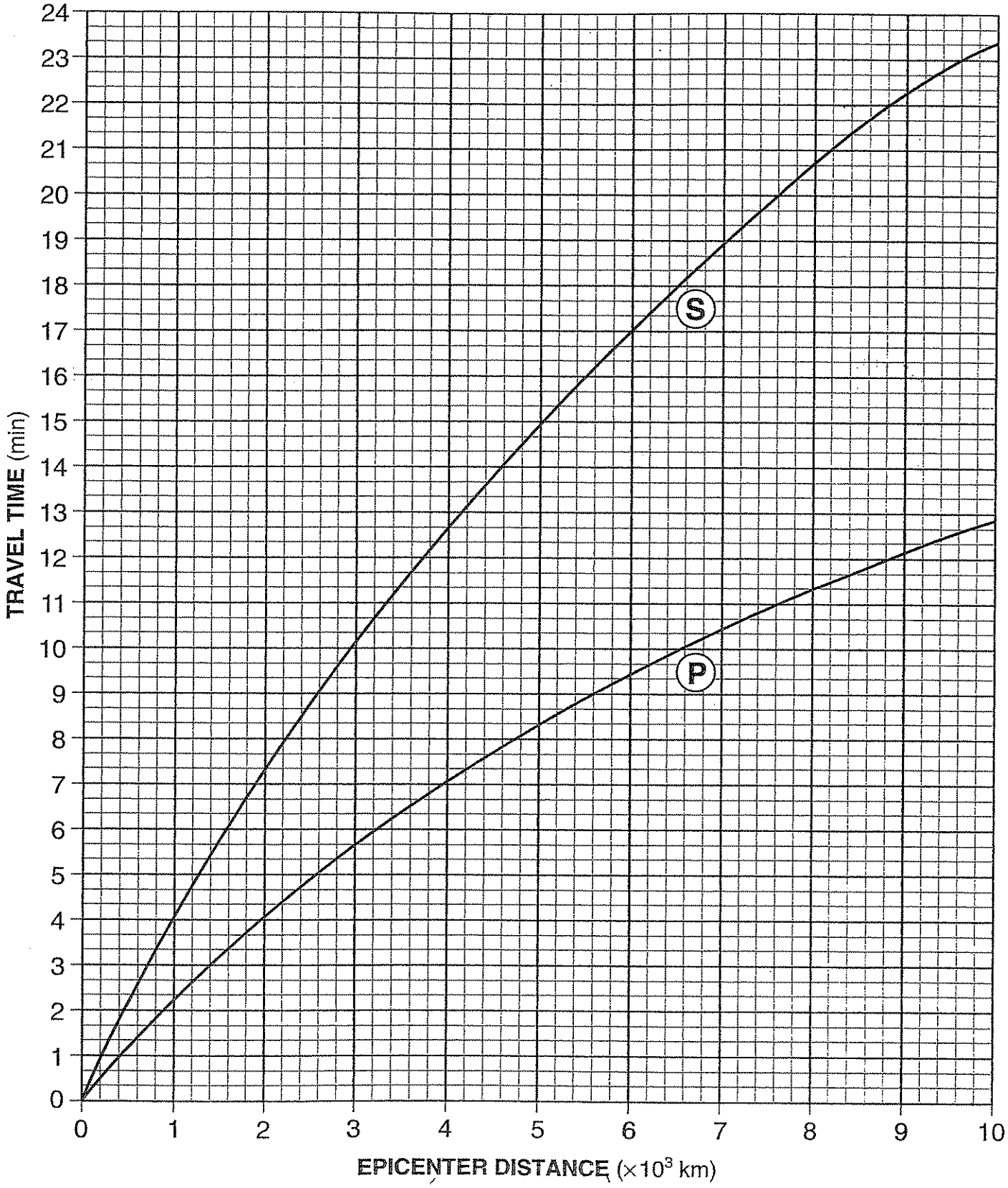
Earthquake P-Wave and S-Wave Travel Time



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Overview:

When the Earth's crust quickly moves or snaps it produces an earthquake, releasing energy in the form of seismic waves that radiate out from the focus. The focus is where the crust broke. Seismic waves have different properties. The *P*-wave is the fastest wave, reaching distance seismographs first. Because it can travel through all phases of matter, it can travel completely through the Earth's interior reaching the other side of the Earth. The arrival of the *P*-wave causes little damage, but it is a warning sign that the slower, more destructive *S*-wave is on its way. The *S*-wave causes much destruction due to its shearing action. The *S*-wave can only travel through solids, thus it is stopped by the liquid outer core.

