Waves Practice Items

1. The wavelength of a harmonic wave divided by its speed of propagation is equal to

   A. the frequency
   B. the angular frequency
   C. the wave number
   D. the period

2. The greater the amplitude of a sound wave, the greater its

   A. frequency
   B. wavelength
   C. wave number
   D. energy

3. The speed of sound through air is approximately 343 m/s at normal room temperature. An E note produced by a piano has a frequency of 660 Hz. What is its wavelength?

   A. 0.5 m
   B. 2.0 m
   C. 11 m
   D. 20 m

4. Which of the following statements about sound wave is true?

   A. They can pass through a vacuum.
   B. Their speed does not depend upon the medium of propagation.
   C. They travel as longitudinal waves.
   D. They cannot be reflected.

5. Which of the following phenomena is **not** characteristic of sound waves:

   A. reflection
   B. polarization
   C. diffraction
   D. interference

6. Without changing the length of the string, the tension of a stretched string is increased 9 times. The fundamental frequency

   A. increases 9 times
   B. decreases 9 times
   C. increases 3 times
   D. remains the same

7. The fundamental frequencies of a set of banjo strings of different gauge but fixed length and tension are

   A. the same
   B. inversely proportional to string diameter
   C. directly proportional to Young's modulus
   D. distributed in simple integer ratios

8. Sound travels at a lower speed through air than through water. Which of the following is the best explanation for this?

   A. Water is less dense than air.
   B. Water is more dense than air.
   C. Air is more compressible than water.
   D. Water is more structured at the intermolecular level than air.

9. When two-out-of-tune flutes attempt to play the same note, one produces a tone that has a frequency of 392 Hz, while the other produces 406 Hz. When a tuning fork is sounded together with the 392 Hz tone, the combined notes quaver at a frequency of 9 Hz. When the same tuning fork is sounded together with the 406 Hz tone, a frequency of 5 Hz is produced. What is the frequency of the tuning fork?

A. 383 Hz
B. 397 Hz
C. 401 Hz
D. 411 Hz

10. During the day, the upper atmosphere is cooler than air at ground level, while during the night, the upper levels are warmer than the lower levels. Traveling more slowly through more dense media, the tendency during the day is for sound waves to veer upwards through the atmosphere, while at night the sound waves veer more downwards. To which of the following is this situation most analogous?

A. the refraction of light
B. convection currents in the ocean
C. the Doppler effect
D. the thermal equilibrium of radiation

11. An organ pipe with one closed end is 0.75 m long. The speed of sound in the room is 330 m/s. Which of the following notes does the pipe produce as its fundamental mode?

A. A (110 Hz)
B. A (220 Hz)
C. B (248 Hz)
D. E (660 Hz)

12. The trombone is the loudest instrument in the orchestra. A trombone produces a loudness of 110 dB from one meter away. Two trombones from one meter away will produce a loudness of

A. 113 dB
B. 120 dB
C. 130 dB
D. 220 dB

13. The sound level at a distance 5 m from a point sourcce is 100 dB. At what distance will the sound level be 80 dB?

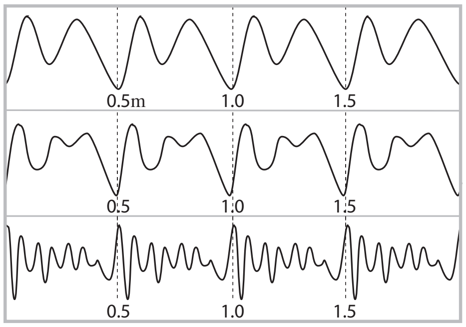
A. 20 m
B. 25 m
C. 50 m
D. 500 m

14. A low flying jet zooms past an airport tower. The speed of sound in the warm air of the airfield is 350 m/s. The pitch frequency of its engine noise shifts from 440 Hz from the listener's perspective as it is flying towards the tower to 330 Hz after it has passed. What is its approximate speed?

