Section 8.2

1 FOCUS

Section Objectives

8.4 **Identify** the three types of seismic waves.

8.5 **Describe** how seismic waves are recorded.

8.6 **Describe** the different ways earthquakes are measured.

8.7 **Explain** how to locate the epicenter of an earthquake.

Reading Focus

Build Vocabulary L2

Word Parts Tell students that the prefix *seismo-* is Greek for "shaking." Ask them to infer what a seismograph and a seismogram are. Challenge them to come up with other terms that begin with the prefix *seismo- (seismology, seismologist).*

Reading Strategy L2

I. Seismic Waves
    A. P Waves
    B. S Waves
    C. Surface Waves
II. Recording Seismic Waves
    A. Seismographs
    B. Seismograms
III. Measuring Earthquakes
    A. Richter Scale
    B. Moment Magnitude
    C. Modified Mercalli Scale
IV. Locating an Earthquake

8.2 Measuring Earthquakes

Reading Focus

Key Concepts

- What are the two categories of seismic waves?
- How are seismic waves recorded?
- How is the size of an earthquake measured?
- How is an earthquake epicenter located?

Vocabulary

- P wave
- S wave
- surface wave
- seismograph
- seismogram
- moment magnitude

Reading Strategy

Outlining As you read, make an outline of the important ideas in this section. Use the green headings as the main topics and the blue headings as subtopics.

Measuring Earthquakes
I. Seismic Waves
A. P Waves
B. ____?____
C. ____?____
II. ____?____

In 2003, a powerful earthquake shook the Alaska wilderness south of Fairbanks along the Denali fault. The earthquake was so strong that it rippled the water in ponds and lakes thousands of kilometers away in Louisiana and Texas. What carries the energy released in an earthquake over such vast distances? The answer is seismic waves.

After an earthquake, Earth vibrates like a bell that has been struck with a hammer. Seismic waves transmit the energy of these vibrations from particle to particle through the materials that make up the lithosphere, mantle, and core.

Seismic Waves

Earthquakes produce two main types of seismic waves—body waves and surface waves. These seismic waves differ in their type of wave motion, their behavior as they travel through Earth, and their speed. The waves that travel through Earth's interior are called body waves. There are two types of body waves: P waves and S waves.

P Waves **P waves** are push-pull waves that push (or compress) and pull (or expand) particles in the direction the waves travel. P waves, shown in Figure 4, are also known as compressional waves. P waves travel faster than S waves. P waves can travel through both liquids and solids.

Go Online active art

For: Seismic Waves activity
Visit: PHSchool.com
Web Code: czp-3081
Students interact with seismic wave activity online.

S Waves **S waves** shake particles at right angles to the waves' direction of travel. Their motion can be modeled by fastening one end of a rope and shaking the other end, as in Figure 4. S waves are also called transverse waves. S waves travel more slowly than P waves. S waves can travel through solids, but not liquids.

Surface Waves When body waves reach the surface, they produce **surface waves**. Surface waves travel more slowly than body waves. Surface waves move up-and-down as well as side-to-side. Surface waves are usually much larger than body waves, so surface waves are the most destructive seismic waves.

