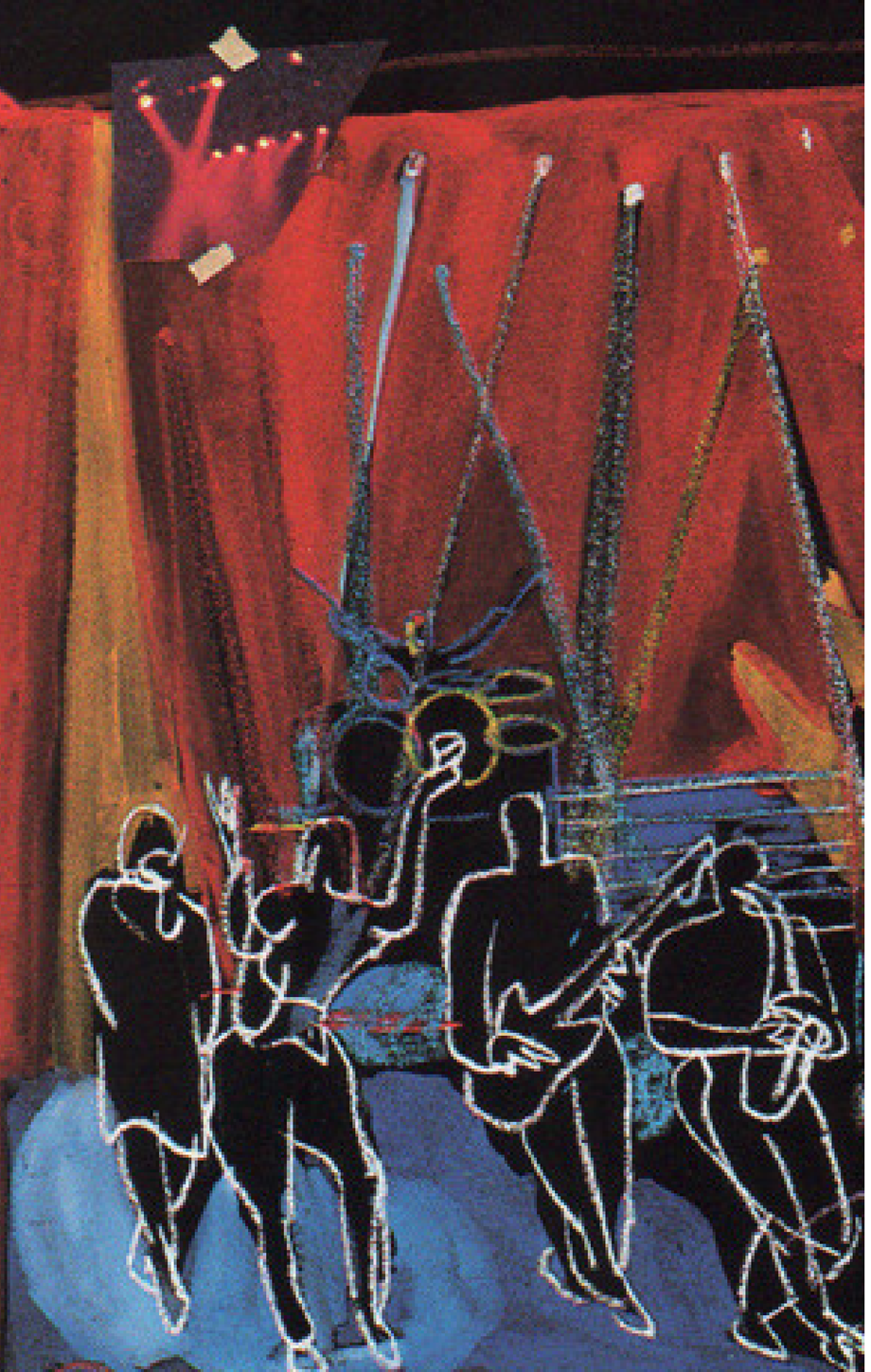


PHY-141

Pressure Waves

Luis Anchordoqui

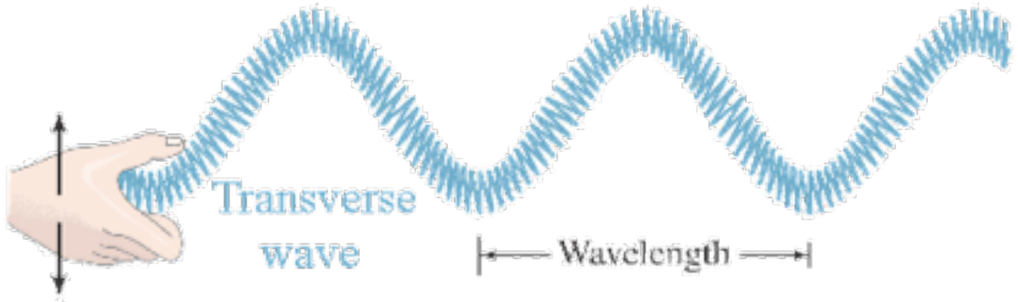
Outline

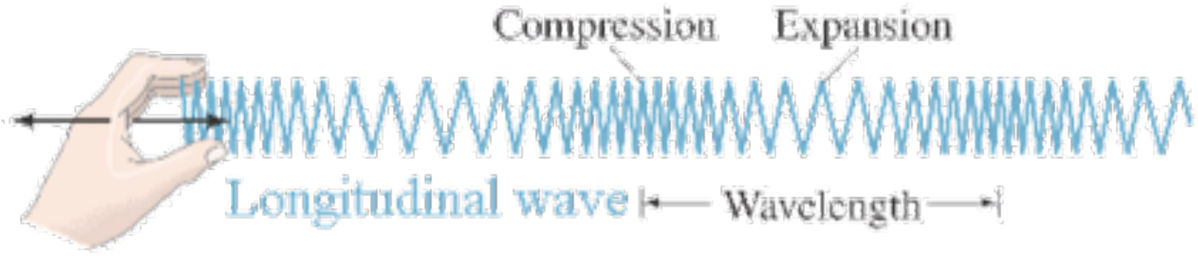
- A wave is a disturbance that transfers energy through space or a medium (solid, liquid, gas) without transporting matter

- While the wave itself moves forward, the particles of the medium typically oscillate around a fixed equilibrium position and do not travel with the wave

Outline

- Waves are categorized according to the direction of oscillation:
- for transverse waves, the medium oscillates perpendicularly to the direction of energy travel (e.g., waves on a string)
- for longitudinal waves, the medium oscillates parallel to the direction of travel, creating regions of compression and rarefaction (e.g., sound waves in air)



