A hypothesis is tested by **experimentation.** An experiment i scientific procedure carried out according to certain guidelines. A experiment enables scientists to test each **variable** that might pro or disprove the hypothesis. A variable is a factor in an experimer that can be changed. An experiment set up to test a variable is ca a *controlled experiment*.

To ensure that only one variable is tested in an experiment, s entists will also run a control. The control will have the same cor tions as the experiment except for the variable being tested. For example, to test the effects of sunlight on a green plant, a scienti would grow two identical plants. To control the experiment, the s entist would vary the amount of sunlight reaching one plant, whil keeping the amount of sunlight constant on the other plant. The s entist would then observe both plants and record the observations. What is the variable in this experiment?

In the study of earth science, setting up controlled experiment to test a hypothesis is often difficult, and sometimes impossible. T scientists studying the disappearance of the dinosaurs, for instance cannot bombard the earth with a giant meteorite to see if it produc life-threatening conditions.

Recently, however, scientists have developed computer model that enable them to test hypotheses by simulating certain condition For example, scientists have entered information into a computer about the possible climatic conditions during the period when the dinosaurs became extinct. They found that a dust cloud resulting

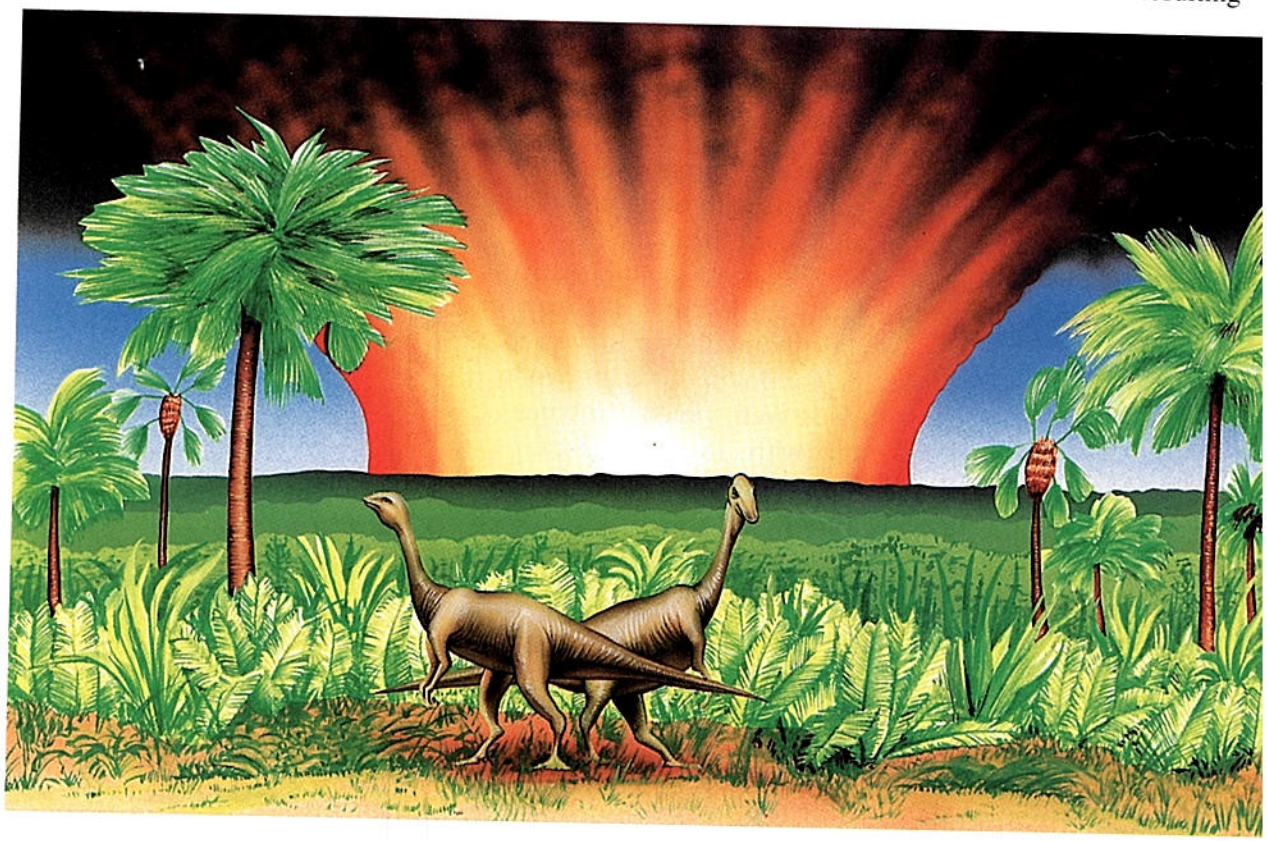

Figure 1-8. According to the meteorite-impact hypothesis, a huge meteorite crashed into the earth 65 million years ago. Dust from the impact blocked out the sun and led to the extinction of the dinosaurs.

Figure 1–9. Meteor Crater, in the northern Arizona desert, is 1,300 m in diameter and nearly 200 m deep. The crater is visible proof of the explosive power of a meteorite hitting the earth.

from the collision of a meteorite 10 km in diameter would have been sufficient to lower the earth's temperature considerably.