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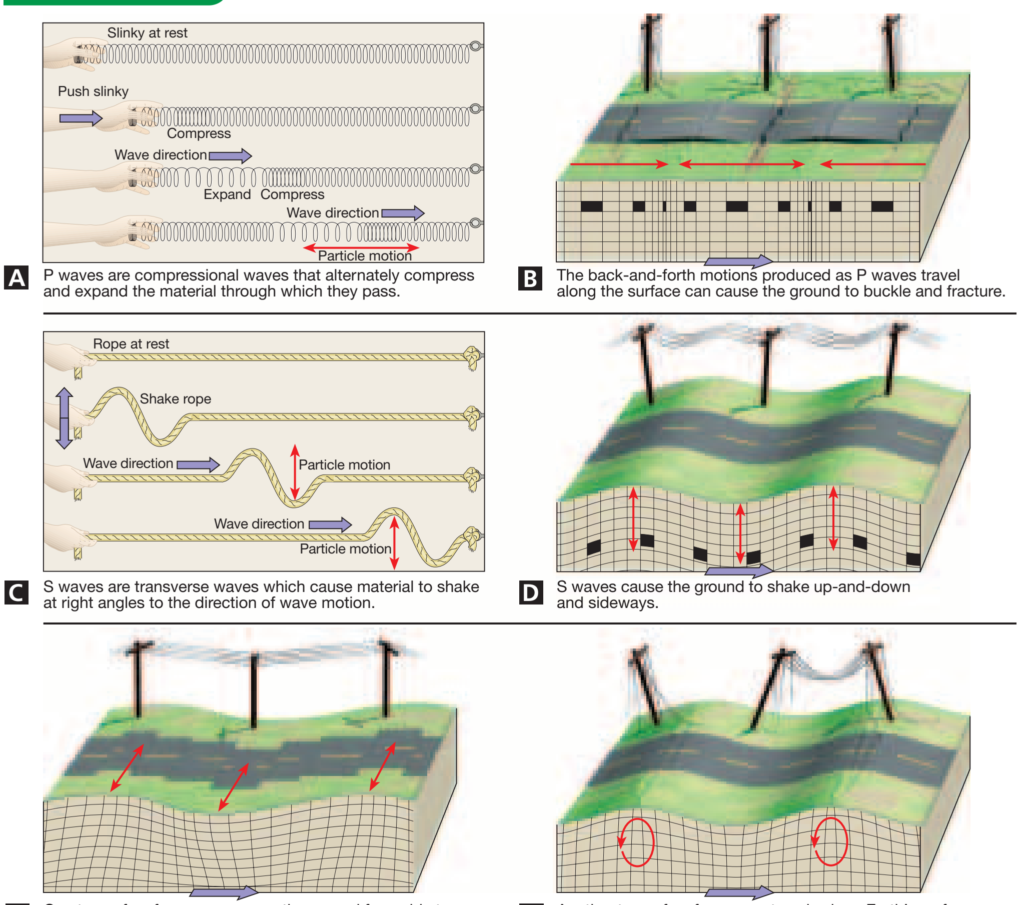
Figure 4 Each type of seismic wave has characteristic motions.

Seismic Waves



A P waves are compressional waves that alternately compress and expand the material through which they pass.

B The back-and-forth motions produced as P waves travel along the surface can cause the ground to buckle and fracture.

C S waves are transverse waves which cause material to shake at right angles to the direction of wave motion.

D S waves cause the ground to shake up-and-down and sideways.

E One type of surface wave moves the ground from side to side and can damage the foundations of buildings.

F Another type of surface wave travels along Earth's surface much like rolling ocean waves.

Customize for Inclusion Learners

Learning Disabled Ask students to simulate P waves and S waves with a slinky and jump rope. Instruct them to recreate the scenarios pictured in Figure 4A and 4C if they require help getting started.

2 INSTRUCT

Seismic Waves

Teacher Demo

Seismic Waves L2

Purpose Students will see the ways that the three different seismic waves move though substances with the use of a coiled spring toy.

Materials coiled spring toy

Procedure Have a student hold one end of the spring toy. Hold the other end of the toy and step away from the student to stretch the spring out. Gather approximately one fifth of the spring in your hand and let go. Ask students to explain what they observed as the bunch of coils moves down the extending spring. Explain to students that this is how a P wave travels through a medium. Again, with the spring stretched out, gently move the toy from side to side in a snake-like motion. Students should observe how the toy moves as a result of such motion. Explain that this is how an S wave moves. Finally, move your end of the toy in a rolling motion (like winding a fishing reel) to model surface waves.
Kinesthetic, Visual

Build Reading Literacy L1

Refer to **p. 216D** which provides the guidelines for this reading strategy.

Compare and Contrast Ask students to use the visuals and the captions in Figure 4 to describe how the three types of waves are different. *(P waves compress and expand material in the same horizontal direction of the waves' energy. S waves are transverse waves that cause the ground to shake up and down, perpendicular to the waves' direction. Surface waves travel along the outer layer and can move in both up-and-down motions and side-to-side motions.)*

Recording Seismic Waves

Build Reading Literacy L1

Refer to **p. 156D** in **Chapter 6,** which provides the guidelines for reciprocal teaching.