A. 50 m/s
B. 65 m/s
C. 70 m/s
D. 110 m/s

15. The three complex sound waves depicted in the figure below

A. have the same wavelength
B. are traveling through different media
C. possess different amplitudes
D. are transverse waves



Passage (Questions 16-21)

Seismic waves are waves of energy that travel through the Earth's layers, and are a result of an earthquake, explosion, or a volcano that imparts low-frequency acoustic energy. The propagation velocity of the waves depends on density and elasticity of the medium. Velocity tends to increase with depth, and ranges from approximately 2 to 8 km/s in the Earth's crust up to 13 km/s in the deep mantle.

There are two types of waves which travel within the body of the Earth. P waves are sometimes called compressional waves or primary waves or push-pull waves and they are propagated by movements of the material in the Earth parallel to the direction in which the wave is moving. S waves are also called shear waves or secondary waves and they propagate by movements of the Earth perpendicular to the direction in which the wave is moving.

P wave velocity depends on the bulk modulus, shear modulus and the density of the medium

$$v = \sqrt{\frac{\frac{4}{3}B + S}{\rho}}$$

S wave velocity depends on the shear modulus and density of the medium

$$v = \sqrt{\frac{S}{\rho}}$$

The crust mantle boundary was discovered in 1909 by a seismologist named Mohorovici (Yugoslav), as a result of his study of an earthquake in Croatia at that time. He found that, out to about 150 km, the time it took for the earthquake waves to reach each seismograph station was proportional to the distance the station was from the earthquake. He determined that the P wave velocity of the upper crust must be about 6 km/s. However, for stations greater than about 150 km from the earthquake, waves arrived with a higher average velocity.

Mohorovici calculated that the distance at which the change in velocity occurred (about 150 km) can be used to calculate the depth to velocity increase. He calculated that the depth to this velocity jump was about 30 km. We interpret this velocity jump as the crust-mantle boundary. At short distances, the "direct waves" that travel along the surface will arrive first. However, at greater distances, the P waves that travel down to the mantle, and are bent and travel along the top of the mantle at the higher velocity, can arrive before the waves traveling directly along the surface.

16. The velocity of seismic waves tends to increase with depth because

A. the medium is both more compressible and less dense at greater depth
B. the density and plasticity of the medium both increase with depth
C. elastic modulus and density both increase at greater depth
D. pressure and rigidity increase faster than density with depth

17. Which of the following may be observed with S waves but not with P waves?

A. polarization
B. constructive interference
C. travel through unsaturated sediments
D. amplitude

18. Within a geological medium through which both P waves and S waves are traveling, which seismic waves are faster?

A. P waves
B. S waves
C. It depends on the medium.
D. Both travel at the same speed.

19. When a seismic body wave encounters a lithological boundary layer, the incident ray can transform into several new rays. Some of the energy goes into the new layer but is bent, and some is reflected back up to the surface. The ray entering the new layer has undergone

A. wave splitting
B. refraction
C. polarization
D. interference

20. The higher velocity P waves observed by Mohorovici as described in the passage

A. had struck the crust mantle interface at the critical angle
B. had undergone conversion from S waves to P waves at the crust mantle interface
C. had been reflected by the crust mantle interface
D. had traveled a greater overall distance

21. From the S wave shadow zone observed with seismic readings taken on the opposite side of the Earth from an earthquake, it has been deduced that no S waves pass through the outer core. The most likely reason is that

A. The greater pressure at deeper levels opposes the perpendicular displacements of the S waves.
B. It is impossible to produce a shearing stress by displacing a section of liquid.
C. The S waves are reflected by the denser strata at that depth.
D. The S waves reach a threshold beyond which the gravitational force can no longer act to restore wave displacement.

