be pinpointed to 13.7 billion years. This fits with what astronomers know about the age of the Milky Way galaxy, which is estimated to be between 12 and 14 billion years old, based on the ages of the oldest star clusters.

Figure 30.21 The universe is either open, flat, or closed, depending on whether gravity or the momentum of expansion dominates.



Possible outcomes Based on the Big Bang theory, there are three possible outcomes for the universe, as shown in **Figure 30.22.** The average density of the universe is an observable quantity with vast implications to the outcome.

Open universe An open universe is one in which the expansion will never stop. This would happen if the density of the universe is insufficient for gravity to ever halt the expansion.

Closed universe A closed universe will result if the expansion stops and turns into a contraction. That would mean the density is high enough that eventually the gravity caused by the mass will halt the expansion of the universe and pull all of the mass back to the original point of origin.

Flat universe A flat universe results if the expansion slows to a halt in an infinite amount of time, but never contracts. This means that while the universe would continue to expand, its expansion would be so slow that it would seem to stop.

Critical density All three outcomes are based on the premise that the rate of expansion has slowed since the beginning of the universe, but the density of the universe is what is unknown. At the critical density, there is a balance, so that the expansion will come to a halt in an infinite amount of time. The critical density, about 6×10^{-27} kg/m^3, means that, on average, there are only two hydrogen atoms for every cubic meter of space. When astronomers attempt to count the galaxies in certain regions of space and divide by the volume, they get an even smaller value. So they would conclude that the universe is open, except that the dark matter has not been included. But even the best estimates of dark matter density are not enough to conclude that the universe is a closed system.

Cosmic Background Radiation

Scientists hypothesize that if the universe began in a highly compressed state before the Big Bang, it would have been extremely hot. Then as the universe expanded, the temperature cooled. After about 750,000 years, the universe was filled with electromagnetic radiation in the form of shortwave radio radiation. With continued expansion, the wavelengths became longer. Today this radiation is in the form of microwaves.

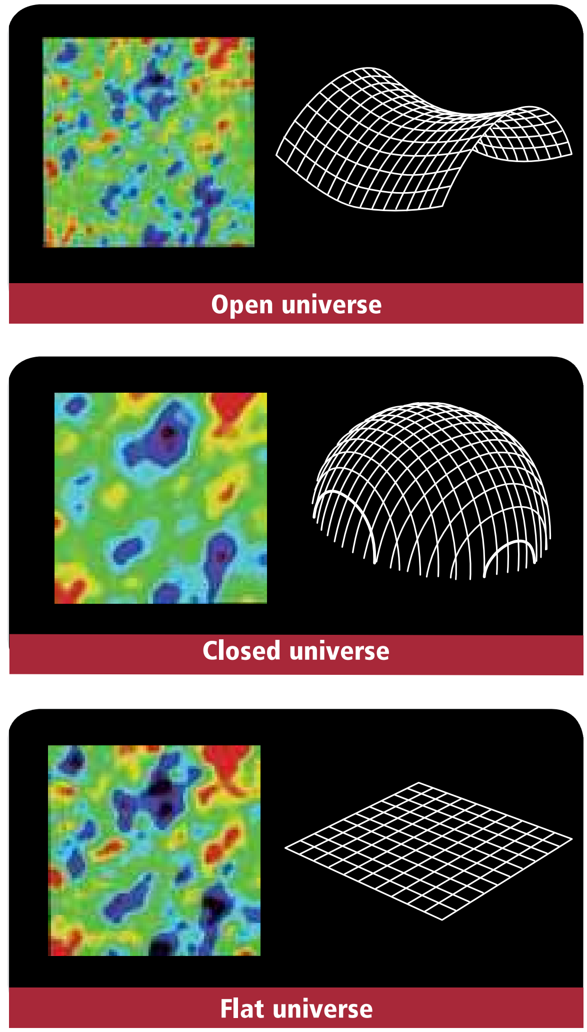
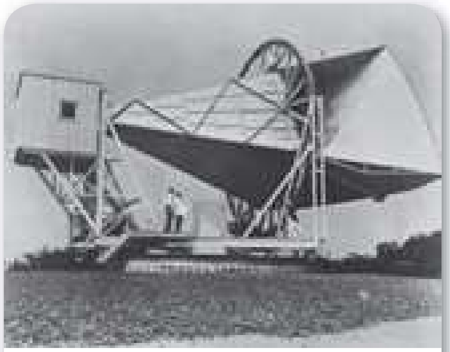


Figure 30.22 There are three possible outcomes for the future of the universe. It could continue to expand forever and be open, it could snap back at the end and be a closed system, or it could be flat and just die out like a glowing ember. The green squares show the estimated cosmic background radiation necessary for each result. See **Figure 30.24.**



■ **Figure 30.23** The cosmic background radiation was discovered by accident with this radio antenna at Bell Labs in Holmdel, New Jersey.

Discovery In 1965, scientists discovered a persistent background noise in their radio antenna, shown in **Figure 30.23.** This noise was caused by weak radiation, called the **cosmic background radiation,** that appeared to come from all directions in space and corresponded to an emitting object having a temperature of about 2.735 K (–270°C). This was very close to the temperature predicted by the Big Bang theory, and the radiation was interpreted to be from the beginning of the Big Bang.

Mapping the radiation Since the discovery of the cosmic background radiation, extensive observations have confirmed that it matches the properties of the predicted leftover radiation from the early, hot phase in the expansion of the universe. Earth's atmosphere blocks much of the radiation, so it is best observed from high-altitude balloons or satellites. An orbiting observatory called the *Wilkinson Microwave Anisotropy Probe (WMAP),* launched by NASA in 2001, mapped the radiation in greater detail, as shown in **Figure 30.24.** The peak of the radiation it measured has a wavelength of approximately 1 mm; thus, it is microwave radiation in the radio portion of the electromagnetic spectrum.