Due to the differences in the speed of the *P* and *S*-waves, a separation time of these waves occurs. The farther a seismograph is from the epicenter of an earthquake, the greater the separation time will be for the arrival of the *P* and *S*-wave. Using the known speeds of the *P* and *S*-waves and the arrival time of these waves as recorded on a seismogram, a seismologist can determine the distance to the epicenter. Using seismograms from three seismographs from different locations, the location of the epicenter can be determined.

The Graph:

The Axis – The *x*-axis is the Epicenter Distance scale. The bold dark lines represent increments of 1000 km (1×10^3 km). The lighter lines represent intervals of 200 km. The *y*-axis is the Travel Time scale. The bold dark lines represent intervals of a minute, while the lighter lines represent intervals of 20 seconds.

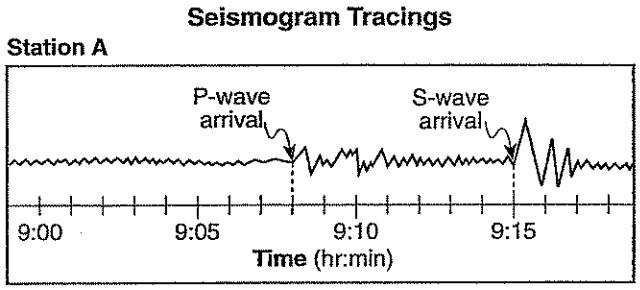
The Graph – The bold graph lines represent the speed of the *P* and *S* seismic waves. When an earthquake occurs, the *P* and *S*-waves are generated at the same time. This is shown on the graph at minute 0. These waves immediately start to separate since the *P*-wave is faster. Thus, the two lines become farther apart as distance increases producing a separation time. To get the travel time for either wave for a certain distance, move upward from the given distance until it intersects the correct seismic line. At this intersection point, read over to the Travel Time axis. For example, a *P*-wave traveling 7200 km would take a travel time of 10:40 (10 min. 40 sec.) to go this distance. The slower *S*-wave would take 19:20 (19 min. 20 sec.) to go the same distance. Given the travel time of a seismic wave, the distance from the epicenter can be determined. For example, how far would a *P*-wave travel in 8:20? Locate this time on the Travel Time axis and move across to the *P*-wave line. At the intersection point, move directly down to the Epicenter Distance axis. The answer is 5000 km. For the same travel time, the slower *S*-wave would have only traveled 2400 km. So as you can see, these problems are "up and over" or "over and down" problems.

Epicenter Distance – If we know the arrival time of both waves, the distance to the epicenter can be determined. The arrival time of the *P*-wave and the *S*-wave may be given to you, or you may have to interpret them from a seismogram. Once you have determined the arrival time of both waves, subtract the *P* arrival time from the *S* arrival time. This is the separation time. Using the edge of a piece of paper, mark off this separation time using the Travel Time axis. You should have two marks representing the separation time. Take this paper with these marks to the graph, position it until the marks fit vertically between the *P* and *S* lines. Reading directly down from this "fitted" position to the *x*-axis will give you the epicenter distance.

Example 1 If the *P*-wave arrived at 10:20:10 and the *S*-wave arrived at 10:26:30, how far away is the epicenter?

Solution: By subtracting, the separation time is 6:20. Using a piece of paper, mark off this time interval from the Travel Time axis. Move this paper, with the two marks, until these marks fit vertically between the *P* and *S* graph lines. Read directly down to the Epicenter Distance axis. If done correctly, the epicenter distance will be 4800 km (±200 km).

Example 2



From the above seismogram, what is the distance from Station A to the epicenter?

Solution: The separation time of the *P* and *S*-wave as shown on the seismogram is 7 mins 00 sec. This time marked off from the Travel Time axis fits vertically between the *P* and *S*-wave graph lines at a distance of 5600 km (±200 km). Practice these problems until you feel comfortable with this procedure.

Epicenter Location – The exact location of the epicenter is determined by using the epicenter distance from three seismic stations. By drawing three circles on a map with the radius of each representing the distance to the epicenter, there will be a common intersection point of the three circles. This intersection point is the location of the earthquake's epicenter.