When experimentation is impossible, scientists often make more observations to gather evidence that will either support or discredit the hypothesis. The hypothesis is then tested by examining how well it fits or explains all the known observations.

To test the meteorite-impact hypothesis further, scientists had to find additional evidence that the iridium in the rock layers on earth had once come from meteorites. Scientists again examined the rock layers and this time they found strangely deformed particles of the mineral quartz. Previously this type of quartz had been found only near meteorite craters, at nuclear-testing sites, and in moon rocks. Scientists concluded that such quartz particles could only have been produced by an extremely powerful explosion. The collision of the earth with a huge meteorite, they reasoned, could have produced such an explosion.

INVESTIGATE!

To learn more about scientific methods, try the In-Depth Investigation on pages 20–21.

State a Conclusion

After many experiments and observations, scientists generally reach conclusions regarding the correctness of the hypothesis being considered. Depending on how well the hypothesis fits the known facts, it may be accepted as stated, altered slightly, or discarded altogether.

The fossil evidence for the meteorite-impact hypothesis does not prove that a meteorite was responsible for the extinction of the dinosaurs. The evidence does show, however, that an abnormally high amount of meteorite dust reached the earth at that time. Thus, until new evidence is found or a better hypothesis is proposed, the meteorite-impact hypothesis serves as one possible explanation of why the dinosaurs disappeared.

Section 1.2 Review

1. What are scientific methods?
2. Define *hypothesis*.
3. How do scientists test hypotheses?
4. Summarize the evidence scientists found to support the meteorite-impact hypothesis.
5. How have scientific methods contributed to the development of modern science?

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.

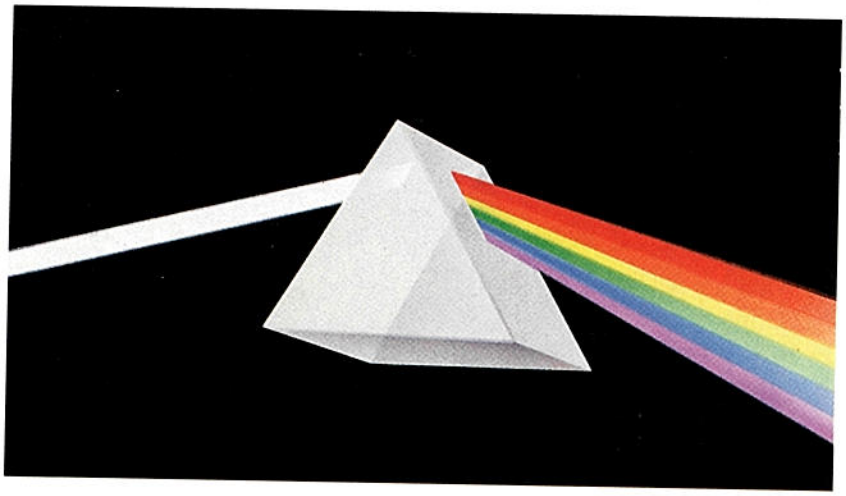

Figure 1–10. A prism bends the different wavelengths of light, separating white light into a rainbow of colors.