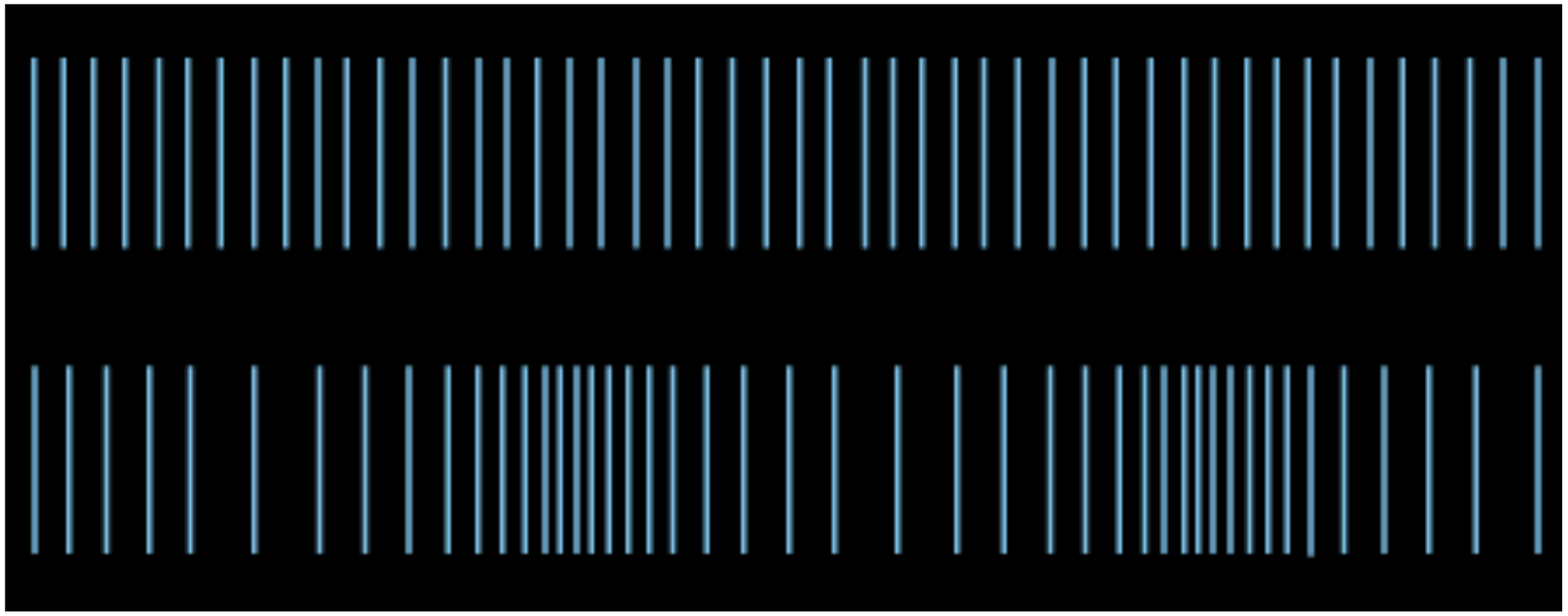


Outline

- Today's class covers the fundamental characteristics of longitudinal waves, specifically examining how particle oscillations occur parallel to energy transfer, resulting in regions of compression and rarefaction
- We will analyze key properties such as wavelength, frequency, velocity, and amplitude

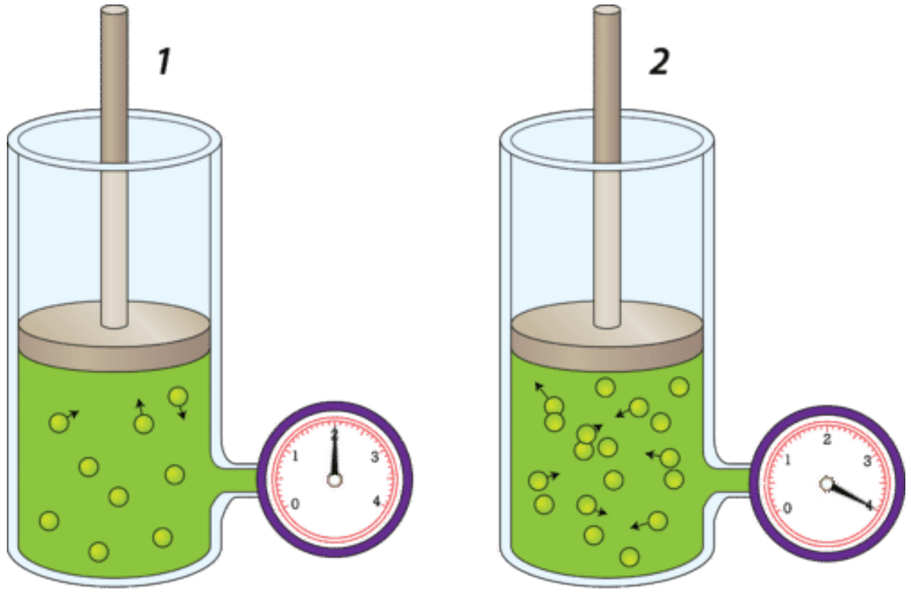
Air at equilibrium

Compressions and rarefactions



Molecular Density

- Gas pressure represents the force exerted by molecules on their surroundings
- The pressure distribution within a substance is not necessarily uniform
- For example, localized pressure increases may occur near an active fan
- Such disparities are transient and arise from differences in molecular density, thermal energy, or a combination of the two
- Throughout this class, we will focus exclusively on molecular concentration gradients, as temperature fluctuations in sound wave propagation are negligible by comparison and can be assumed constant
- Molecular concentration is quantified as number density, defined as the total number of particles per volume, $n = N/V$



$n_2 > n_1$ $P_2 > P_1$

V and T are constant

Gas Pressure

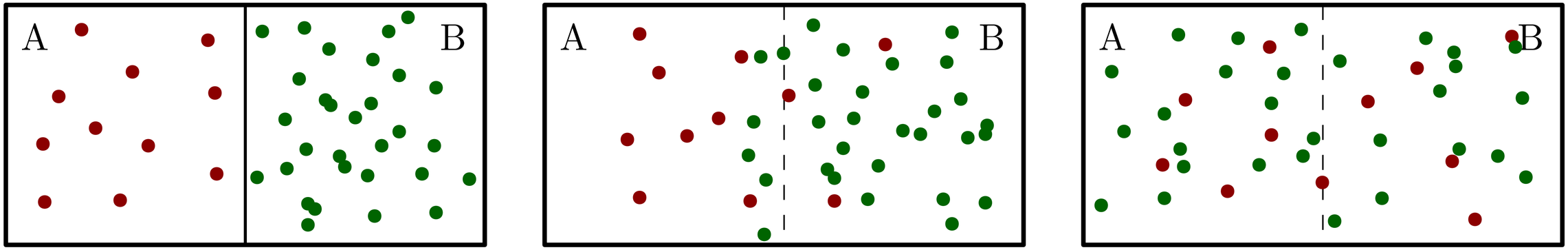
- Gas pressure is often applied unidirectionally
- For example, when inflating a balloon, molecules are forced into the interior from the outside in a specific direction
- A fan operates similarly, creating directional airflow away from its blades

Gas Mixture

- The figure shows how two gas regions with disparate densities achieve equilibrium;

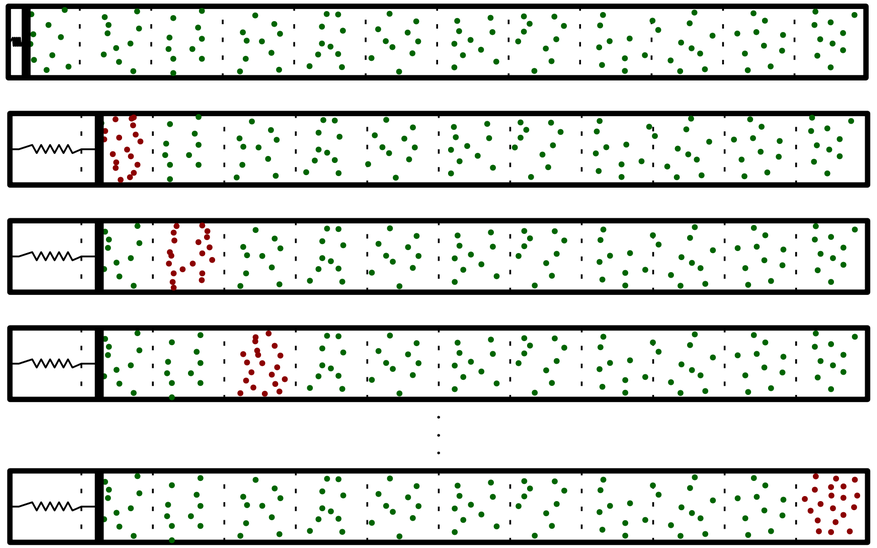
  the higher rate of molecular transfer from the denser region B to the sparser region A eventually results in a homogeneous state