Waves

Answers and Explanations

1. D

It's hard to resist answering frequency with this question. It can be this way with the easiest questions on the MCAT. Before toggling the answer, take a moment to check to make sure of what you think you see. It just takes just a moment. The MCAT is always testing your attention.

Frequency is not the wavelength divided by wave speed. That would be the reciprocal of frequency.

$$f = \frac{v}{\lambda}$$

The period is the reciprocal of the frequency. The period tells you how many seconds per cycle.

$$T = \frac{1}{f}$$

2. D

Amplitude is the magnitude of maximum disturbance of the medium, during one cycle of a periodic wave, known as peak deviation. The amplitude of a wave is related to the amount of energy it carries. A high amplitude wave carries a large amount of energy. We talk about the energy of sound in terms of intensity (W/m^2). Intensity goes up with the square of the amplitude of a sound wave.

3. A

The speed of a harmonic wave is the product of wavelength and frequency.

$$v = \lambda f$$

Divide frequency into wave speed to get the wavelength.

$$\lambda = \frac{v}{f} = \frac{343\text{ m/s}}{660\text{ s}^{-1}} = 0.5\text{ m}$$

4. D

Sound waves are longitudinal waves. Vibration is in the same direction as wave propagation.

5. B

Polarization is the phenomenon of transverse waves only. It does not happen in longitudinal waves such as sound waves. The disturbances in longitudinal waves are in the direction of wave propagation. In transverse waves the disturbances are perpendicular to the direction of wave propagation. Electromagnetic waves are transverse and may be polarized.

6. B

The wavelength of the fundamental vibrational mode of a stretched string is twice the length of the string. If the length of the stretched string isn't altered, the wavelength of the fundamental mode doesn't change. However, the speed of the wave on the string does change. The speed is proportional to the square root of the tension.

$$v = \sqrt{\frac{F}{\mu}}$$

Frequency equals wave speed divided by wavelength.

$$f = \frac{v}{\lambda}$$

A three fold increase in wave speed corresponds to a three fold increase in frequency.

7. B

The wavelength of the fundamental mode is twice the length of the string, so the wavelength is the same for all of the banjo strings. However, frequency is proportional to the wave speed and the wave speed is different.

$$f = \frac{v}{\lambda}$$

And wave speed is proportional to the square root of the tension and inversely proportional to the mass per unit length.

$$v = \sqrt{\frac{F}{\mu}}$$

In other words, the frequency is inversely proportional to the mass per unit length.

A banjo string is an extended cylinder. The mass per unit length is proportional to the volume per unit length. The volume per unit length equals the cross-sectional area. The cross sectional area is proportional to the square of the diameter.

In summary! The frequency is inversely proportional to the square root of the square of the diameter, or, more plainly, frequency is inversely proportional to the diameter.

8. C

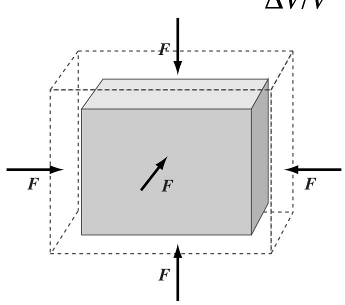
The speed of sound in a particular medium equals the square root of the bulk modulus of the medium divided by its density.

$$v = \sqrt{\frac{B}{\rho}}$$

Sound travels more slowly in air than water, but, by itself, the lower density of air vs. water predicts sound to travel faster in air. The reason sound travels more slowly in air is that air has a much lower bulk modulus.

The bulk modulus is a property of a material. Its the ratio of an applied pressure to the percent compression observed of the material.