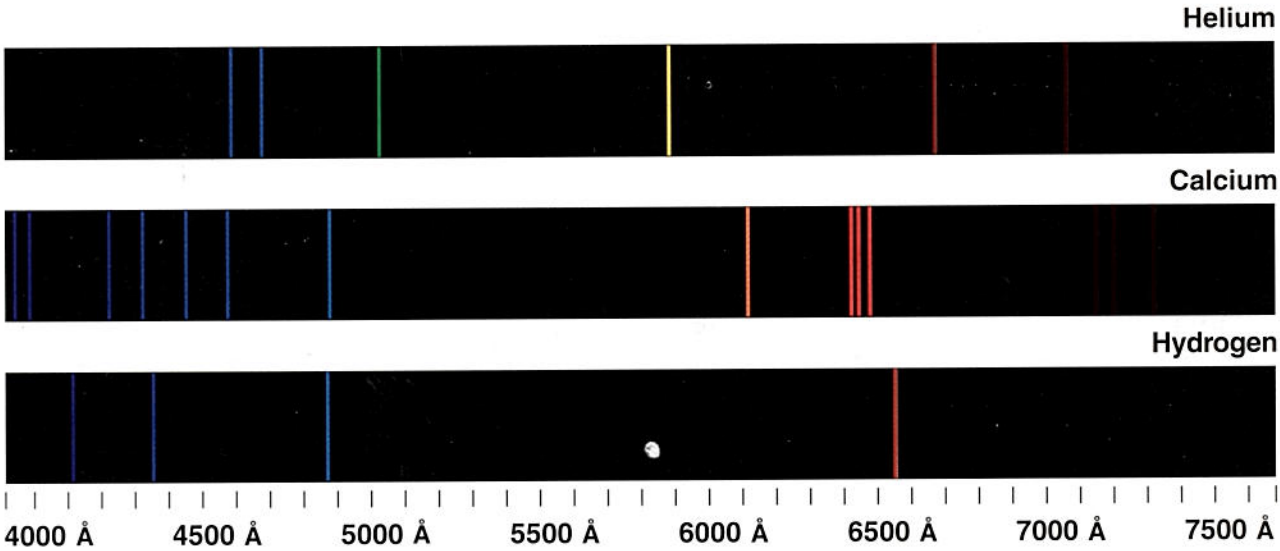

Figure 1–11. Each element produces a bright-line spectrum when heated.

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,*

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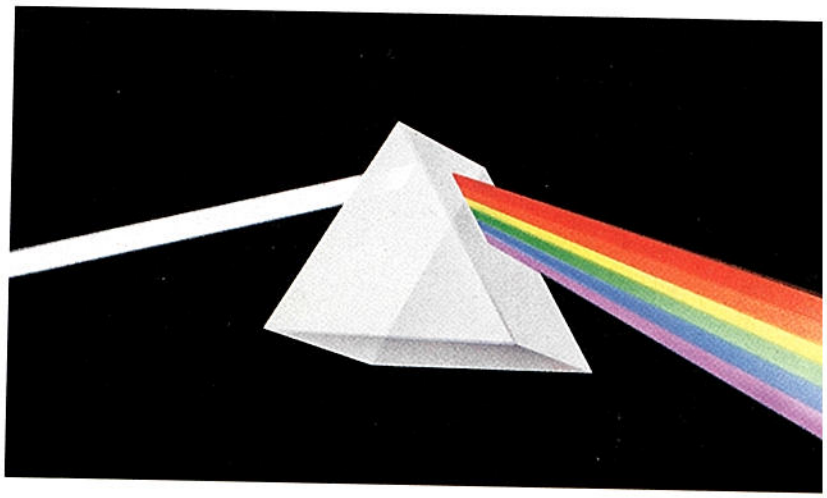