Additional Information:

- During an earthquake there is a major area that surrounds the Earth that does not receive any *P* or *S*-waves. This area is known as the shadow zone and is caused by the refraction, reflection, and absorption of seismic waves as they encountered different density layers of our Earth.
- By studying the amplitude of the seismic waves, as recorded on the seismogram, the magnitude or strength of the earthquake can be determined. This becomes its Richter Scale number. The Mercalli Scale is used for measuring the intensity of an earthquake using observable damage.
- Most of the knowledge of the interior of the Earth has been revealed by studying seismic waves.
- The origin time of an earthquake is the exact time that the earthquake occurred. The origin time can be determined by knowing the travel time of the *P*-wave to a seismic station. This time is then subtracted from the time that the seismograph recorded the arrival of the *P*-wave.

  Example: A seismograph recorded the first *P*-wave at 10:10:40 and it was determined that the *P*-wave traveled 2,200 km. What was the origin time of the earthquake?

  Solution: It takes 4:20 (4 min. 20 sec.) for a *P*-wave to travel 2,200 km. Subtract this time from 10:10:40, and the origin time would be 10:06:20.

Set 1 — Earthquake P-Wave and S-Wave Travel Time

1. How long would it take for the first *S*-wave to arrive at a seismic station 4,000 kilometers away from the epicenter of an earthquake?

   (1) 5 min 40 sec
   (2) 7 min 0 sec
   (3) 12 min 40 sec
   (4) 13 min 20 sec 1 _____

2. An earthquake's *P*-wave arrived at a seismograph station at 02 hours 40 minutes 00 seconds. The earthquake's *S*-wave arrived at the same station 2 minutes later. What is the approximate distance from the seismograph station to the epicenter of the earthquake?

   (1) 1,100 km (3) 3,100 km
   (2) 2,400 km (4) 4,000 km 2 _____

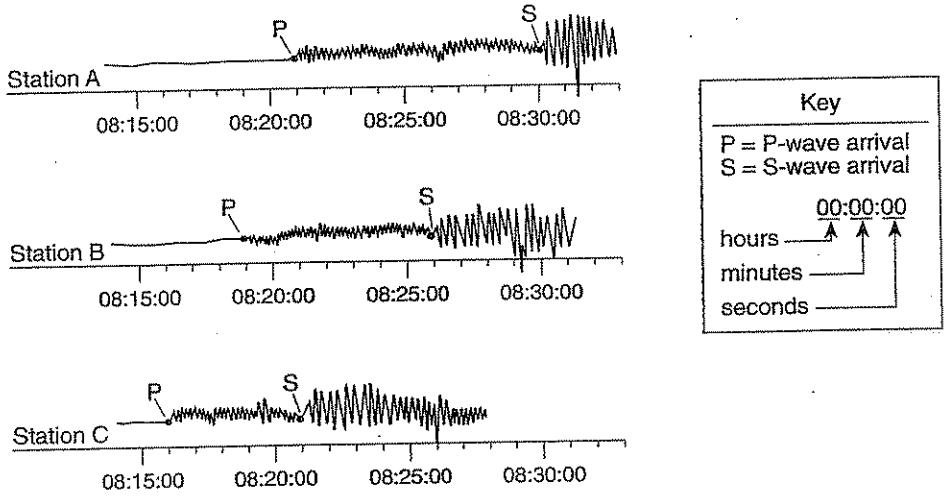
3. How far will a *S*-wave travel in 10 minutes and 40 seconds?

   (1) 3200 km (3) 5600 km
   (2) 3900 km (4) 7200 km 3 _____

4. A *P*-wave takes 8 minutes and 20 seconds to travel from the epicenter of an earthquake to a seismic station. Approximately how long will an *S*-wave take to travel from the epicenter of the same earthquake to this seismic station?

