## Section Objectives

- Distinguish between a hypothesis, a theory, and a scientific law.
- Describe the Doppler effect.
- Summarize the big bang theory of the origin of the universe.
- List evidence for the big bang theory.

# 1.3 Birth of a Theory: The Big Bang

Scientific methods are useful tools for the study of earth science. However, the development and testing of a hypothesis is just one step along the way to scientific understanding. Once a hypothesis has been tested and generally accepted, it may lead to the development of a **theory.** A theory is a hypothesis or a set of hypotheses that is supported by the results of experimentation and observation. A theory provides a general explanation for scientific observations that is consistent with known facts.

Once a theory is well established through research and experimentation, it may become a **scientific law.** A scientific law is a rule that correctly describes a natural phenomenon. To become a law, a theory must be proven correct every time it is tested. For example, the law of conservation of mass and energy, which states that the total amount of matter and energy in the universe does not change, has been tested again and again. It has never been found to fail.

## Light and the Doppler Effect

One of the most exciting theories of modern science—how the universe began—has its roots in observations made more than 300 years ago. In 1665, the British scientist Isaac Newton observed that sunlight passing through a glass prism produced a rainbow of colors: red, orange, yellow, green, blue, and violet. Newton named this display of colors the **spectrum** (pl. spectra).

Light travels in waves. The distance from the crest of one wave to the crest of the next is a **wavelength.** Each color in the spectrum has a different wavelength. Red light has the longest wavelength, and violet light has the shortest. As light passes through a prism, each wavelength is bent at a different angle, and the band of colors results.