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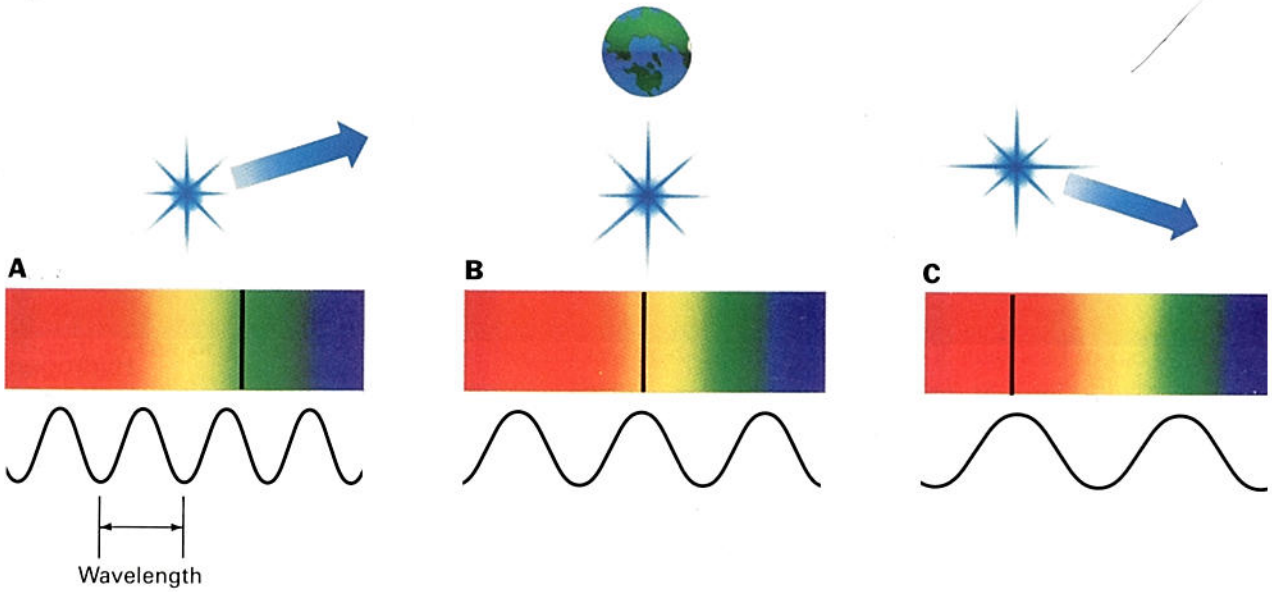


Figure 1-12. The wavelengths of light produced by star A, moving toward the earth, appear shorter. Therefore, the spectral lines of star A are shifted toward the blue end of the spectrum. The wavelengths of light produced by star C, moving away from the earth, appear longer. Therefore, the spectral lines 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 t determine the speed at which the galaxies were traveling. Scientists found that the most distant galaxies showed the greatest red shift an thus were moving away the fastest. From these observations of spec tra, 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 c years ago, all the matter and energy in the universe was compressec into an extremely small volume. About 17 billion years ago, a sud- den event called the *big bang* sent all the matter and energy hurtlir outward in a giant cloud. As the cloud expanded, some of the matte 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, number of scientists did not accept the big bang hypothesis. They argued that if the big bang had taken place as the hypothesis pro- posed, 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

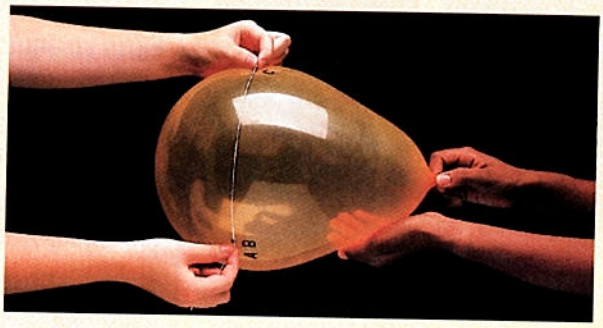
According to the big bang theory, almost all galaxies are moving outward from all other galaxies. You can demonstrate the principles of this expansion with a simple model.

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?