- Consequently, the system will, over time, spontaneously eliminate any initial pressure imbalances



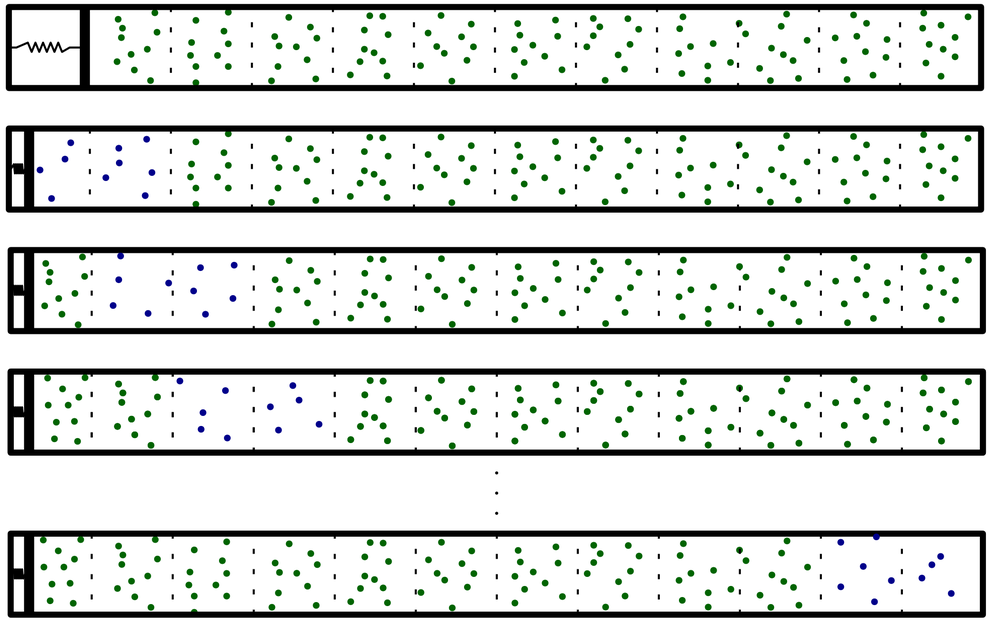
Compression Pulse

- An easy way to increase gas pressure is to force its molecules together
- When a device pushes molecules from the left, it creates a region of higher density (represented in red)
- Because molecules in this dense area move faster to the right than they do to the left, this compressed region propagates, or moves, through the gas
- This moving area of high pressure is known as a compression pulse



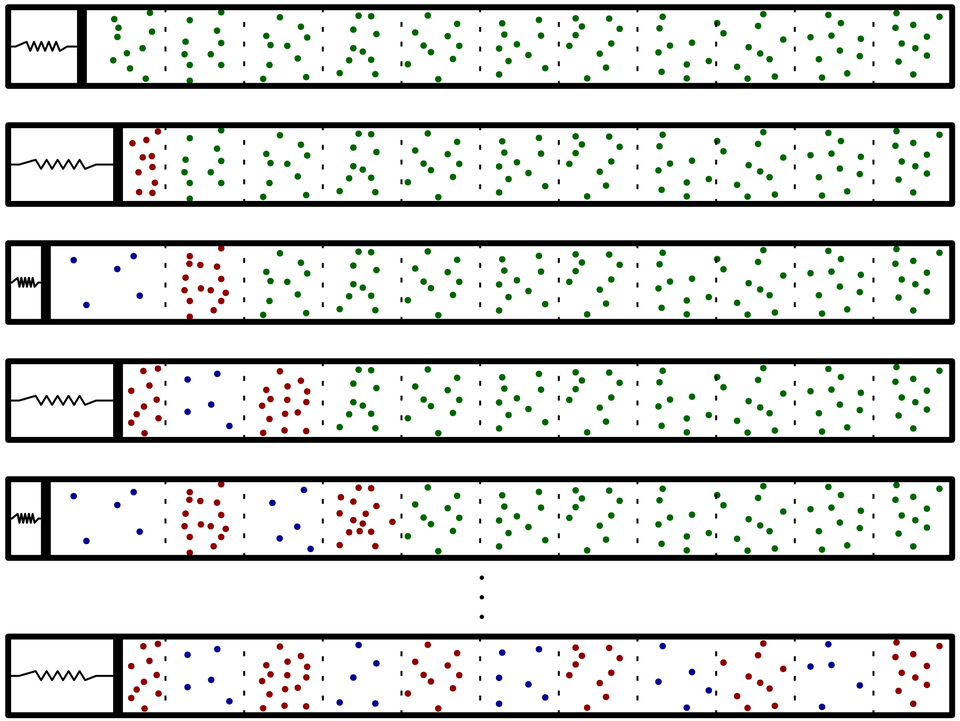
Rarefaction Pulse

- In a manner analogous to the process discussed I'm previous slide, lowering the pressure (instead of raising it) reduces the density of gas molecules
- This change spreads through the gas as a *rarefaction pulse*
- Blue regions of diminished density represent rarefaction, which is simply the inverse of compression



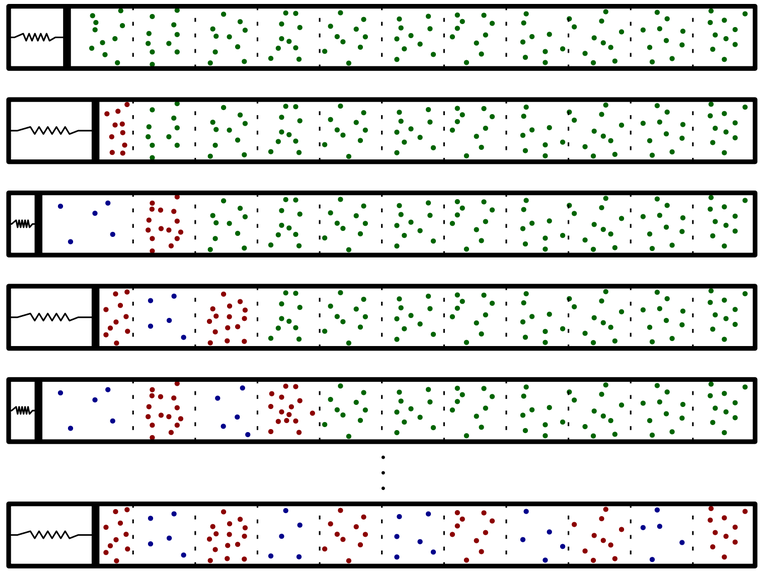
Compression-Rarefaction Wave

- The previously described processes can be generated repetitively, where compressions and rarefactions alternate in succession
- This phenomenon is known as a compression-rarefaction wave, or simply a pressure wave