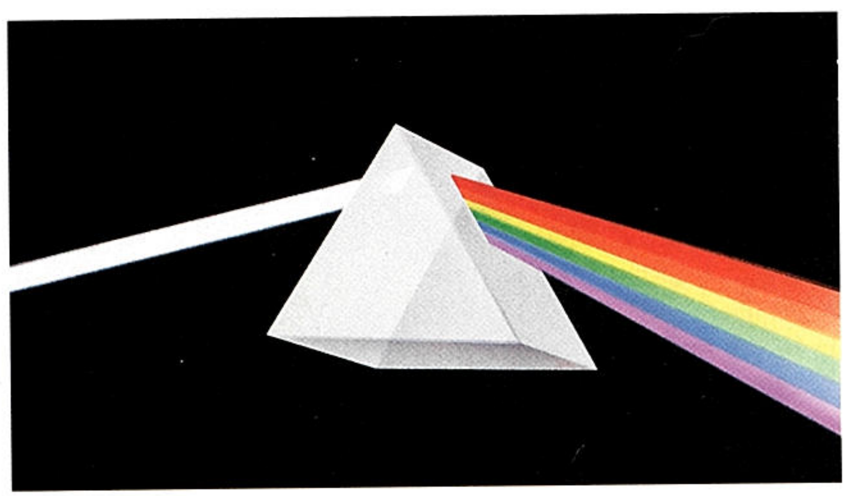


**Figure 1–10. A prism bends the different wavelengths of light, separating white light into a rainbow of colors.**

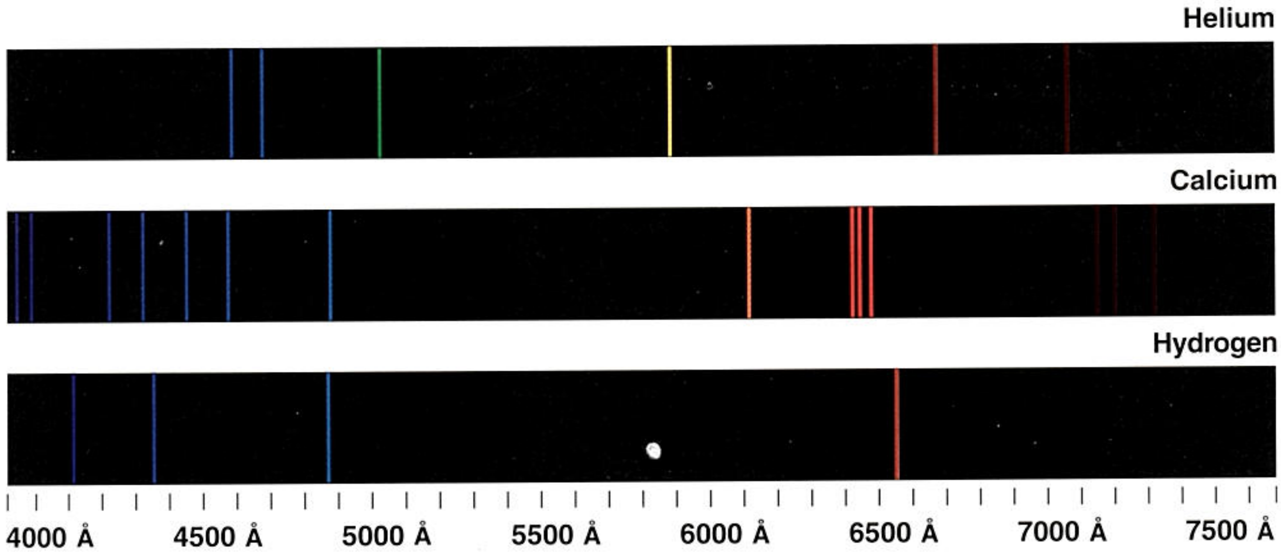



**Figure 1–11. Each element produces a bright-line spectrum when heated.**

In the late nineteenth century, research revealed that when chemical **elements** are heated, they too produce spectra. An element is a substance, such as hydrogen or iron, that cannot be broken down into a simpler form by ordinary chemical means. Instead of a full spectrum of continuous colors, like that produced by sunlight, a heated element produces only a series of thin colored lines spaced at uneven intervals. This series of colored lines, called a *bright-line spectrum,* indicates that the light source is sending out only certain wavelengths of light. An example of a bright-line spectrum is shown in Figure 1–11. Each element produces its own bright-line spectrum, as unique as a set of fingerprints.

Scientists also discovered that when a light source is moving toward an observer, the wavelengths of the light produced appear shorter to the observer. As a result, the spectral lines of the light source appear to shift slightly toward the shorter wavelengths, or the blue end of the spectrum. When a light source is moving away from an observer, the light waves appear longer to the observer. The spectral lines of the light source appear to shift toward the longer wavelengths, or the red end of the spectrum. The faster a light source is moving, the greater the shift of its spectrum. The apparent shift in the wavelengths of energy emitted by an energy source moving away from or toward an observer is called the **Doppler effect.**

## Evidence: Red Shift

Using an instrument called a **spectroscope,** scientists studied starlight to determine what elements were present in the stars. A spectroscope contains a prism, which splits starlight into a spectrum of different colors and wavelengths. By comparing the spectrum produced by each star with the spectra of known elements, scientists were able to determine the chemical makeup of various stars. The sun, for example, was found to be about 92 percent hydrogen and almost 8 percent helium, with traces of nearly 100 other elements.

The study of starlight spectra revealed surprising information about our universe. Scientists found that the spectra of most *galaxies,*

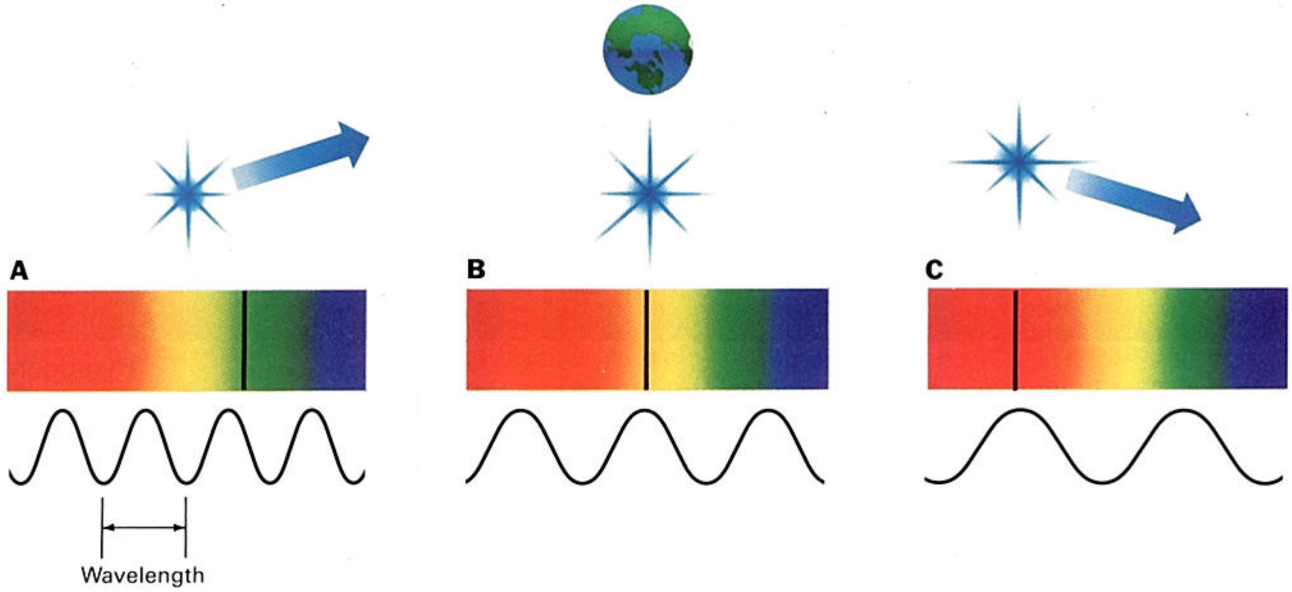



**Figure 1-12. The wavelengths of light produced by star A, moving toward the earth, appear shorter. Therefore, the spectral lines of star A are shifted toward the blue end of the spectrum. The wavelengths of light produced by star C, moving away from the earth, appear longer. Therefore, the spectral lines of star C are shifted toward the red end of the spectrum. Star B is stationary.**

or large systems of stars, tested were shifted toward the red end of the spectrum. Only a few close galaxies showed a shift toward the blue end of the spectrum. The red shift indicates that almost all of the galaxies in the universe are moving away from the earth.