Reading Check **Identify** what discovery helped solidify the Big Bang theory.

Vocabulary

Science usage v. Common usage

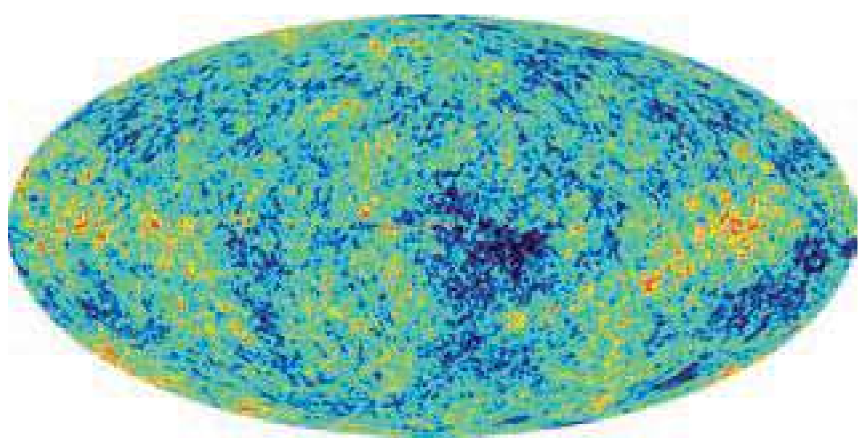
Cosmic

Science usage: of or relating to the universe in contrast to Earth alone

Common usage: characterized by greatness of thought or intensity

Acceleration of the expansion The data produced by *WMAP* have provided enough detail to refine cosmological models. In particular, astronomers have found small wiggles in the radiation representing the first major structures in the universe. This helped to pinpoint the time at which the first galaxies and clusters of galaxies formed and also the age of the universe. According to every standard model, the expansion of the universe is slowing down due to gravity. However, the debate about the future of the universe based on this model came to a halt with the surprising discovery that the expansion of the universe is now accelerating. Astronomers have labeled this acceleration dark energy. Although they do not know its cause, they can determine the rate of acceleration and estimate the amount of dark energy.

■ **Figure 30.24** Temperature differences of one-millionth of a degree can be noted in the WMAP of cosmic background radiation.
Write ***one-millionth of a degree in scientific notation.***



Contents of the Universe

All the evidence is now pointing in the same direction, and astronomers can say with a high degree of precision of what the universe is composed. Their best clue comes from the radiation left in space from the universe's beginning. The ripples left during the time of cooling of the universe's beginning radiation set the density at that point of time and dictated how matter and energy would separate. This in turn laid the groundwork for future galaxies. **Figure 30.25** gives one view into the universe.

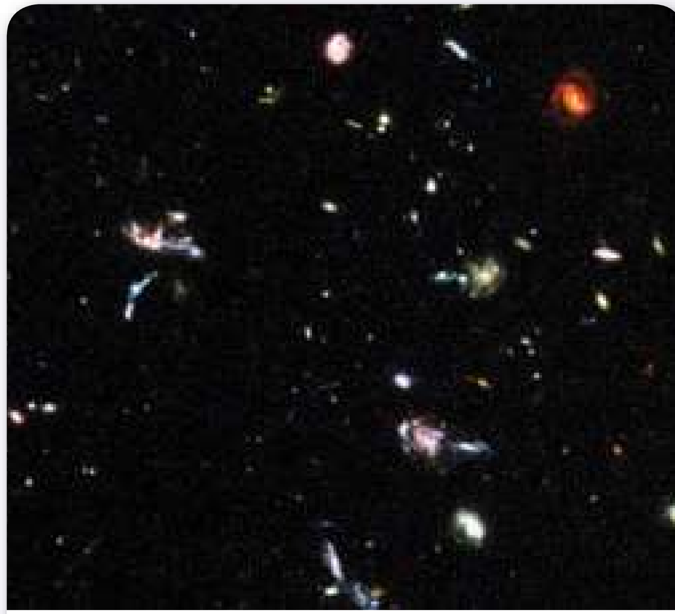


Figure 30.25 Astronomers estimate that only 4 percent of the universe is composed of luminous matter.

Dark matter and energy Cosmologists estimate that the universe is composed of dark matter (21 percent), dark energy (75 percent), and luminous matter. If you compare the universe to Earth, dark energy is like the water covering the surface of Earth. That would be like saying that 70 percent of Earth is covered with something that is not identified.

What is unknown today is the nature of the dark matter and dark energy. Dark matter is thought to consist of subatomic particles, but of the known particles, none display the right properties to explain or fully define dark matter. And although scientists recognize the effects of dark energy, they still do not know what it is.

Section 30.3 Assessment

Section Summary

- The study of the universe's origin, nature, and evolution is cosmology.
- The Big Bang model of the universe came from observations of density and acceleration.
- The critical density and the amount of dark energy of the universe will determine whether the universe is open or closed.
- Cosmic background radiation gives support to the Big Bang theory of the universe.
- Mapping the cosmic background radiation has indicated the existence of dark matter and dark energy.

Understand Main Ideas

1. MAIN Idea **Compare and Contrast** What are the differences among the three possible outcomes of the universe?
2. **Describe** how the age of the universe can be calculated using the Big Bang model.
3. **Explain** why dark matter is important in determining the density of matter in the universe.
4. **Explain** why the cosmic background radiation was an important discovery.

Think Critically

5. **Determine** What does dark matter have to do with the critical density of the universe?
6. **Analyze** All of the models tell us that the universe should be slowing down, but instead it is speeding up. How does this affect our model of the universe?

WRITING in Earth Science

7. Write one paragraph summarizing the evidence for the Big Bang model of the universe.