Reciprocal Teaching Have students read the section with a partner. One partner reads a paragraph out loud. Then the other partner summarizes the paragraph's contents and explains the main concepts. The partners continue to switch roles with each new paragraph until they have finished the section. **Intrapersonal**

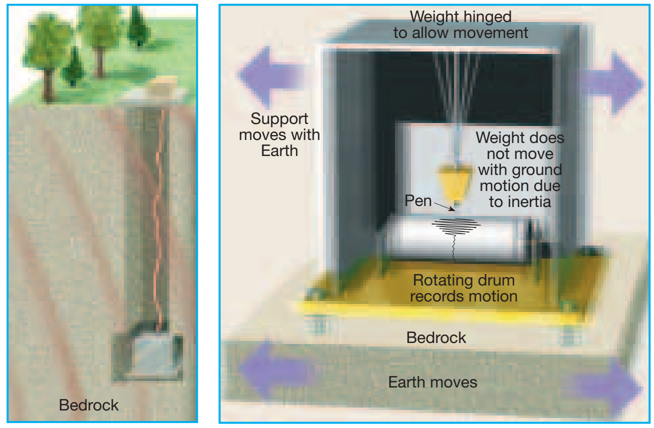


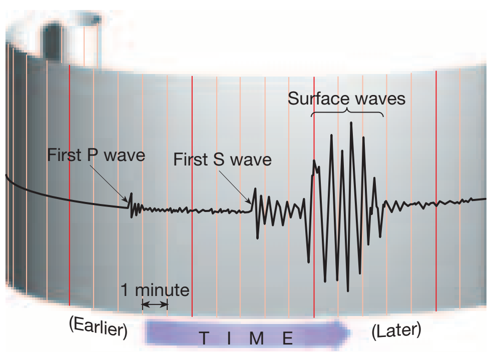
Figure 5 The seismograph (*seismos* = shake, *graph* = write) amplifies and records ground motion.

Recording Seismic Waves

Scientists have developed an instrument to record seismic waves—the seismograph. The word *seismograph* is formed from the Greek words *seismos*, meaning "shake" and *graph*, meaning "write."

Seismographs How does a seismograph work? As shown in Figure 5, a **seismograph** can consist of a weight suspended from a support attached to bedrock. When seismic waves reach the seismograph, the inertia of the weight keeps it almost stationary while Earth and the support vibrate. Because the weight stays almost motionless, it provides a reference point for measuring the amount of ground movement caused by seismic waves. In older seismographs a pen records the movement of Earth relative to the stationary weight on a rotating drum. Modern seismographs amplify and record ground motion electronically.

Figure 6 Typical Seismogram The first wave to arrive is the P wave, followed later by S waves. The last waves recorded are the surface waves. **Measuring** ***What is the time interval in minutes between the arrival of the first P wave and the arrival of the first S wave?***



Seismogram A seismograph produces a time record of ground motion during an earthquake called a **seismogram.** A seismogram shows all three types of seismic waves. The stronger the earthquake, the larger the waves on the seismogram. By reading a typical seismogram, as shown in Figure 6, you can see that P waves arrive first at the seismograph, followed by S waves, and then surface waves.

Reading Checkpoint ***What is a seismogram?***

Customize for Inclusion Students

Learning Disabled Place the palms of your hands together and slide one quickly against the other. This movement represents two rock surfaces slipping against each other. The fingertips of the hand that moves forward are like the rock that moves forward. This is called a "push wave" or P wave. The wave travels at about 8 km/s.

Earthquakes also send out a second kind of wave. This time put your hands together with a pencil between them. Slide one hand forward to represent the slipping rock surfaces. The pencil rotates, or twists, as you move your palm. In the same way, rocks twist between slipping surfaces. The twisting rocks send a "twist wave," or S wave, throughout Earth. A twist wave travels more slowly than a push wave, moving through Earth at about 5 km/s.

Measuring Earthquakes

Intensity is a measure of the amount of earthquake shaking at a given location based on the amount of damage. Magnitude (abbreviated as "M") is a measure of the size of seismic waves or the amount of energy released at the source of the earthquake. **The Richter scale and the moment magnitude scale measure earthquake magnitude. The Modified Mercalli scale is based on earthquake intensity.**

Richter Scale A familiar but outdated scale for measuring the magnitude of earthquakes is the Richter scale. The Richter scale is based on the height of the largest seismic wave (P, S, or surface wave) recorded on a seismogram. A tenfold increase in wave height equals an increase of 1 on the magnitude scale. For example, the amount of ground shaking for a M5.0 earthquake is 10 times greater than the shaking produced by an earthquake of M4.0 on the Richter scale.