By examining the degree of red shift, scientists were also able to determine the speed at which the galaxies were traveling. Scientists found that the most distant galaxies showed the greatest red shift and thus were moving away the fastest. From these observations of spectra, most scientists have concluded that the universe is expanding.

## A Theory Emerges

Observations of red shift led scientists to propose a hypothesis to explain the expanding universe. The hypothesis states that billions of years ago, all the matter and energy in the universe was compressed into an extremely small volume. About 17 billion years ago, a sudden event called the *big bang* sent all the matter and energy hurtling outward in a giant cloud. As the cloud expanded, some of the matter gathered into clumps that evolved into galaxies. Today the universe is still expanding, and the galaxies continue to move apart from one another. This movement causes the apparent red shift in the spectra of galaxies.

Despite the evidence of red shift in the spectra of the galaxies, a number of scientists did not accept the big bang hypothesis. They argued that if the big bang had taken place as the hypothesis proposed, the energy left from the explosion would be found evenly distributed throughout the expanding universe. If this energy could not be found, they insisted, then there was little reason to accept the big bang hypothesis.

An important discovery in the 1960's finally convinced most scientists who had doubted the evidence of red shift. Using radio telescopes, researchers detected low levels of energy, called **background radiation,** evenly distributed throughout the universe. The presence of this energy convinced most scientists that the big bang hypothesis was correct. Because of the abundant evidence and

## SMALL-SCALE INVESTIGATION

### The Big Bang Theory

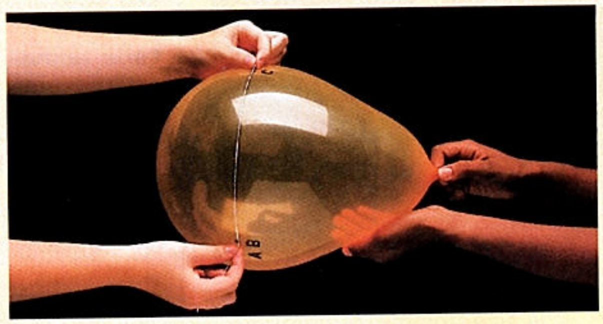
According to the big bang theory, almost all galaxies are moving outward from all other galaxies. You can demonstrate the principles of this expansion with a simple model.

#### Materials

large (6–7 cm), uninflated round balloon; water-based felt-tip pen; string, 30 cm long; ruler

#### Procedure

1. Mark a pair of dots 0.5 cm apart across the middle of the uninflated balloon. Label them **A** and **B**. Mark a third dot 5.0 cm away from **B**. Label this dot **C**.
2. Blow into the balloon for 2–3 seconds. Record your elapsed time. Pinch the end of the balloon between your fingers to keep it inflated, but do not tie the neck.
3. Use the string and ruler to measure the distance between **A** and **B** and between **C** and **B**.
4. Calculate the rate of change in the distances between **A** and **B** and between **C** and **B**. To calculate the rate, subtract the original starting distance between the dots from the distance measured after inflation. Divide this number by the number of seconds you blew into the balloon.



5. With the balloon still inflated from Step 2, blow into the balloon for an additional 2–3 seconds.
6. Measure and calculate the rate of change in the distances between **A** and **B** and between **C** and **B**. To calculate the rate, use the distance measured in Step 3 as the "original" distance.

#### Analysis and Conclusions

1. Did the distance between **A** and **B** or between **C** and **B** show the greatest rate of change?
2. Did the rate of change for either set of dots differ in Steps 4 and 6?
3. Suppose dots **C** and **A** represent galaxies and dot **B** represents the earth. How does the distance between the galaxies and the earth relate to the rate at which they are moving apart?

widespread acceptance of the big bang hypothesis, this explanation of the origin of the universe became known as the **big bang theory.**

Like any theory, the big bang theory must continue to be tested against each new discovery about the universe. As new information about our universe emerges, the big bang theory may be revised, or a new theory may take its place.

## Section 1.3 Review

1. What is a scientific theory?
2. Describe the Doppler effect for light.
3. Describe the universe before the big bang.
4. What evidence supports the big bang theory?
5. If scientists discovered blue shift in the spectra of some distant galaxies, how might this information affect the big bang theory?