

# The Spectroscope: New Meanings in Light



**Figure 5.17** Isaac Newton demonstrated that light is made up of all the colours.

Now that astronomers could gaze deeper into the universe using simple telescopes, they faced a new challenge — the stars. Galileo had seen the stars through his telescope, but what were they made of? The spectroscope was one important technological advance that helped us learn more about the stars. In Topic 3, you will learn what a spectroscope is, what it does, and how it helps astronomers learn about stars.

## Spectral Lines

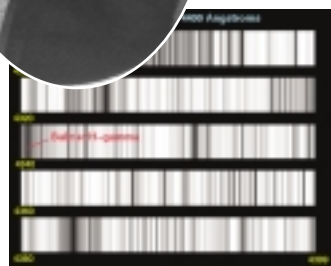
During scientific inquiry, Isaac Newton passed a beam of sunlight through a prism to produce a **spectrum** of colours. Newton's experiment showed that sunlight, which is white light, is made up of all colours.

If you pass a beam of light through a narrow slit before sending it through a prism, the resulting spectrum shows much finer detail. A **spectroscope** is a device that produces this kind of focussed spectrum. In the 1820s, Joseph von Fraunhofer, a German optician, used a spectroscope to observe the Sun's spectrum. This spectroscope had very fine prisms. He noticed hundreds of dark lines in the Sun's spectrum (also called the solar spectrum). These dark lines are called **spectral lines**. He mapped the solar spectrum completely, although he was mystified as to what the spectral lines meant.

## Spectroscopy: The Science of Colour

About 50 years after Fraunhofer's discoveries, the significance of spectral lines was discovered. Chemists knew that the vapours of different elements give off different colours when heated to incandescence. (Recall that incandescence means that something is hot enough to glow.) For example, sodium vapour gives a yellow colour, while mercury gives a bluish colour.

Gustav Kirchoff, a German physicist, and Robert Bunsen, a German chemist, heated various chemicals to incandescence and examined their light through a spectroscope. They discovered that not all of the colours of the rainbow were present. Instead, they saw that each spectrum was a series of coloured lines with black spaces between them.



**Figure 5.18** Joseph von Fraunhofer discovered hundreds of dark lines in the Sun's spectrum.

Each element they studied had a particular set of spectral lines different from the others. Each spectrum was unique and could be used to identify the element. For example, Figure 5.19 shows the spectral lines unique to hydrogen. These results helped found the science of **spectroscopy** as a part of chemistry. Spectroscopy is the study of spectra (the plural form of spectrum).

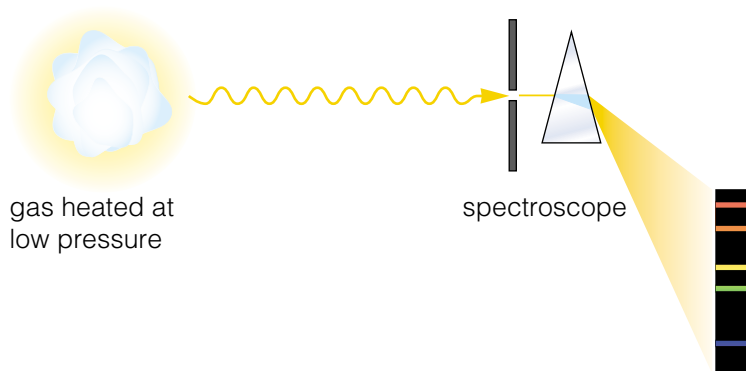


**Figure 5.19** This illustration shows the spectral lines that are produced when hydrogen is heated.

### Three Types of Spectra Discovered

Kirchoff and Bunsen discovered that each element produces a unique spectral pattern. These scientists also learned that there are three types of spectra, which are illustrated below in Figures 5.20–5.22.

#### 1. Emission or Bright Line Spectrum

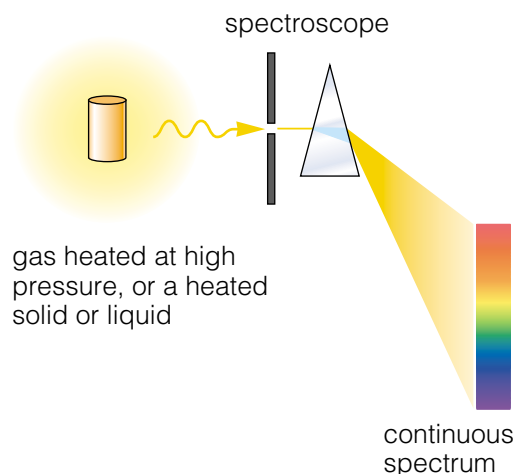


**Figure 5.20** If you heat a gas at low pressure (a mercury vapour lamp, for example), it produces a spectrum that is only a set of bright lines of certain colours on a black background. This is called an *emission*, or *bright line spectrum*.