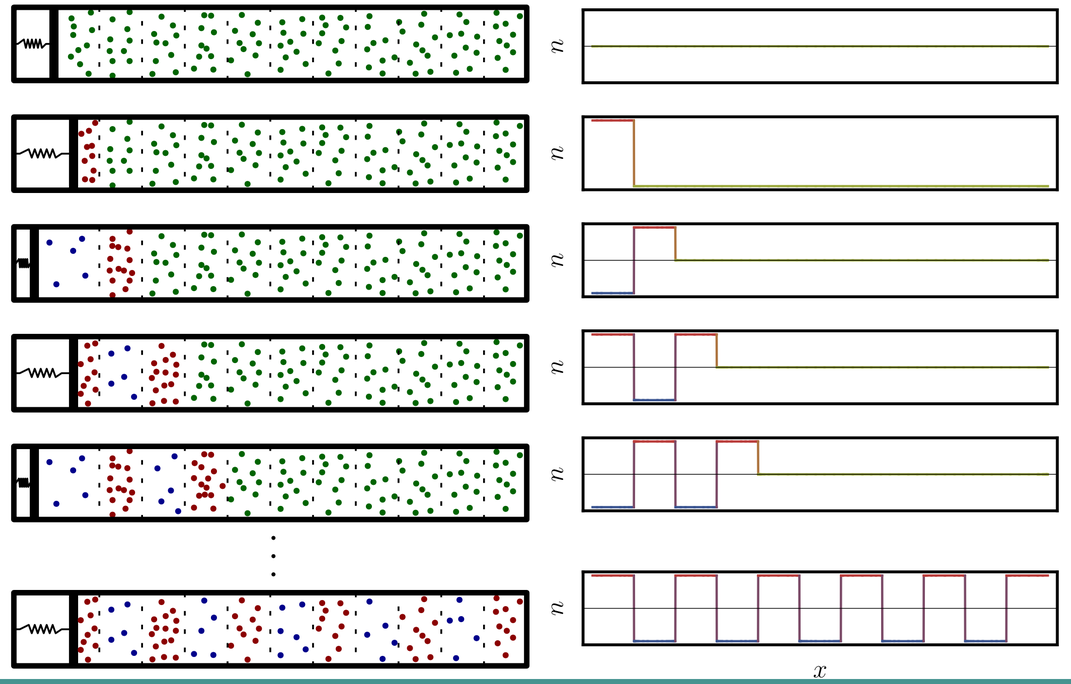
Simplified Picture

- It is apparent from the figure that the gas number density n is spatially and temporally non-uniform
- Since n depends on three position variables (one for each direction of space) and time, visualizing it requires simplification, as we can only plot two variables at once
- To address this, we will reduce the problem to one dimension
- By focusing on propagation along a single axis rather than all of space, we create a manageable model that still accurately describes realistic situations such as acoustic pipes (wind instruments) and vibrating strings



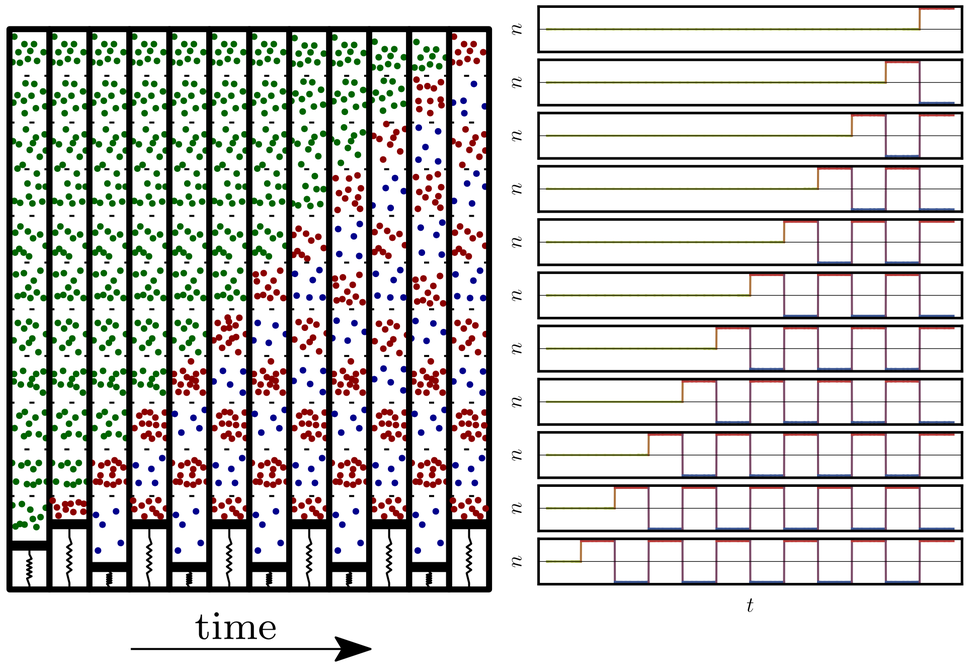
Spatial Variation of the Density

- The focus now shifts to how number density changes across space and time
- Because plotting requires holding one variable constant, we can generate plots of n against time for a fixed position, or against position for a fixed instant in time
- The side-by-side plots in the figure illustrate the spatial variation in number density
- Each plot represents a fixed moment in time, essentially serving as a snapshot of the wave's entire length



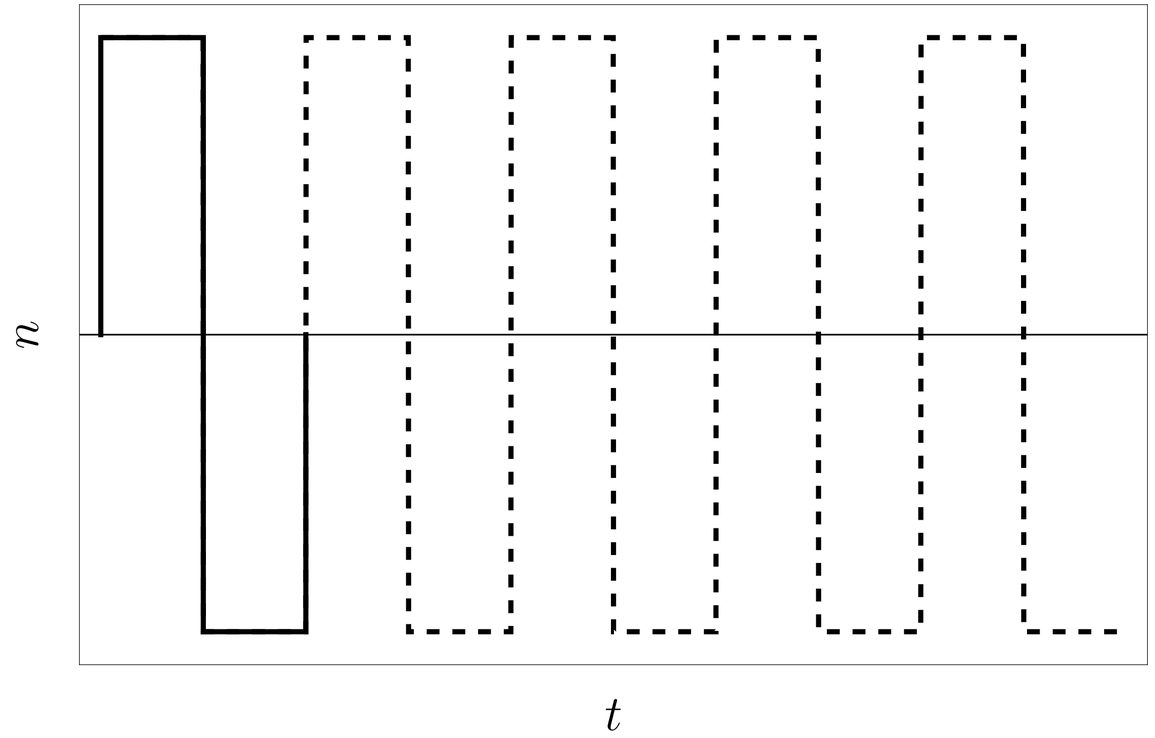
Temporal Variation of the Density

- The figure illustrate density changes over time at a fixed location, functioning like a video of a single point along the wave
- It is crucial to distinguish this from spatial representations, as the similarity between time-based and position-based plots of compression waves can easily lead to confusion
- Always verify whether the horizontal axis represents time or position