Chapter 1 Review

Key Terms

- astronomy (6)
- atmosphere (7)
- background radiation (16)
- big bang theory (17)
- biodegradable (8)
- biosphere (7)
- Doppler effect (15)
- earth science (3)
- ecology (7)
- ecosystem (7)
- elements (15)
- experimentation (12)
- geology (4)
- geosphere (7)
- hydrosphere (7)
- hypothesis (11)
- measurement (9)
- meteorology (5)
- observation (9)
- oceanography (5)
- pollution (8)
- scientific law (14)
- scientific methods (9)
- spectroscope (15)
- spectrum (14)
- theory (14)
- variable (12)
- wavelength (14)

Key Concepts

The four main branches of earth science are geology, oceanography, meteorology, and astronomy. **See page 3.**

Earth scientists and ecologists often work together to protect the environment. **See page 8.**

Scientific research attempts to solve problems logically through scientific methods. **See page 9.**

The meteorite-impact hypothesis provides a possible explanation for the mass extinction of the dinosaurs. **See page 11.**

Through observation and experimentation, scientists develop hypotheses, theories, and laws to describe natural phenomena. **See page 14.**

The Doppler effect describes the shift in the spectrum of a moving energy source, including light. **See page 14.**

The big bang theory provides a possible explanation of the origin of the universe. **See page 16.**

Evidence for the big bang theory comes from the study of starlight spectra and background radiation. **See page 16.**

Review

On your own paper, write the letter of the term that best completes each of the following statements.

1. The study of the solid earth is called
   a. geology. b. oceanography.
   c. meteorology. d. astronomy.
2. The earth scientist most likely to study storms is
   a. a geologist. b. an oceanographer.
   c. a meteorologist. d. an astronomer.
3. The study of the complex relationships between living things and their environment is called
   a. geology. b. meteorology.
   c. ecology. d. astronomy.
4. An example of a nonbiodegradable waste product is
   a. an apple core. b. a plastic milk jug.
   c. a pile of rotting leaves. d. an eggshell.
5. Usually the first step in scientific problem solving is to
   a. form a hypothesis. b. state the problem.
   c. gather information. d. state a conclusion.
6. A possible explanation for a scientific problem is called
   a. an experiment. b. an observation.
   c. a theory. d. a hypothesis.

7. The development of the meteorite-impact hypothesis began with the observation of
   a. blue shift in the spectra of stars.
   b. red shift in the spectra of stars.
   c. background radiation.
   d. iridium in earth rocks.

8. A statement that consistently and correctly describes some natural phenomenon is a scientific
   a. hypothesis. b. observation.
   c. law. d. control.

9. The apparent change in the wavelengths of a moving energy source is called
   a. the big bang. b. the Doppler effect.
   c. the spectrum. d. background radiation.

10. Scientists have found that as a light source moves toward a stationary observer, the wavelengths of the light source appear
    a. longer. b. shorter.
    c. higher. d. lower.

11. The big bang theory states that the galaxies in the universe are
    a. moving away from one another.
    b. moving towards one another.
    c. remaining stationary.
    d. being bombarded by meteorites.

12. Evidence for the big bang theory includes
    a. iridium in earth rocks.
    b. deformed quartz particles in earth rocks.
    c. blue shift in the spectra of galaxies.
    d. red shift in the spectra of galaxies.

Critical Thinking

On your own paper, write answers to the following questions.

1. A meteorite lands in your back yard. Which earth scientist would you call to study the meteorite? Why?
2. A stream that feeds a small pond gradually dries up. How might this change affect the ecosystem of the pond?
3. Some scientists have hypothesized that meteorites have periodically bombarded the earth, causing mass extinctions every 26 million years. How might this hypothesis be tested?
4. Imagine that you are on another planet in a galaxy far from the earth. If you used a spectroscope to examine the spectrum of the sun, would you expect to find red shift, blue shift, or no shift at all? Why?
5. According to the big bang theory, the original big bang took place about 17 billion years ago. How might scientists have been able to determine this?