### Pause & Reflect

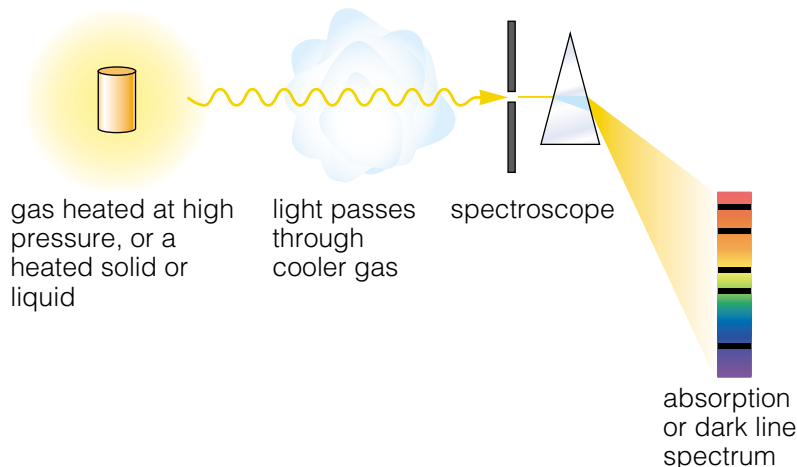
Fraunhofer discovered that the spectrum of the Moon is identical to the Sun's spectrum. What conclusion might he have made about the source of moonlight from this observation? Write your ideas in your Science Log.

#### 2. Continuous Spectrum



**Figure 5.21** If you heat a solid, liquid, or a gas at high pressure, the resulting spectra contain all the colours blending into one another. These are called *continuous spectra*. A rainbow that you see in the sky is an example of a continuous spectrum.

#### 3. Absorption or Dark Line Spectrum



**Figure 5.22** When continuous spectrum light, such as white light, passes through a cooler substance, the spectrum observed is a continuous spectrum with dark gaps between colours. This is called an *absorption* or *dark line spectrum*. It is the same type of phenomenon that Fraunhofer saw when he looked at the solar spectrum. It is called an absorption spectrum because the gas that the light passes through absorbs, or removes, some of the colours of light in the spectrum.

## DidYouKnow?

“Holographic” trading cards do not have holograms in them. They actually have diffraction gratings attached to the parts of the cards that display the colours. Light reflects off the diffraction grating plastic that is on the card’s surface. A spectrum results when light reflects off a grating as well as when it passes through a grating.

## DidYouKnow?

A CD creates rainbow reflections because it acts as a diffraction grating. The information on the CD is organized in a spiral “groove” consisting of pits burned into the disk’s surface. (Space between the pits is called “land.”) The distance between each line of pits is twenty times smaller than the thickness of an average human hair!



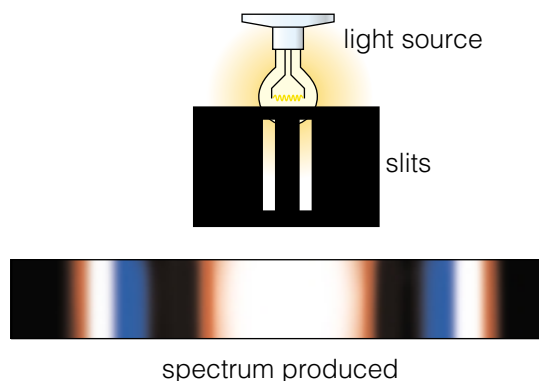
## Diffraction Gratings

You’ve learned that astronomers look at light waves through spectroscopes. A wave is a way of transferring energy through a medium of some kind. Think of a disturbance in a pool of water — suppose you throw a stone into a pool. The waves in the water move out from the point of origin, which is where the stone hits the water. Light waves work the same way. Think of any light source—the Sun, for example. The Sun is one origin of light waves in the universe. The Sun is like the stone hitting the pool of water. Like the waves in the pool, the Sun’s light energy ripples out through space. Some of those light waves come to Earth.