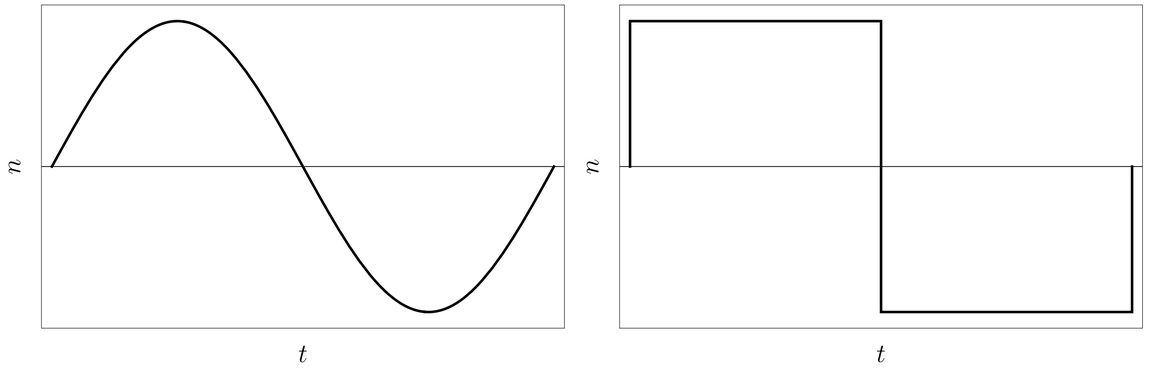
Periodicity

- Many common waves are periodic ☛ meaning the pattern repeats identically over time
- The solid line in the figure represents the fundamental unit, which repeats indefinitely
  - ☛ a defining characteristic of all periodic waves



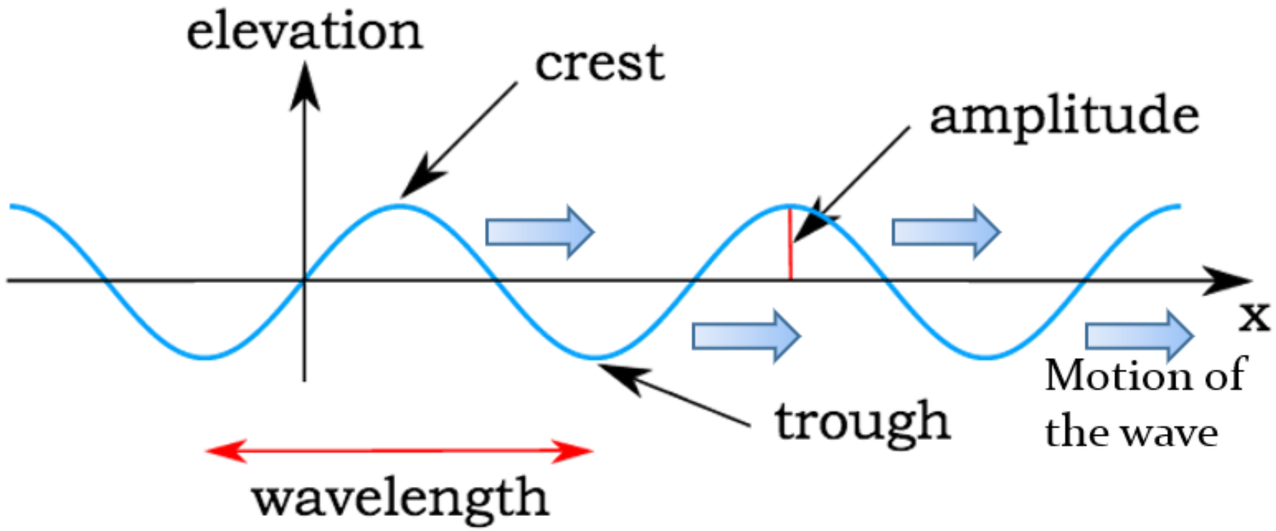
Sinusoidal Waves

- In reality, the *perfect* square wave is impossible to achieve because it would require infinite bandwidth
- Physical systems inherently act as filters that round off the sharp corners of a square wave, making it appear more sinusoidal (such as the SHM displacement) as high-frequency components are lost



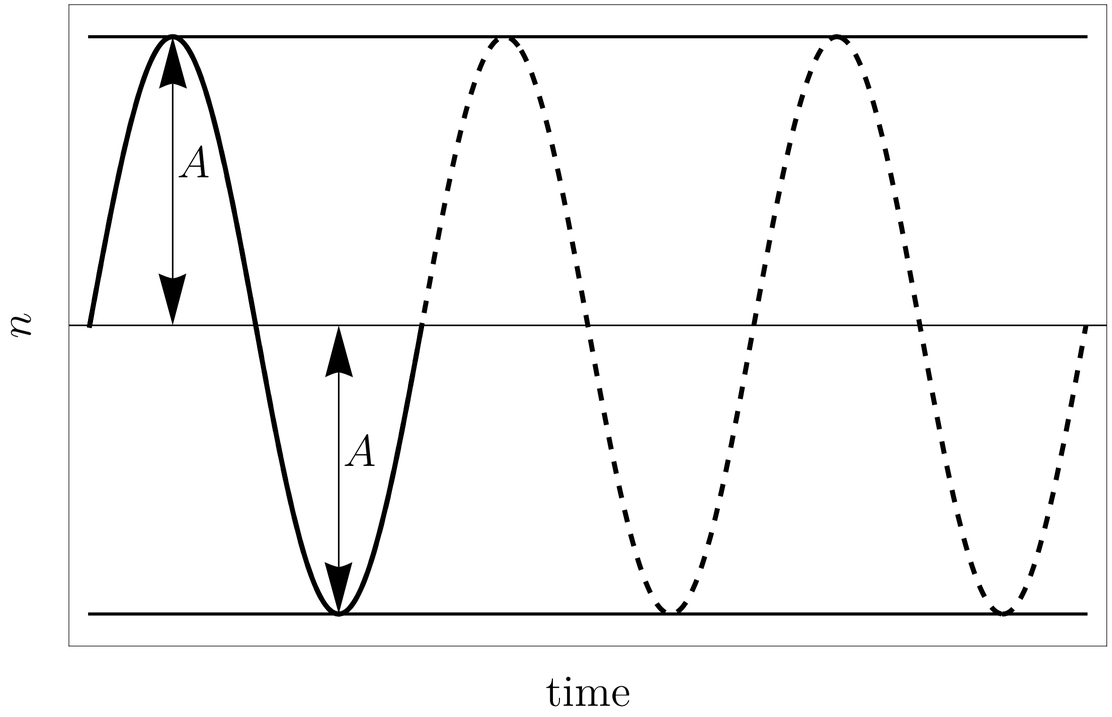
Periodic Waves

- Because periodic waves follow a repeating pattern, they are straightforward to define
- Even if the wave shapes look complex and hard to describe without a graph, they are characterized by simple, measurable properties: amplitude, period, frequency, and wavelength