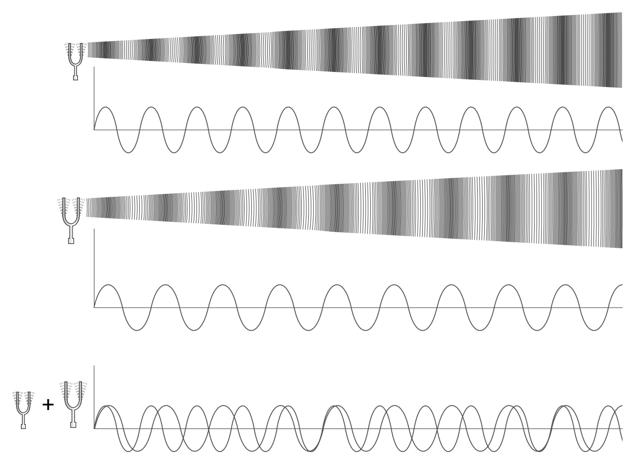
$$\text{bulk modulus} = -\frac{F/A}{\Delta V/V}$$



A high value of B indicates a material resists compression, while a low value indicates volume appreciably decreases under uniform pressure. The reciprocal of the bulk modulus is compressibility, so a substance with a low bulk modulus has high compressibility. Air has a much higher compressibility than water, in other words, a much lower bulk modulus. Hence, sound travels more slowly in air than water despite the lower density of air.

8. C

Beats are fluctuations in sound intensity produced when two tones nearly equal in frequency are sounded simultaneously. When sounds of slightly different frequencies are in the same position in space, the sound waves are periodically in phase, resulting in constructive interference, and then out of phase, resulting in destructive interference. The resulting audible pulsations in intensity are called beats.



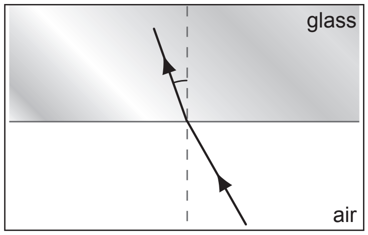
The number of beats one hears per second, the beat frequency, is simply the arithmetic difference between the frequencies of the contributing sound waves.

$$f_b = f_1 - f_2$$

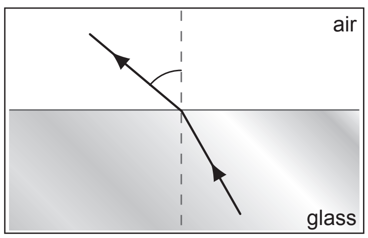
Our tuning fork produces a 9 Hz beat frequency with the 392 Hz tone and a 5 Hz beat frequency with the 406 Hz tone. 9 Hz from 392 and 5 Hz from 406, its frequency must be 401 Hz.

10. A

In the transmission of light, as light moves from a fast to a slow medium it bends towards the normal due to refraction.

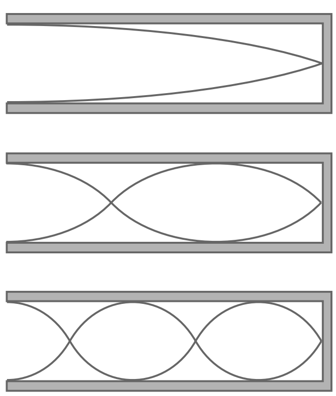


As light is transmitted from a slow to a fast medium it bends away from the normal.



11. A

The wavelength of the fundamental mode of the standing waves in an air column closed at one end is four times the length of the pipe.



$$\lambda_n = 4L, \ \frac{4L}{3}, \ \frac{4L}{5}, \ \ldots \ \frac{4L}{n}$$

$$(n = 1,3,5,\ldots)$$

Hence, the wavelength of the fundamental mode is

$$\lambda_n = 4L = 4(0.75 \text{ m}) = 3.0 \text{ m}$$

To determine frequency when you have the wavelength, divide the wavelength into the wave speed.

$$f = \frac{v}{\lambda} = \frac{330 \text{ m/s}}{3 \text{ m}} = 110 \text{ Hz}$$

12. A

Intensity measures the actual energy flux produced by a sound source in watts per square meter.