Some spectroscopes use prisms to split the light into a spectrum. However, there’s a different way to split the light. This is by using a diffraction grating instead of a prism.

You may have learned in previous studies that when light passes through very small openings that are close together, a spectrum is produced (see Figure 5.23). This occurs because waves bend around corners (they diffract) and then pass through each other causing interference (they can cancel each other out, or reinforce each other). A device made of thousands of closely spaced slits is called a **diffraction grating**.

The spectrum produced by a diffraction grating has much better detail in it than a spectrum from a prism. Modern spectroscopes use diffraction gratings instead of prisms to split the light into spectra. The spectroscope you will use in the next investigation probably uses a diffraction grating.



**Figure 5.23** When white light passes through narrowly spaced slits, it is split into a spectrum. Notice that a spectrum has been produced on both sides of the white light (in the middle).



Turn to the Unit 5 Project, “An Arm of Your Own,” on page 432. Start thinking of design ideas to build your own remote manipulator.

# Identifying Spectra

Kirchoff and Bunsen discovered three types of spectra — emission, continuous, and absorption. In this investigation, you will examine various light sources using a spectroscope. You will analyze your results to identify the types of spectra produced by each light source.

## Question

What types of spectra are associated with various light sources?

## Hypothesis

Based upon what you know about light sources, make a hypothesis and a prediction about the kind of spectrum that a fluorescent and an incandescent light should have.

### Safety Precautions

**Never look directly at the Sun with your eyes. Do not look at the Sun through any optical instruments such as binoculars, telescopes, or spectroscopes.**

### Apparatus

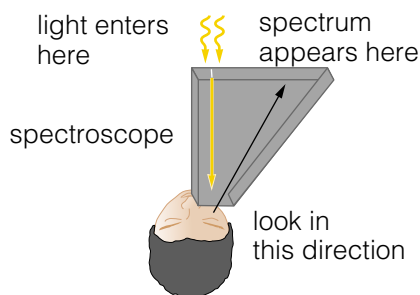
spectroscope

### Materials

coloured pens or pencils

## Procedure

- 1** **Observe** a fluorescent light through your spectroscope. Draw a sketch of its spectrum in your notebook.
- 2** **Repeat** step 1, this time observing sunlight. Point the spectroscope toward the sky to see the sunlight. **Do not look directly at the Sun.** Sunlight will enter the spectroscope without your looking directly at the Sun.
- 3** Use the spectroscope to **observe** and draw the spectra of other kinds of lights that are available (light bulbs, gymnasium lights, neon signs, plant-growing lights).



## Skill FOCUS

For tips on scientific drawing, turn to Skill Focus 11.



## Analyze

1. For each light source, classify the spectrum (emission, absorption, continuous, or combinations of these).
2. Write a statement of what substance you think each of your light sources uses to make its light.
3. Was your prediction verified about fluorescent and incandescent light spectra correct? Explain why or why not.

## Conclude and Apply

4. You can buy “full-spectrum” fluorescent lights. What do you think this term means?
5. We use the term “neon light” for lights of many different colours. Why is this name not completely accurate?

## Extension

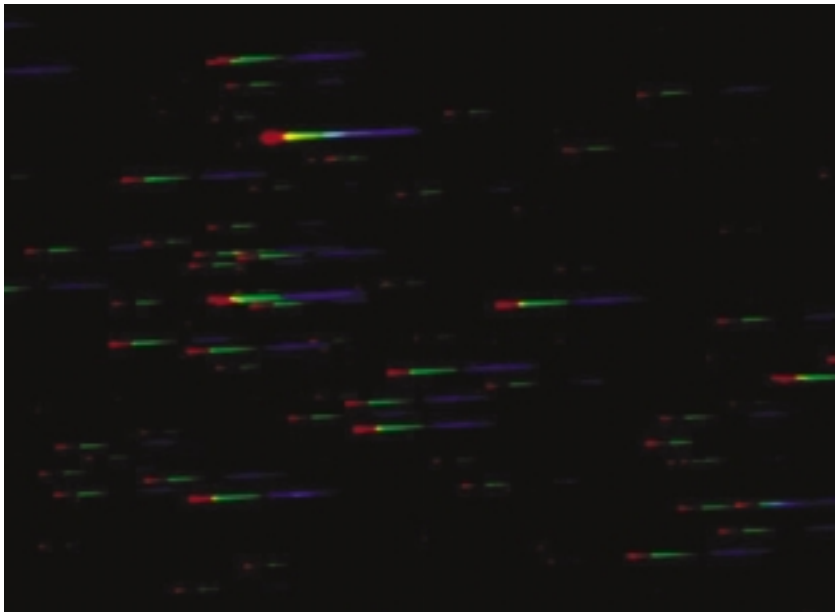
6. Contact a neon sign designer. Find out what he or she puts in the lights to get different colours.