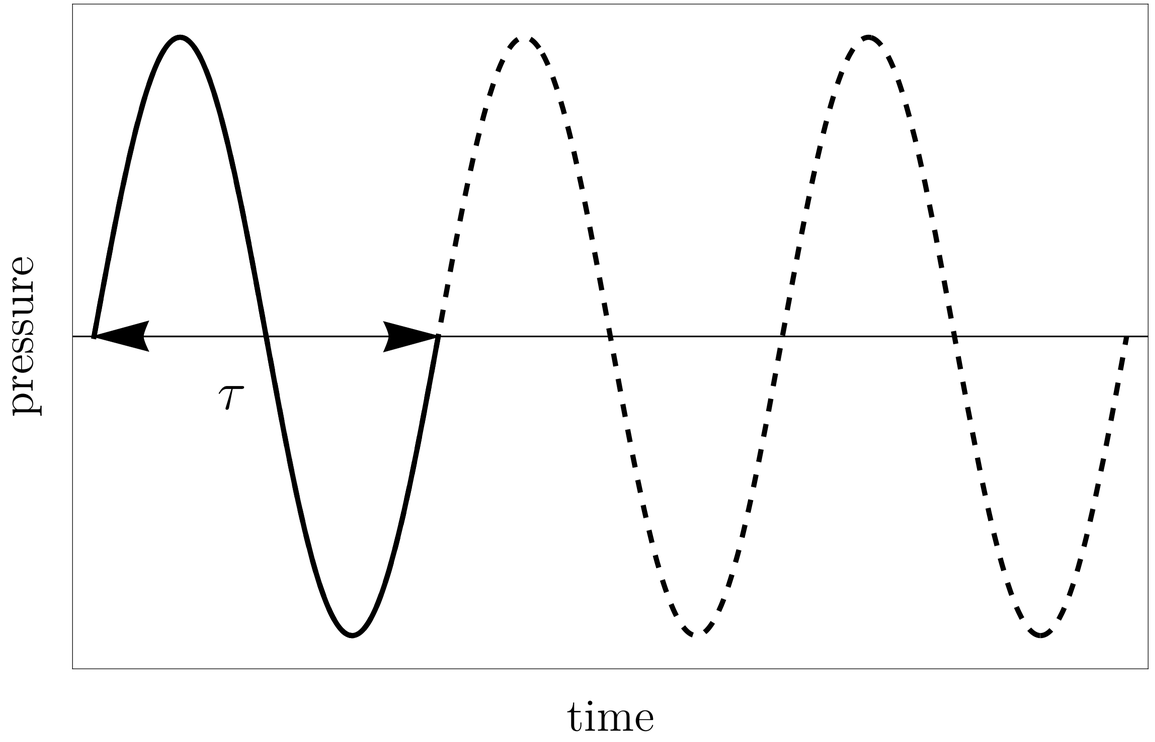
Amplitude

- *Amplitude* (A) is the maximum displacement or distance moved by a point on a wave measured from its equilibrium (rest) position
- It is directly related to the amount of energy the wave carries—a higher amplitude indicates more energy



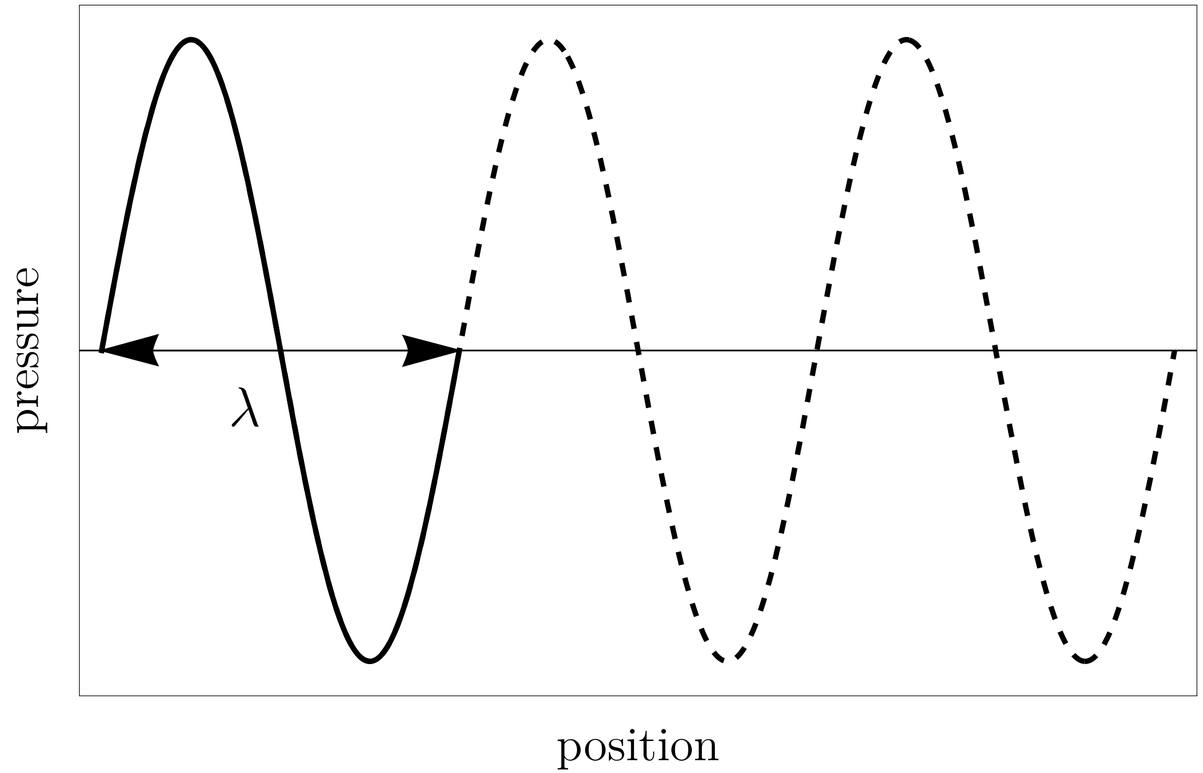
Frequency and Period

- *Frequency* (f) is the number of wave cycles that pass a specific point per second, measured in hertz (Hz)
- Higher frequency means more wave cycles pass in a given time



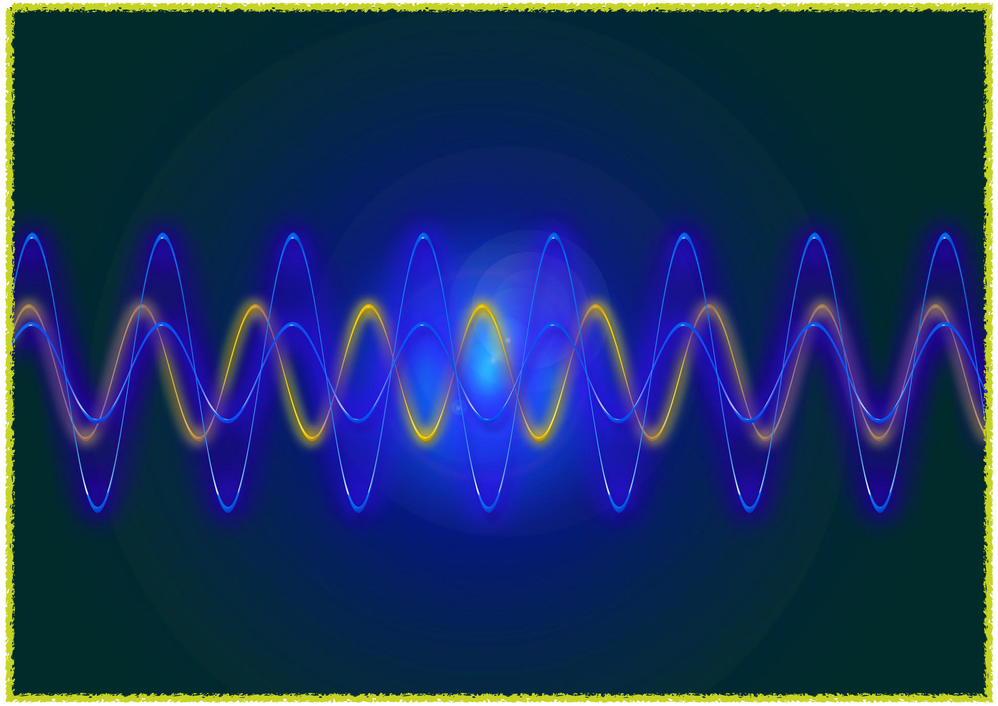
Wavelength

- *Wavelength* (λ) is the spatial distance between two corresponding points on consecutive waves, such as from crest to crest or trough to trough
- It is measured in meters



Wave Speed Equations

- The period and wavelength of a wave are linked by its propagation speed u
- The relation between the times between peaks (period) and the distance between them (wavelength) is defined as ☛ $u = \lambda/\tau$
- Since frequency is the reciprocal of the period u can also be expressed as ☛ $u = \lambda f$