Seismic waves weaken as the distance between the earthquake focus and the seismograph increases. The Richter scale is only useful for small, shallow earthquakes within about 500 kilometers of the epicenter. News reports often use the Richter scale in reporting earthquake magnitudes. Scientists, however, no longer use it routinely.

Moment Magnitude Scientists today use a more precise means of measuring earthquakes. It is called the moment magnitude scale. Moment magnitude is the most widely used measurement for earthquakes because it is the only magnitude scale that estimates the energy released by earthquakes. The **moment magnitude** is derived from the amount of displacement that occurs along a fault. The moment magnitude is calculated using several factors in addition to seismographic data. These factors include the average amount of movement along the fault, the area of the surface break, and the strength of the broken rock. Together these factors provide a measure of how much energy rock can store before it suddenly slips and releases this energy during an earthquake. The table describes the incidence of earthquakes of different magnitudes. During the last 100 years, there were only a few earthquakes with magnitudes of 9.0 or greater. These rare but extremely powerful earthquakes all occurred on faults located around or near the Pacific basin. Three of these earthquakes are listed in Table 2 on page 229.

Reading Checkpoint *What is moment magnitude?*

Table 1 Earthquake Magnitudes

Moment Magnitudes	Effects Near Epicenter	Number per Year
< 2.0	Generally not felt	> 600,000
2.0–2.9	Potentially perceptible	> 300,000
3.0–3.9	Rarely felt	> 100,000
4.0–4.9	Can be strongly felt	13,500
5.0–5.9	Can be damaging shocks	1,400
6.0–6.9	Destructive in built-up areas	110
7.0–7.9	Major earthquakes; serious damage	12
8.0 and above	Great earthquakes; destroy communities near epicenter	0–1

Address Misconceptions

L2

Many students may think that small- to medium-sized earthquakes in an area will reduce the chances of a major earthquake in the same region because the smaller earthquakes will release all of the built-up energy. To challenge this misconception, ask students to consider the amount of energy released in an earthquake. Ask: **How much more ground shaking does an earthquake with a measure of 8.0 on the Richter scale have compared with an earthquake with a measure of 3.0 on the Richter scale?** *(about 100,000 times more ground shaking)* **How many smaller earthquakes measuring 3.0 on the Richter scale would need to occur to equal the same amount of ground shaking of an 8.0 earthquake?** *(about 100,000 smaller earthquakes)*
Logical

Answer to . . .

Figure 6 *about 5 minutes*

Reading Checkpoint *a graphic record of an earthquake's seismic waves*

Facts and Figures

Locating Earthquakes While the difference between P and S waves, combined with triangulation, provides a good pedagogical demonstration, earthquakes have not been located this way for a very long time. Instead, all available arrival times of P and S waves (mostly P waves, because they occur first, and are more easily recognized) are entered into a computer program to find the location. For large earthquakes, this can involve thousands of arrival times. A mathematical algorithm called an inversion is used to find the epicenter, depth, and origin time that do the best job of simultaneously matching all of the observed data.