   (1) 6 min 40 sec
   (2) 9 min 40 sec
   (3) 15 min 00 sec
   (4) 19 min 00 sec 4 _____

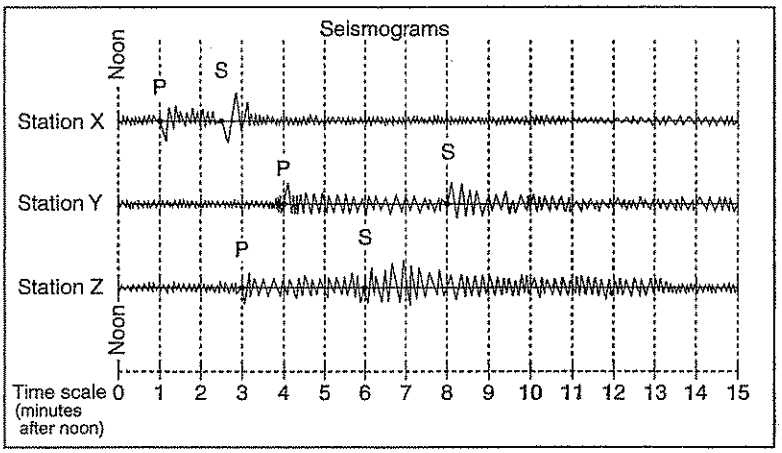
5. The diagram below represents three seismograms showing the same earthquake as it was recorded at three different seismic stations, *A*, *B*, and *C*.

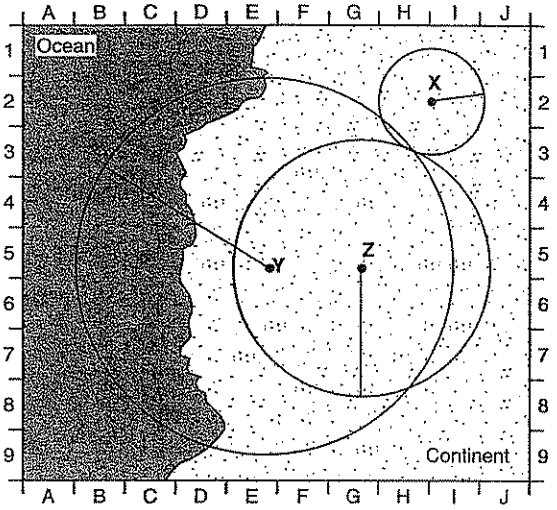


Which statement correctly describes the distance between the earthquake epicenter and these seismic stations?

(1) *A* is closest to the epicenter, and *C* is farthest from the epicenter.
(2) *B* is closest to the epicenter, and *C* is farthest from the epicenter.
(3) *C* is closest to the epicenter, and *A* is farthest from the epicenter.
(4) *A* is closest to the epicenter, and *B* is farthest from the epicenter. 5 _____

Base your answers to questions 6 through 9 on the diagram and map below. The diagram shows three seismograms of the same earthquake recorded at three different seismic stations, *X*, *Y*, and *Z*. The distances from each seismic station to the earthquake epicenter have been drawn on the map. A coordinate system has been placed on the map to describe locations. The map scale has not been included.





6. Approximately how far away from station *Z* is the epicenter?

   (1) 1,300 km
   (2) 1,800 km
   (3) 3,900 km
   (4) 5,200 km

   6 _____

7. The *S*-waves from this earthquake that travel toward Earth's center will

   (1) be deflected by Earth's magnetic field
   (2) be totally reflected off the crust-mantle interface
   (3) be absorbed by the liquid outer core
   (4) reach the other side of Earth faster than those that travel around Earth in the crust

   7 _____

8. Seismic station *X* is 800 kilometers from the epicenter. Approximately how long did it take the *P*-wave to travel to station *X*?

   (1) 1 min 50 sec
   (2) 2 min 50 sec
   (3) 3 min 20 sec
   (4) 6 min 30 sec

   8 _____

9. On the map, which location is closest to the epicenter of the earthquake?

   (1) E–5
   (2) G–1
   (3) H–3
   (4) H–8

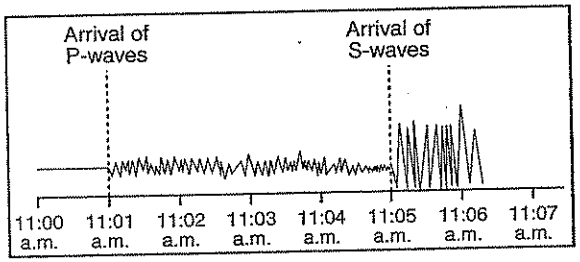
   9 _____

Set 2 — Earthquake P-Wave and S-Wave Travel Time

10. Scientists have inferred the structure of Earth's interior mainly by analyzing

(1) the Moon's interior
(2) the Moon's composition
(3) Earth's surface features
(4) Earth's seismic data 10 _____

Base your answers to questions 11 and 12 on the earthquake seismogram below.