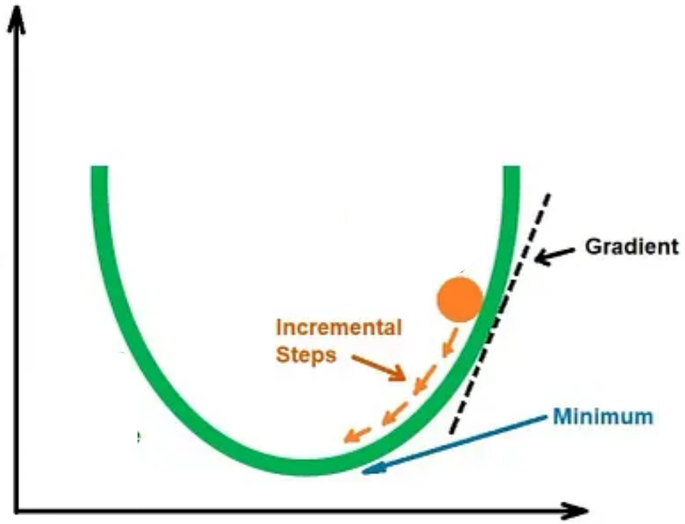


Gradient Slope

Gradient represents how steep a slope is:

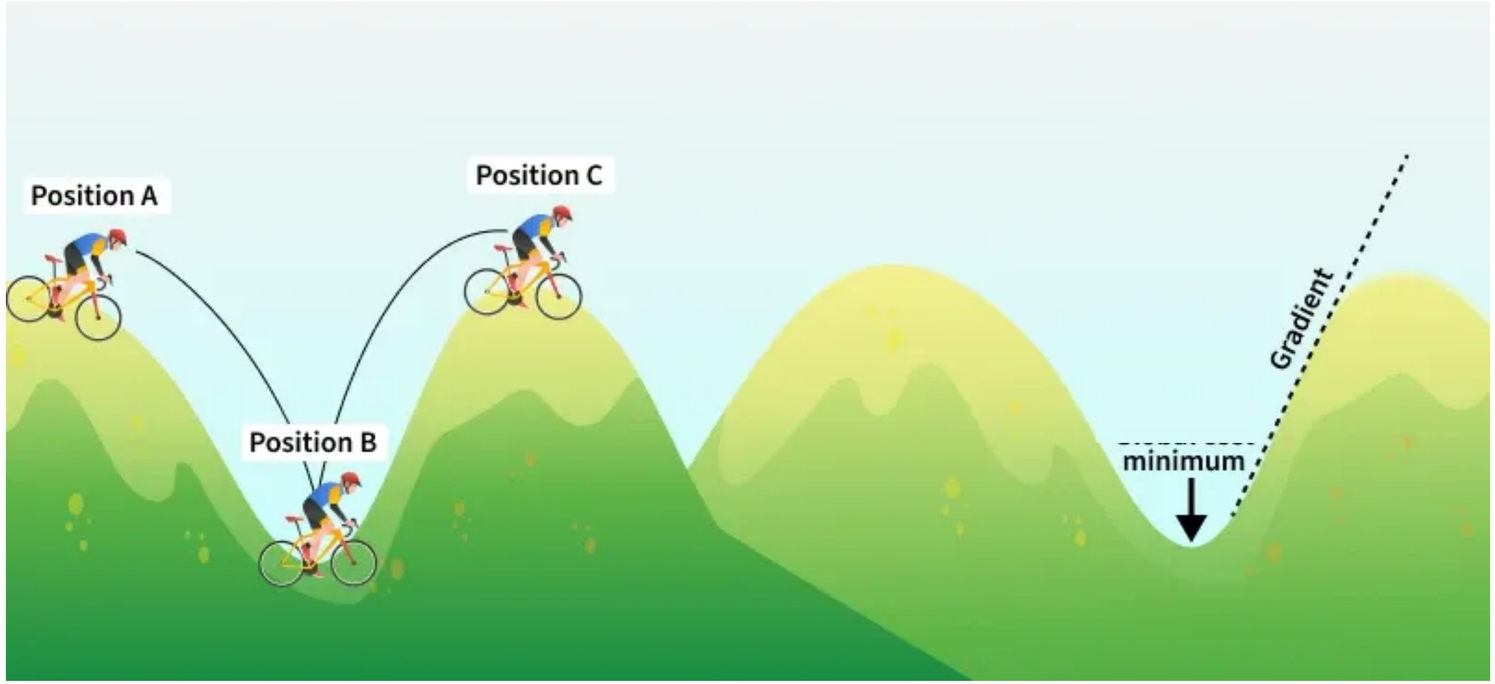
uphill slope ☛ positive

downhill slope ☛ negative



Characterizing Pressure Wave Dynamics

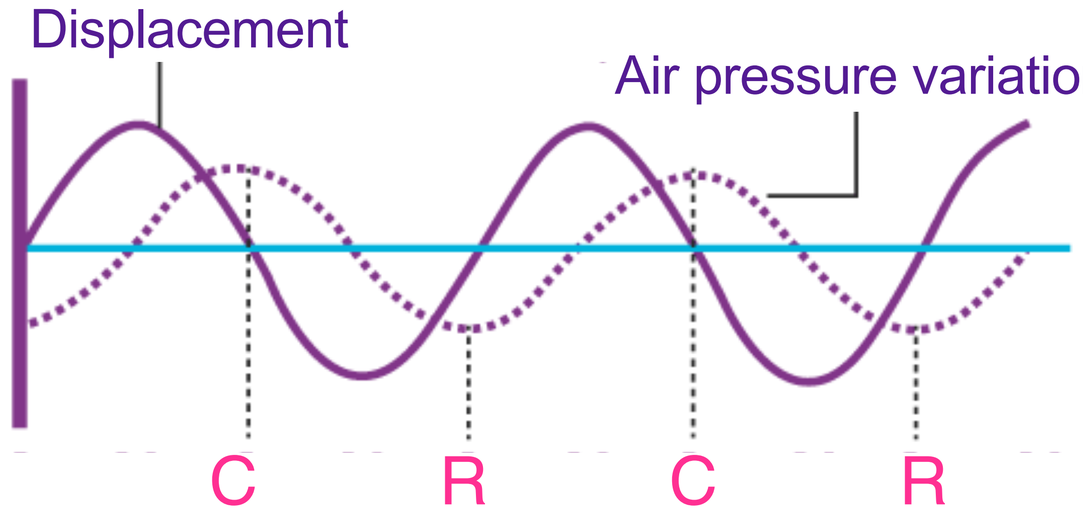
- A pressure wave can also be described in terms of particle displacement by relating the local pressure change to the gradient of the displacement wave



- Pressure fluctuations are caused by regions where particles in the medium are compressed together or spread apart

Mapping Pressure Wave Oscillations

- The pressure variation at a point is directly proportional to the negative spatial gradient of the displacement $x(t)$
- The pressure wave is $90°$(or a quarter-cycle) out of phase with the displacement wave