Integrate Math

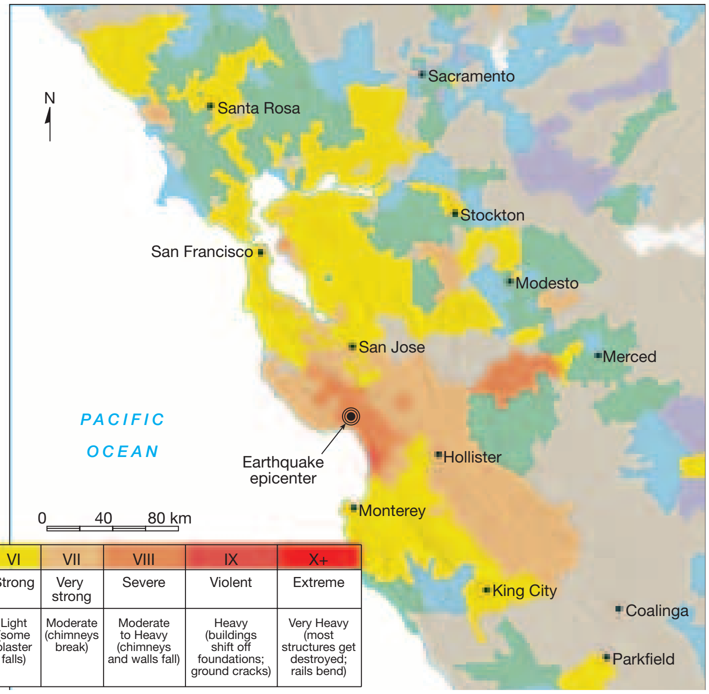
L2

The epicenter of an earthquake is located using information on the arrival times of the P and S waves at three seismograph stations. Ask: **Why must three seismograph stations be used? Why aren't two enough to locate the epicenter?** *(The intersection of three circles will yield a more exact location. If only two stations were used, these two circles would most likely intersect at two points. This would give two possible locations for the same earthquake.)*
Logical, Visual

Use Visuals

L1

Figure 8 Make sure students understand how to read the travel-time graph. Explain that distance is expressed in both kilometers (bottom) and miles (top), and tell them that one kilometer equals approximately 0.6 mile. Ask: **If a station records 2 minutes elapsed time between the arrival of the first P wave and the arrival of the first S wave, how far in kilometers is that station from the epicenter?** *(about 1000 km)* A good way to help students comprehend all the information compiled in a travel-time graph is to create one on the board. Plot data points to simulate how seismic recordings are used to create P and S wave curves.



Modified Mercalli Scale

Intensity	I	II-III	IV	V	VI	VII	VIII	IX	X+
Shaking	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
Damage	none	none	none	Very light (some windows break)	Light (some plaster falls)	Moderate (chimneys break)	Moderate to Heavy (chimneys and walls fall)	Heavy (buildings shift off foundations; ground cracks)	Very Heavy (most structures get destroyed; rails bend)

Figure 7 The magnitude-6.9 Loma Prieta earthquake struck the northern San Andreas fault near Santa Cruz, California, in 1989.

Modified Mercalli Scale Another scale used to rate earthquakes is the Modified Mercalli scale. This scale rates an earthquake's intensity in terms of the earthquake's effects at different locations. The scale has 12 steps, expressed as Roman numerals. An earthquake that can barely be felt is rated I. An earthquake that causes near total destruction is rated XII. The same earthquake can receive different Mercalli scale ratings at different locations. For example, an earthquake might be rated VIII (severe damage) near the epicenter, but only IV (light damage) 50 kilometers away. The map in Figure 7 uses the Mercalli scale to show areas affected by different levels of shaking from a major California earthquake.

Locating an Earthquake

The difference in speeds of P and S waves provides a way to locate the epicenter. The movement of these two types of seismic waves is like a race between two cars. The winning car is faster than the losing car. The P wave always wins the race, arriving ahead of the S wave. The longer the race, the greater the difference will be between the arrival times of the P and S waves at the finish line (the seismic station). The greater the interval between the arrival of the first P wave and the first S wave, the greater the distance to the earthquake epicenter.

Customize for English Language Learners

Tell students that, after a significant earthquake, the United States Geologic Survey (USGS) sends out questionnaires to people in the area affected by the quake. The questionnaire asks them to use the modified Mercalli scale to rate the shaking and damage experienced in their area. Explain that, in this activity, they will use the Mercalli scale to describe the effects of an earthquake.

Have students work in pairs. Each pair should pick one of the locations on the map in Figure 7 above. Referring to the Mercalli scale in the figure, each pair of students should write a sentence describing how the Loma Prieta earthquake might have affected that location. Students should then read their sentences aloud to the class.