The loudness scale is related to intensity, but it is based on how humans perceive sound, and is proportional to the logarithm of intensity.

$$\beta = 10 \log \left(\frac{I}{I_0}\right)$$

If I_1 is the original intensity, doubling the number of amplifiers will produce a new intensity of $2I_1$. The decibel level with this new intensity will be:

$$\beta_2 = 10 \log \left(\frac{2I_1}{I_0}\right) = 10\left[\log \left(\frac{I_1}{I_0}\right) + \log 2\right]$$

Doubling the intensity results in the addition of 10 log (2) decibels, or about 3.

If you don't remember that the common logarithm of 2 is about 0.3, then ask yourself, to what power do I need to raise 10 to get 2? Well, 2 is a bit less than the cube root of 10, so the logarithm of 2 is a bit less than one third.

A faster path for answering this particular question would be to remember the following:

Increase intensity 10 fold and you add 10 dB.

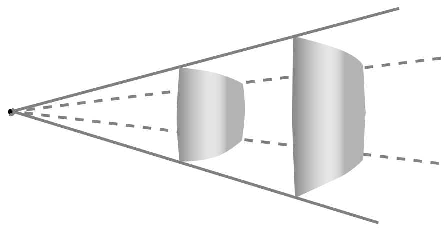
Increase intensity 100 fold and you add 20 dB.

Increase intensity 1000 fold and you add 30 dB.

We only doubled intensity, so the addition to loudness is necessarily less than 10 dB. Choice 'A' is the only possibility.

13. A
Sound waves spread out into space from a point source. The spatial volume into which the sound waves are spreading increases and the intensity decreases with the square of the distance from the point source. The increasing volume of space into which the sound has spread dilutes its intensity.

$$I \circ \frac{1}{r^2}$$



The loudness scale is related to intensity, but it is based on how humans perceive sound, and is proportional to the logarithm of intensity.

$$\beta = 10 \log \left(\frac{I}{I_0}\right)$$

In our problem, the sound level at a distance 5 m from a point source is 100 dB. To determine the distance at which the sound level would be 80 dB remember that a decrease in 20 dB represents a 100 fold decrease in intensity. To *decrease* intensity 100×, we need to *increase* the distance from the point source 10×. The sound level will be 80 dB at 50m.

14. A
The Doppler effect causes the frequency measured by an observer to be different than the frequency of the source whenever there is relative motion between the source and observer. A coefficient can be derived, depending on the speeds of the waves, observer, and source, to adjust the source frequency to the observer frequency.

$$f' = f\left(\frac{v \pm v_0}{v \mp v_s}\right)$$

f' = observed frequency
f = source frequency
v = wave speed
v_o = speed of observer
v_s = speed of source

If the observer is moving toward the source, use the positive sign in the numerator, which would lead to an increased observed frequency. If the observer is moving away from the source, use the negative sign. If the source is moving toward the observer, use the negative sign in the denominator, which would lead to an increased observed frequency. If the observer is moving away from the source, use the negative sign.

In our problem, the observer is stationary. The first equation below describes the shift in observed frequency as the plane approaches the tower, the second after it has passed.

$$440 \text{ Hz} = f\left(\frac{350 \text{ m/s}}{350 \text{ m/s} - v_s}\right)$$

$$330 \text{ Hz} = f\left(\frac{350 \text{ m/s}}{350 \text{ m/s} + v_s}\right)$$

At this stage we can foresee combining these two equations to solve for v_s.

$$440 \text{ Hz}\,(350 \text{ m/s} - v_s) = f\,(350 \text{ m/s})$$

$$330 \text{ Hz}\,(350 \text{ m/s} + v_s) = f\,(350 \text{ m/s})$$

It makes sense to hold off on doing any arithmetic. Combining the equations should simplify things for us.

$$(440 \text{ Hz})(350 \text{ m/s}) - (440 \text{ Hz})\,v_s = f\,(350 \text{ m/s})$$

$$(330 \text{ Hz})(350 \text{ m/s}) + (330 \text{ Hz})\,v_s = f\,(350 \text{ m/s})$$