Application

1. You find a yellow rock and wonder if it is gold. How could you apply scientific methods to this problem?
2. A scientist observes that each eruption of a volcano is preceded by a series of small earthquakes. The scientist then makes the following statement: Earthquakes cause volcanic eruptions. Is the scientist's statement a hypothesis or a theory? Why?
3. 

Construct a **concept map** using 10 of the new terms listed on page 18 by making connections that illustrate the relationship among the terms. See page xxi for instructions on making concept maps.

Extension

1. Assume that you must lose all the benefits of one of the earth sciences. Which would you give up first? Why? Defend your selection in an essay.
2. Choose an ecosystem and draw a diagram showing some of the interrelationships between the living things and their environment. Identify the living things according to their roles as producers, consumers, or decomposers.
3. Find out about the organizations in your community that are working to protect the environment. Write a short profile describing the work of each organization. Put the information together in a directory.

In-Depth Investigation

Scientific Method

Materials

- meter stick
- hand lens

Introduction

Not all scientists think alike; nor do they always agree about var ious theories. However, all scientists use *scientific method,* part of which includes the skills of observing, inferring, and predicting. In this investigation, you will apply scientific method as you examine a place where puddles often form after rainstorms. You can study the puddle area even when the ground is dry, but it would be best to observe the area again when it is wet. Since water is the most effective agent of change in our environment, you will be able to make many observations.

Prelab Preparation

1. Review Section 1.2, pages 9–13.
2. Find out the difference between a quantitative observation and a qualitative observation.

Procedure

1. Examine the area of the puddle and the surrounding area carefully. On a sheet of paper, write the heading "Observations." Make a numbered list of what can be seen, heard, smelled, or felt. Sample observations: "The ground where th puddle forms is lower than the surrounding area," "There ar cracks in the soil," and so forth. *Note: Avoid any suggestion of causes.*
2. On another sheet of paper, write the heading "Inferences." Review your observations and write possible causes for tho observations. Sample: "Cracks in the soil (Observation 2) ma have been caused by lack of rain (Observation 5)."

3. Review your observations and possible causes, and place them into similar groups if possible. Can one cause or set of causes explain several observations? Is each cause reasonable when compared with the others? Does any cause contradict any of the other observations?
4. Start a new page labeled "Hypotheses." You have learned that a hypothesis is a possible explanation to a problem or an occurrence. Create a hypothesis for each group of causes and observations above. Look for the underlying and general mechanisms that produce and link these events. Example: "The clays in the soil shrink as they lose water, thereby causing cracks to form."
5. Based only on your hypotheses, make some predictions about what will happen at the puddle as conditions change. Describe the changes you expect and your reasoning. Sample prediction: "The cracks will grow wider as the puddle dries. Any added water will shrink the cracks."
6. Revisit the puddle several times to see if the changes you observe match your predictions.

Analysis and Conclusions

1. Which of your senses did you use most to make your observations? How could you improve observations using this sense?
2. What could you have used to measure, or put into numbers, many of your observations? Is quantitative observation better than qualitative observation? Explain.
3. Can inferences generally be relied on as true? Explain.
4. If your predictions are found to be incorrect, was the act of forming your inferences a waste of time? Explain.
5. When knowledge is derived from observation and prediction, this process is called "scientific method." After reporting the results of a prediction, how might a scientist continue his or her research?

Extensions

1. Decide whether each of the following statements is an observation (O) or an inference (I).

Note: It does not matter whether the statement happens to be true or false.

a. Grass is present inside the puddle.
b. The grass surrounding the puddle is greener and taller than that inside the puddle.
c. During a rainstorm, some soil is washed into the puddle.
d. Water always runs downhill.
e. Gravity causes the water to run downhill.
f. The soil that washes out of the puddle will eventually become part of a stream.
g. Brownish water contains suspended soil particles.
h. The soil particles are suspended because water is flowing fast.
i. When the rain stops, the puddle water looks clear.
j. Mud cracks result from drying the soil.

2. Choose another small area to examine, but look for changes caused by a different factor, such as wind. Follow the steps outlined in the investigation to predict changes that will occur in the area. Use scientific method to design an experiment you can test. Briefly describe your experiment and how you tested it.