11. Approximately how far away is the epicenter?

(1) 2000 km (3) 3500 km
(2) 2600 km (4) 4400km 11 _____

12. How many additional seismic stations must report seismogram information in order to locate this earthquake?

(1) one (3) three
(2) two (4) four 12 _____

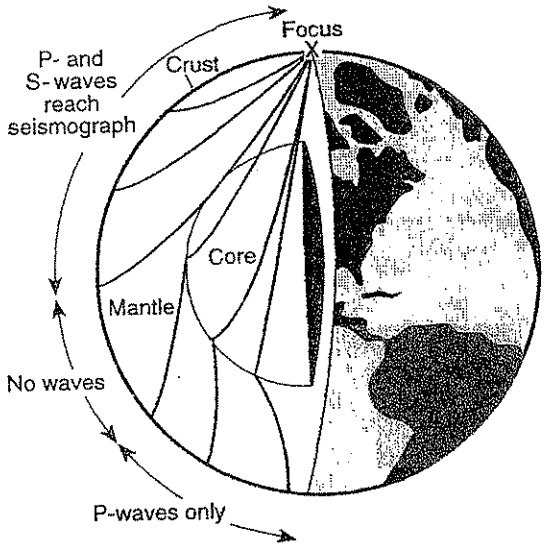
13. The distance from an epicenter of an earthquake to New York City is 3,000 kilometers. What was the approximate travel time for the *P*-waves from this epicenter to New York City?

(1) 1 min 20 sec
(2) 5 min 40 sec
(3) 7 min 30 sec
(4) 10 min 00 sec 13 _____

14. An earthquake's first *P*-wave arrives at a seismic station at 12:00:00. This *P*-wave has traveled 6000 kilometers from the epicenter. At what time will the first *S*-wave from the same earthquake arrive at the seismic station?

(1) 11:52:20 (3) 12:09:20
(2) 12:07:40 (4) 12:17:00 14 _____

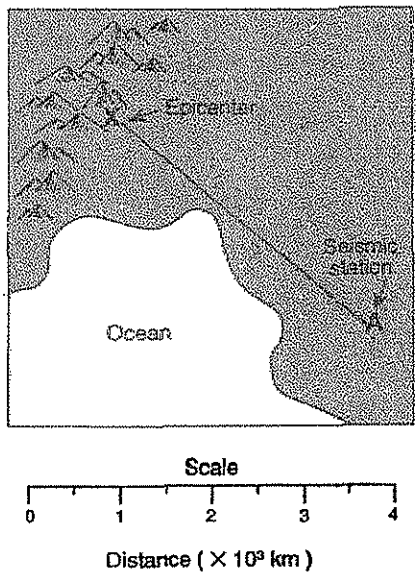
15. The cutaway diagram below shows the paths of earthquake waves generated at point *X*.



Only *P*-waves reach the side of Earth that is opposite the focus because *P*-waves

(1) are stronger than *S*-waves
(2) travel faster than *S*-waves
(3) bend more than *S*-waves
(4) can travel through liquids and *S*-waves cannot 15 _____

Base your answers to questions 16 and 17 on the map below. The map shows point *X*, which is the location of an earthquake epicenter, and point *A*, which is the location of a seismic station.



16. Approximately how long did the earthquake's *P*-wave take to arrive at the seismic station?

(1) 3 min 40 sec
(2) 5 min 10 sec
(3) 6 min 20 sec
(4) 11 min 5 sec 16 _____

17. Which statement best describes the arrival of the initial *S*-wave at the seismic station?

(1) It arrived later than the *P*-wave because *S*-waves travel more slowly.
(2) It arrived earlier than the *P*-wave because *S*-waves travel faster.
(3) It arrived at the same time as the *P*-wave because *S*-waves and *P*-waves have the same velocity on Earth's surface.
(4) It never reached location *A* because *S*-waves can travel only through a liquid medium. 17 _____

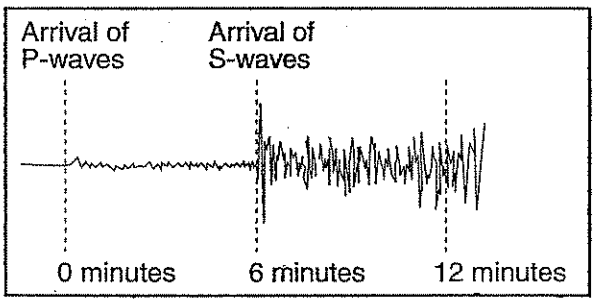
18. The epicenter of an earthquake is located 2,800 kilometers from a seismic station. Approximately how long did the *S*-wave take to travel from the epicenter to the station?