We subtract the second equation above from the first and then solve for v_s.

$$(110 \text{ Hz})(350 \text{ m/s}) - (770 \text{ Hz})\,v_s = 0$$

$$350 \text{ m/s} - 7v_s = 0$$

$$v_s = 50 \text{ m/s}$$

15. A

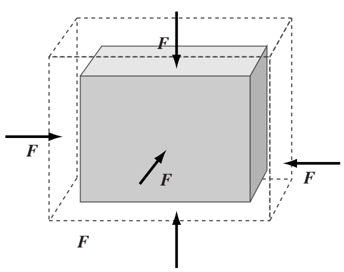
These are periodic but non-sinusoidal wave forms. With sinusoidal waves, the wavelength is the distance from crest to crest or trough to trough, but the true definition of the wavelength is the distance over which the wave's shape repeats. These all have the same wavelength.

16. D

For both P waves and S waves, wave speed is greater with greater elastic modulus. P waves are compression waves. Both shear and bulk modulus are relevant with P waves. S waves are transverse. The only relevant modulus with S waves is shear modulus.

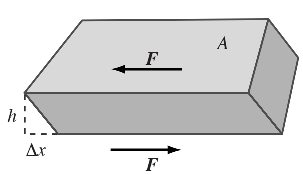
Bulk modulus the ratio of an applied pressure to the percentage compression observed of the material. The higher the bulk modulus the more rigid the material is to pressure.

$$\text{bulk modulus} = -\frac{F/A}{\Delta V/V}$$



The higher the shear modulus the more rigid the material is to a shearing stress.

$$\text{shear modulus} = \frac{F/A}{\Delta x/h}$$



Whether P waves or S waves, the more rigid the medium the faster the wave. The more dense the material the slower the wave. Choice 'D' is the only answer which is logically consistent with this underlying basis for wave speed.

17. A

S waves are transverse. P waves are longitudinal. Only transverse waves can be polarized. With transverse waves, the disturbances are perpendicular to the direction of wave velocity. There can be variation in the plane of oscillation transverse to wave velocity. Polarization describes selection preference in this geometric orientation. With longitudinal waves on the other hand, the oscillations only occur along the wave parallel to wave velocity. It doesn't make sense to speak of "polarization" of longitudinal waves.

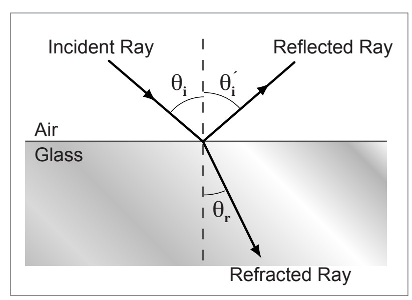
18. A

You can see this in the expressions for wave speed. By mathematical necessity, the expression for P wave speed on the left below must be greater than S wave speed on the right.

$$\sqrt{\frac{\frac{4}{3}B + S}{\rho}} > \sqrt{\frac{S}{\rho}}$$

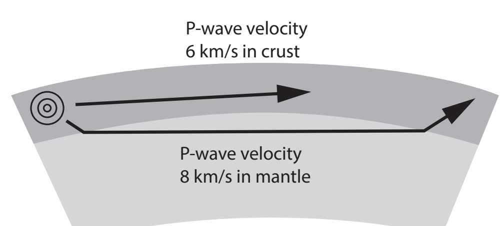
19. B

The figure below shows a similar process of reflection and refraction of electromagnetic waves (light) at the boundary between air and glass.



20. D

The mental projection in reading comprehension should be along the lines of the figure below.