## Spectroscopy for Astronomers

So far you know that there are three kinds of spectra — emission (bright line), continuous, and absorption (dark line). You may have discovered in the last investigation that each different light source produces one or more of these three types of spectra. You also know, as Kirchoff and Bunsen discovered, that each element (such as hydrogen, helium, calcium, and so on), as a low-pressure gas, produces a unique pattern of spectral lines. These lines are used like human fingerprints to identify different gases found in light sources. Just as each set of human fingerprints is unique to each person, each set of spectral lines belongs to one light source only. Think back to Fraunhofer's discovery of the solar spectrum. Kirchoff and Bunsen's discoveries help us understand the meaning of the dark lines in the solar spectrum.

Remember that as light passes through a gas, parts of the light are absorbed. This creates the dark lines in the spectrum. Now think about the solar spectrum. If the Sun's spectrum also has dark lines in it, it must mean that sunlight passes through some gases. The conclusion is that gases in the Sun's atmosphere absorb the light that is removed from the solar spectrum.

So which gases exist in the Sun's atmosphere? In such situations, astronomers use **spectral analysis**. If the dark lines' placement in the solar spectrum matches the bright lines produced by various elements, then those elements are present in the Sun's atmosphere. For example, look again at the bright line spectrum produced by the element hydrogen in Figure 5.19, on page 377. In the solar spectrum, dark lines will appear in the same location as the bright lines.



**Figure 5.24** Astronomers often attach spectroscopes to their telescopes. This is a spectral look at a cluster of stars in the constellation Taurus. Very few dark lines are visible in these spectra.

Astronomers tried the same method to find out about thousands of stars. They attached spectroscopes to their telescopes and examined the spectral lines made by different stars. Since the stars are much dimmer than the Sun, astronomers can't identify the hundreds of lines in their spectra. However, the few lines that are observed can be used to infer something about the composition of the stars. Try the next investigation to learn how to examine the spectra of stars just as astronomers do.

# Long-Distance Chemistry: Using Spectral Analysis to Identify Star Composition

## Think About It

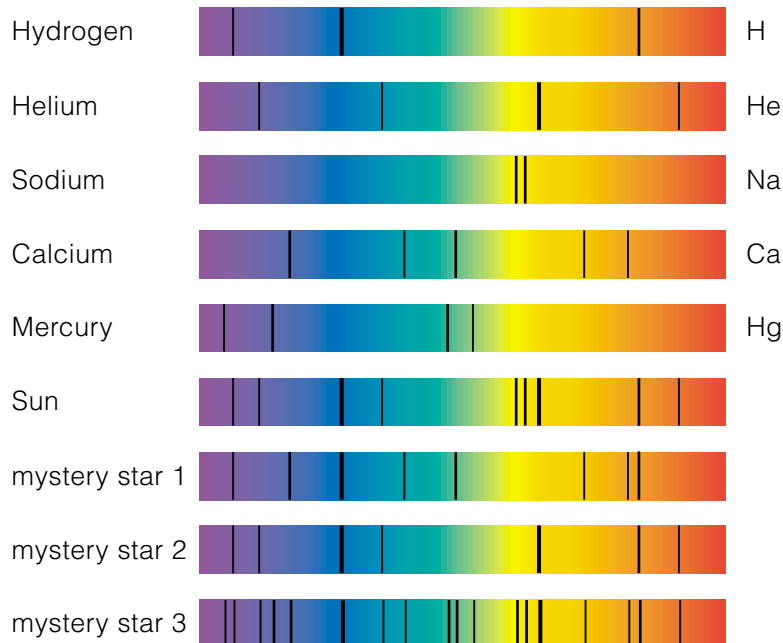
In this investigation, you have an opportunity to apply the method that astronomers use to detect the chemical make-up of a star. You will examine the simplified spectra of five known chemical elements and use that information to interpret the composition of the Sun and three “mystery stars.”