(1) 11 min 15 sec
(2) 9 min 35 sec
(3) 5 min 20 sec
(4) 4 min 20 sec 18 _____

19. How far from an earthquake epicenter is a city where the difference between the *P*-wave and *S*-wave arrival times is 5 minutes and 00 seconds?

(1) 1.7×10^3 km
(2) 9.9×10^3 km
(3) 3.5×10^3 km
(4) 4.7×10^3 km 19 _____

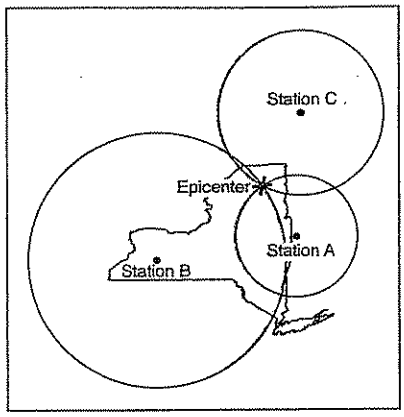
20. The seismogram below shows *P*-wave and *S*-wave arrival times at a seismic station following an earthquake.



The distance to the epicenter is approximately

(1) 1,600 km (3) 4,400 km
(2) 3,200 km (4) 5,600 km 20 _____

21. The map below shows the location of an earthquake epicenter in New York State. Seismic stations *A*, *B*, and *C* received the data used to locate the earthquake epicenter.



The seismogram recorded at station *A* would show the

(1) arrival of *P*-waves, only

(2) earliest arrival time of *P*-waves

(3) greatest difference in the arrival times of *P*-waves and *S*-waves

(4) arrival of *S*-waves before the arrival of *P*-waves 21 _____

22. An earthquake's magnitude can be determined by

(1) analyzing the seismic waves recorded by a seismograph

(2) calculating the depth of the earthquake faulting

(3) calculating the time the earthquake occurred

(4) comparing the speed of *P*-waves and *S*-waves 22 _____

23. List two actions a homeowner could take to prepare the home or family for an earthquake.

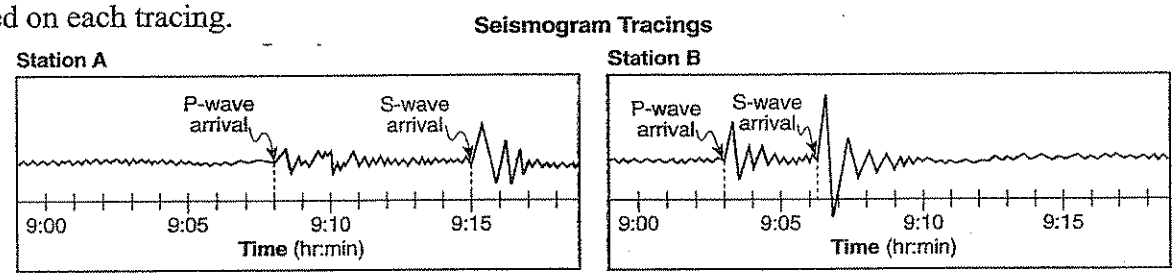
1 _____

_____

2 _____

_____

Base your answers to questions 24 *a* and *b* on the diagram below, which shows two seismogram tracings, at stations *A* and *B*, for the same earthquake. The arrival times of the *P*-waves and *S*-waves are indicated on each tracing.



24. *a*) Explain how the seismic tracings recorded at station *A* and station *B* indicate that station *A* is farther from the earthquake epicenter than station *B*.

_____

_____

b) Seismic station *A* is located 5,400 kilometers from the epicenter of the earthquake. How much time would it take for the first *S*-wave produced by this earthquake to reach seismic station *A*?

_____