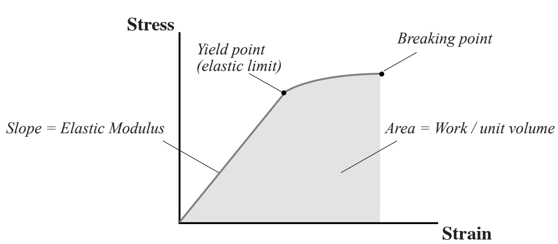
21. B

A teaching purpose with this passage is to provide a bit of an orientation for the topic of elastic deformation. Elasticity isn't mentioned as a specific item on AAMC's MCAT topic outline. However, it intersects with several important topics that are on the outline, for example, what determines the speed of sound in a particular medium. Elasticity is right on the edge of the scope of the test. The speed of sound in a particular medium equals the square root of the bulk modulus of the medium divided by its density. Bulk modulus is an elastic property of the medium which describes how hard the material is to compress.

$$v = \sqrt{\frac{B}{\rho}}$$

The elastic properties of a solid body govern the manner of its deformation under external forces. A stress is the array of forces causing a deformation. Strain measures the degree of deformation. The elastic modulus governs the relationship between stress and strain below the elastic limit, also called the yield point. After the yield point has been reached, the deformation is no longer completely reversible (the object no longer resumes its original shape when the stress is removed). If the elastic modulus for a particular material has a high value, objects made from that material are difficult to deform (and a reversible deformation stores much energy for a given strain).

$$\text{elastic modulus} = \frac{\text{stress}}{\text{strain}}$$



Curve of **Stress vs. Strain** *which describes the mechanical deformation of a solid body.*

Three types of elastic modulus describe the three major kinds of deformation, Young's modulus (tensile stress and strain), shear modulus (shear stress and strain), and bulk modulus (volume stress and strain).

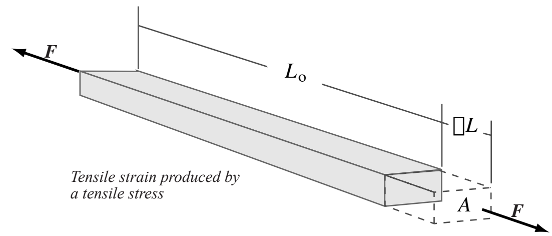
$$\text{Young's modulus} = \frac{F/A}{\Delta L/L_o}$$

tensile stress = $\frac{F}{A}$

F = force
A = cross-sectional area

tensile strain = $\frac{\Delta L}{L_o}$

ΔL = change in length
L_o = original length



Tensile strain produced by a tensile stress

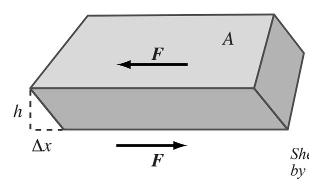
$$\text{shear modulus} = \frac{F/A}{\Delta x/h}$$

shear stress = $\frac{F}{A}$

F = tangential force
A = area of face being sheared

shear strain = $\frac{\Delta x}{h}$

Δx = horizontal distance sheared face moves
h = height of object



Shear strain produced by a shear stress

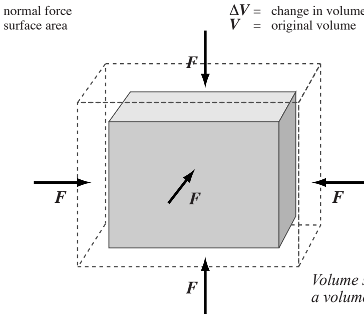
$$\text{bulk modulus} = -\frac{F/A}{\Delta V/V}$$

volume stress = $\frac{F}{A}$

F = normal force
A = surface area

volume strain = $\frac{\Delta V}{V}$

ΔV = change in volume
V = original volume



Volume strain produced by a volume stress

S waves are transverse. Solid geological materials can transmit S waves because a solid body can support a shear stress. In liquids, though, a shear stress simply causes the fluid laminae to slide past each other. A liquid supports a volume stress but not a shear stress. For this reason only P waves, which are longitudinal, can transmit through the liquid core.