## What to Do

- 1 The figure below displays the spectral patterns for five elements. Study these spectra to familiarize yourself with their patterns.
- 2 Examine the spectra for the Sun and the three “mystery stars.” Using a ruler to help you line up the spectral lines, compare the spectral patterns of the known elements to those of the Sun and the three unknown stars. Then, answer the following questions.

## Analyze

1. Which elements are present in the Sun’s spectrum?
2. In which two mystery stars is calcium present?
3. Which mystery star contains Na?
4. Only one mystery star contains Hg. Which one is it?
5. Which mystery star’s composition is least like that of the Sun?
6. In a paragraph, briefly describe how a star’s composition can be inferred by analyzing its spectral pattern.



## DidYouKnow?

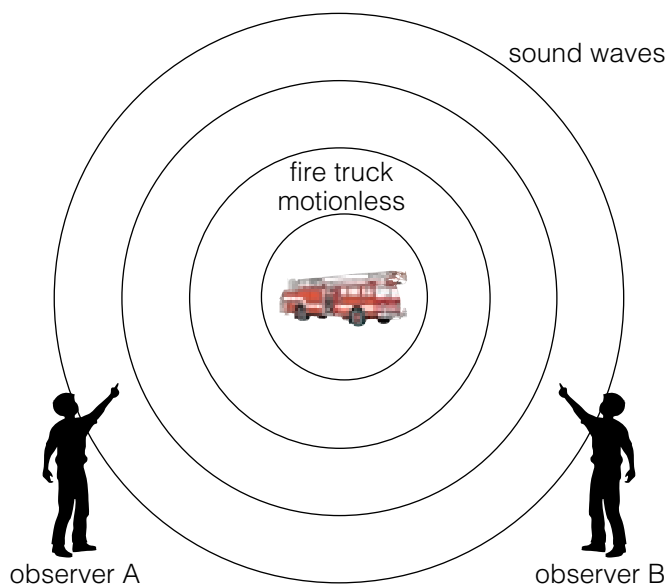
When police catch traffic speeders by using a radar gun, they are putting the Doppler effect to work. The radar gun sends out a radio signal of known wavelength. The returning wave has a different wavelength if the car is moving. The size of the change in wavelength shows how fast the car is moving.



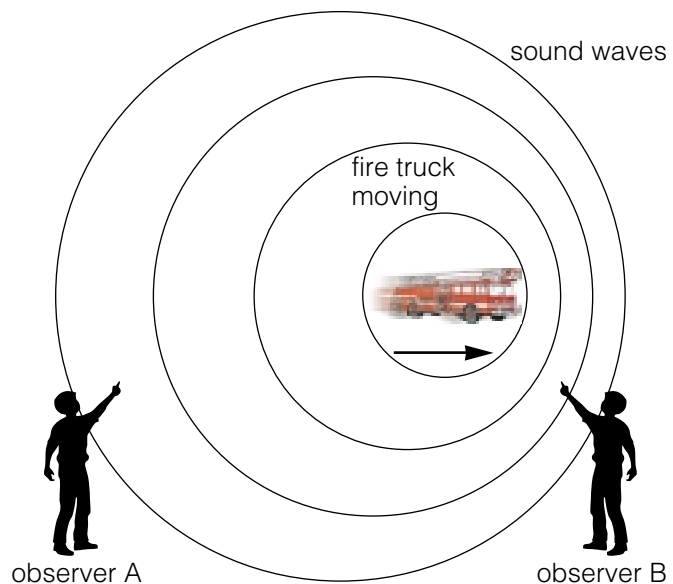
## The Doppler Effect

You have learned how spectroscopes are used to identify the chemical make-up of the atmospheres of celestial objects. Spectroscopes also have another important use in astronomy. They can tell us how fast a celestial body, such as a star, is moving toward or away from us.