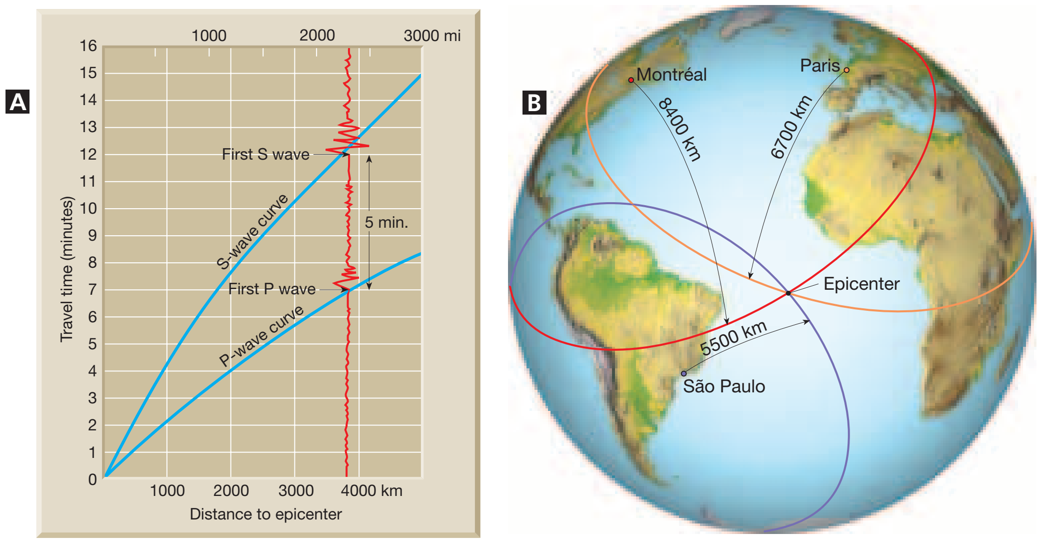


Figure 8 Locating an Earthquake A The distance to the epicenter. The difference in arrival times of the first P wave and the first S wave on the travel-time graph is 5 minutes. So the epicenter is roughly 3800 kilometers away. **B** The point where the circles intersect is the epicenter.
Reading Graphs ***What is the difference in arrival times between P waves and S waves for a seismic station that is 2000 km from an epicenter?***

The difference in arrival times of P waves and S waves can be shown on a travel-time graph like the one in Figure 8. **A travel-time graph, data from seismograms made at three or more locations, and a globe can be used to determine an earthquake's epicenter.** First, using the travel-time graph, you determine the distance from each seismic station to the earthquake. Then, on a globe showing each seismic station, as in Figure 8, you draw circles at the correct scale for the distance from each station to the epicenter. The radius of each circle equals the distance to the earthquake from that station. In Figure 8, you can see that the point where the three circles intersect is the epicenter of the earthquake.

Section 8.2 Assessment

Reviewing Concepts

1. List the two categories of seismic waves.
2. Describe how scientists detect and record seismic waves.
3. Describe the three different ways to measure the size of an earthquake.
4 Briefly describe how the epicenter of an earthquake is located.

Critical Thinking

5. **Comparing and Contrasting** Describe the differences in speed and mode of travel between primary waves and secondary waves.
6. **Applying Concepts** How does a seismograph measure an earthquake?

Writing in Science

Descriptive Paragraph Write a paragraph describing in your own words what would occur in an earthquake with a moment magnitude of 6.0.

3 ASSESS

Evaluate Understanding L2

Have students write three review questions for this section. Students should then break into groups of three or four and ask each other their questions.

Reteach L1

Review the types of seismic waves from earthquakes by asking students to explain what they see in Figure 7.

Writing in Science

An earthquake measuring a moment magnitude of 6 could prove to be potentially devastating to structures not built to new earthquake standards. Poorly built structures would suffer significant damage. However, structures that were constructed with earthquake safety in mind would most likely fare well. Students should use Tables 1 and 2 from the text as a reference in looking at the damage caused by earthquakes with a moment magnitude of 6 or more.

Answer to . . .

Figure 8 *about 3.5 minutes*

Section 8.2 Assessment

1. The two categories of seismic waves are body waves (P and S) and surface waves.
2. To detect and record seismic waves, scientists use an instrument called a seismograph. The graphic record produced by a seismograph, called a seismogram, shows when the different types of seismic waves arrived at the seismograph.
3. Earthquakes can be measured by their intensity (or level of damage done) or by the magnitude (amplitude of seismic waves).
4. The epicenter of an earthquake is located using data taken from at least three different seismograph stations. The time that the first P wave arrives at the station is then subtracted from the time that the first S wave arrives. This value can then be turned into a distance using a travel-time diagram. This distance means that the epicenter is that far from the station. A circle is drawn around each seismograph station and the circles meet where the earthquake epicenter is likely to be found.
5. P waves push and pull rocks in the direction of travel. Their velocity is greater than the velocity of S waves. S waves shake the particles of material at right angles to their direction of travel.
6. In concept, a seismograph has a weight which is suspended from a support that is attached to bedrock. When the bedrock shakes, the weight remains stationary which allows it to act as a reference point. The movement of Earth can then be compared to the weight and recorded on a stationary drum.