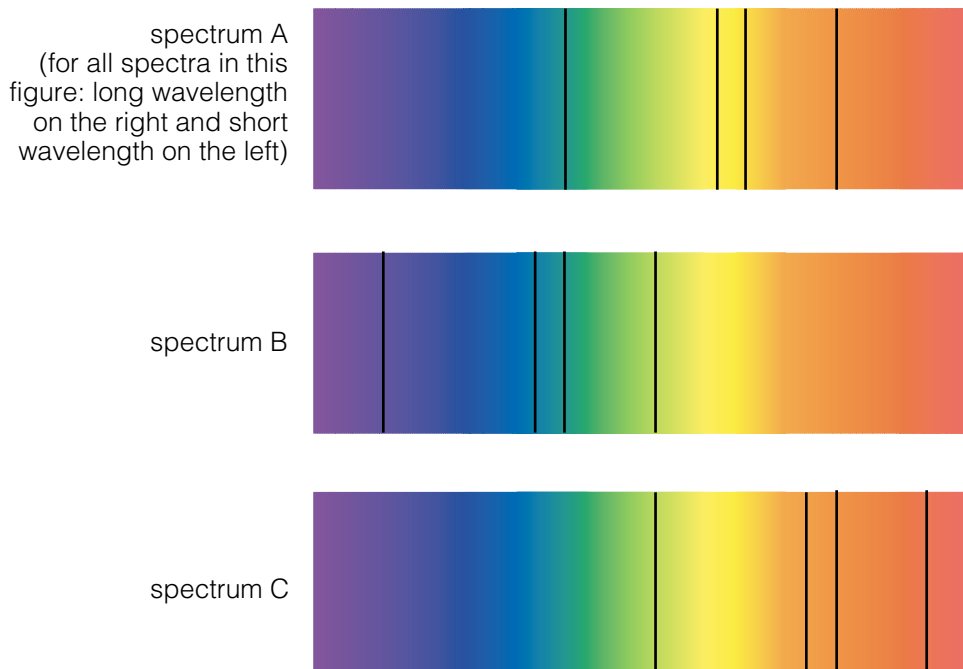
You have probably noticed that the siren on an ambulance or fire truck sounds different as the vehicle approaches, passes, and then moves away from you. The siren's change in pitch is called the **Doppler effect** and is caused by the change in the sound's wavelength. As Figures 5.25 A and B show, sound waves are compressed in front of the vehicle as it speeds along. This results in a shorter wavelength and higher pitch. Behind the vehicle, the sound waves stretch out, creating a longer wavelength and lower pitch.



**Figure 5.25A** When the fire truck is not moving, the siren's sound has the same pitch in all directions because the sound waves are uniform.



**Figure 5.25B** When the fire truck is moving quickly, the sound of the siren seems to change in pitch, becoming higher as the truck moves toward the observer and lower as it moves away from the observer.



**Figure 5.26** Dark lines are shown in the spectrum of a stationary star (spectrum A). If the star is moving toward Earth, the lines will shift toward the blue end of the spectrum (spectrum B). If the star is moving away from Earth, the lines will shift toward the red end (spectrum C). The amount of shift that occurs corresponds to the speed with which the star is approaching or receding. The amount of the Doppler shift is greatly exaggerated.

Light, like sound, travels in waves. Thus, the Doppler effect can be used to measure the speed and direction of light-emitting objects such as stars. While the sound waves from a moving object differ in pitch, the light waves from a moving object differ in colour. If a star is approaching you, its wavelengths of light become compressed. As a result, the dark lines in the star's spectrum shift toward the shorter-wavelength end of the spectrum — the blue end. If the star is going away from you, its spectral lines will be **red shifted** — moving toward the longer-wavelength part (red end) of the spectrum. Figure 5.26 illustrates how spectral lines in a star can reveal whether the star is moving toward or away from Earth.

## An Amazing Tool!

The spectroscope is truly an amazing tool! In the mid-1800s, the French philosopher Auguste Comte said that it would be forever impossible for humans to learn of what material the stars are composed. Less than 20 years after he said this, the spectroscope was used for this purpose. Its application to astronomy allowed astronomers to do what Comte thought impossible. Astronomers' next quest was to use the spectroscope to look at as many stars as possible. In the next Topic, you'll learn how they did that by using bigger telescopes.

## DidYouKnow?

The only direct way to measure stellar distances is with parallax, but this works only for close stars. The red shift is a reliable distance-finding method for galaxies far beyond our Milky Way.



### TOPIC 3 Review

1. Describe how a spectroscope works.
2. If you heat a piece of wire until it glows, what type of spectrum should it produce?
3. Describe how a spectroscope is used to find out what elements are present in the Sun's atmosphere.
4. If a star's light is "red shifted," what can astronomers conclude about that star?
5. **Thinking Critically** What should the spectrum of the Moon look like? Justify your answer.
6. **Apply** The diagrams at the bottom left of the page show models of two different light waves. One represents blue light, the other red light. Which one represents blue light? Which one represents red?
7. **Apply** Look at the spectral diagrams at the bottom right of the page. What can astronomers say about the composition of the stars producing these spectra?