C ☛ compression

R ☛ rarefaction

This means that

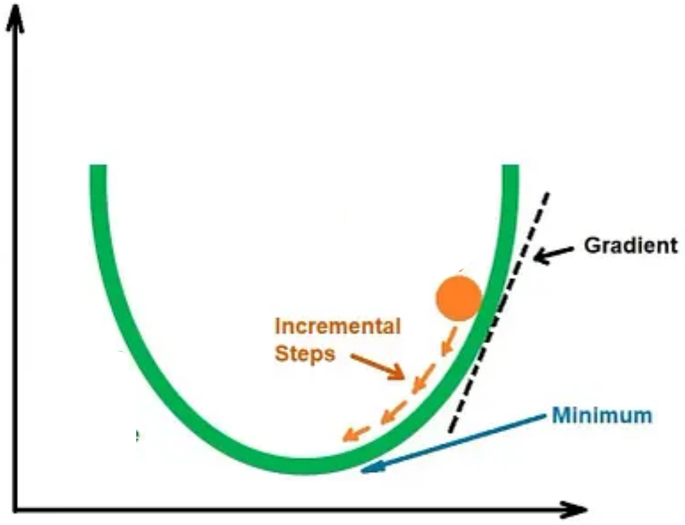
- Maximum pressure (compression) occurs where the displacement gradient is steepest, which is at the points of zero displacement (equilibrium position)
- Minimum pressure (rarefaction) also occurs at points of zero displacement, but where particles are moving away from each other
- Zero pressure change occurs at maximum or minimum displacement (turning points)
- Maximum pressure fluctuation is directly proportional to the displacement amplitude A

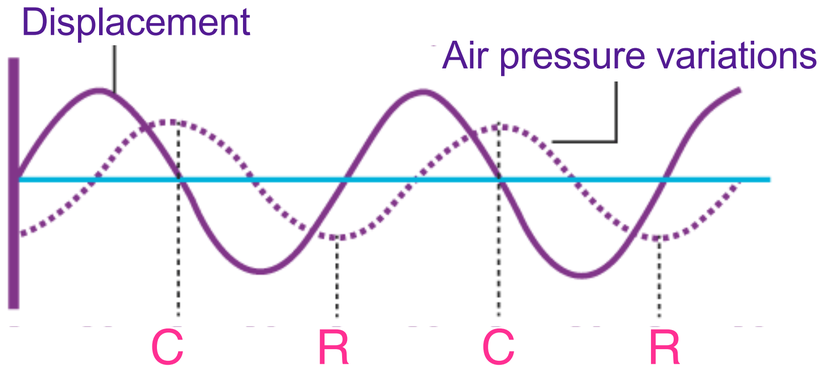
Displacement vs. Pressure

Point in wave	Displacement	Displacement gradiente	Pressure
Compression	Zero	Negative	Maximum
Zero crossing	Maximum	Zero	Zero
Rarefaction	Zero	Positive	Minimum

Summary

- Pressure variation at a point is directly proportional to the negative spatial gradient of the displacement





C ☛ compression

R ☛ rarefaction

A pressure wave is best described as which type of wave?

A. Transverse wave

B. Longitudinal wave

C. Electromagnetic wave

D. Surface wave

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The number of pressure waves passing a point per second is called the wave's:

A. Amplitude

B. Wavelength

C. Frequency

D. Speed

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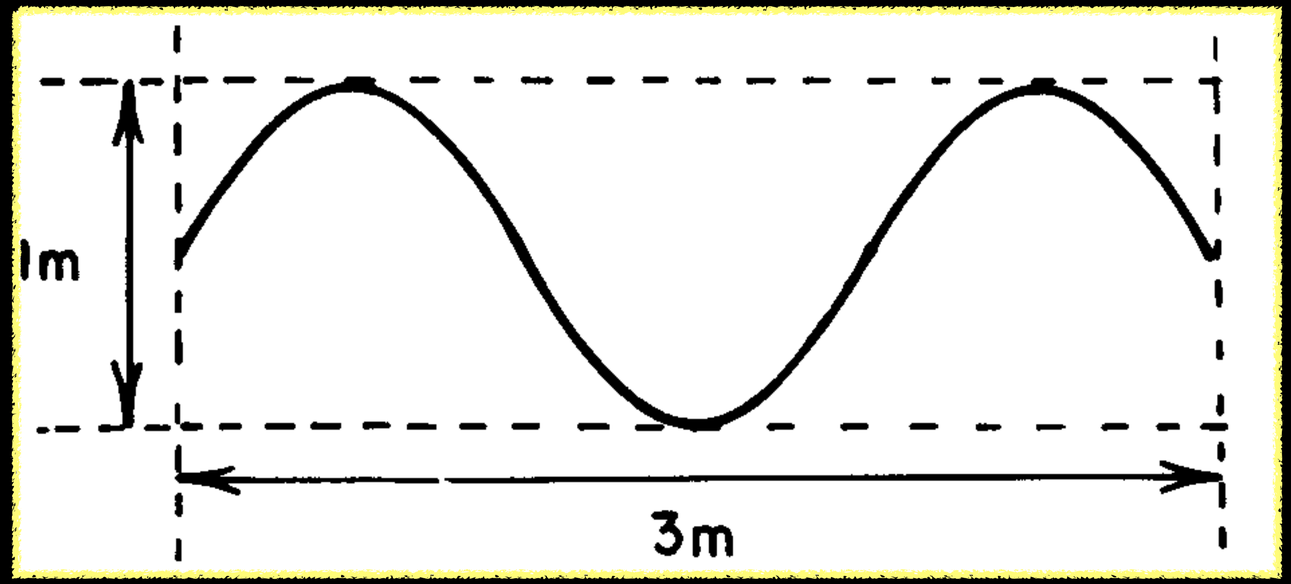
What is the wavelength of the wave shown in to diagram below?

A. 1m

B. 2m

C. 3m

D. 0.5m



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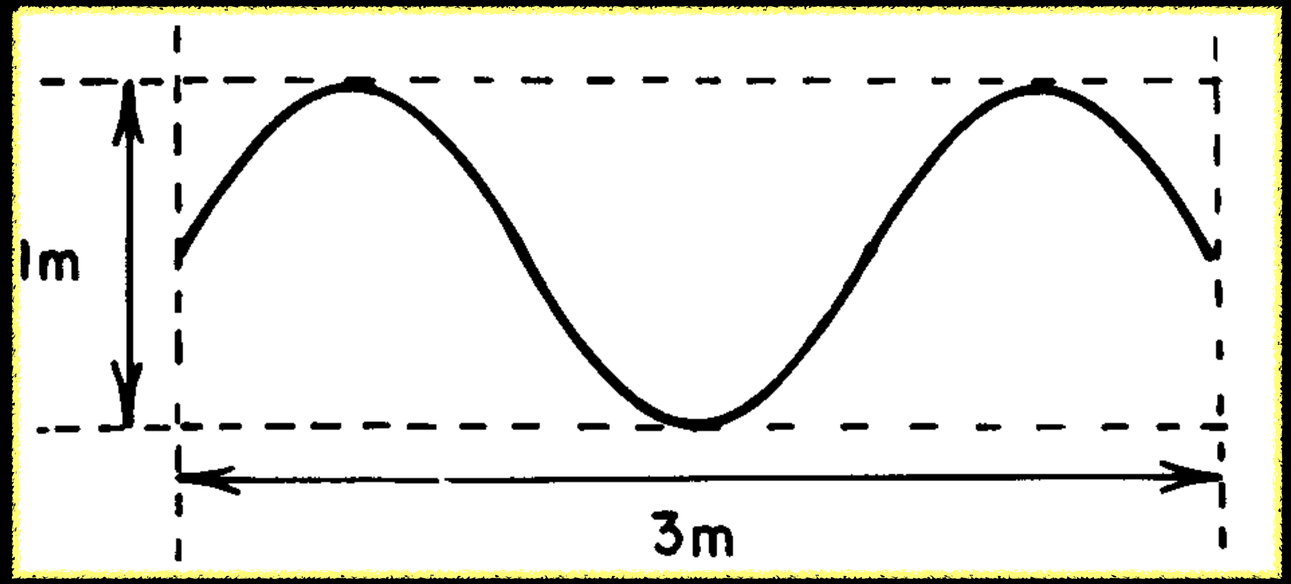


The diagram below shows two points, A and B, on a wave train

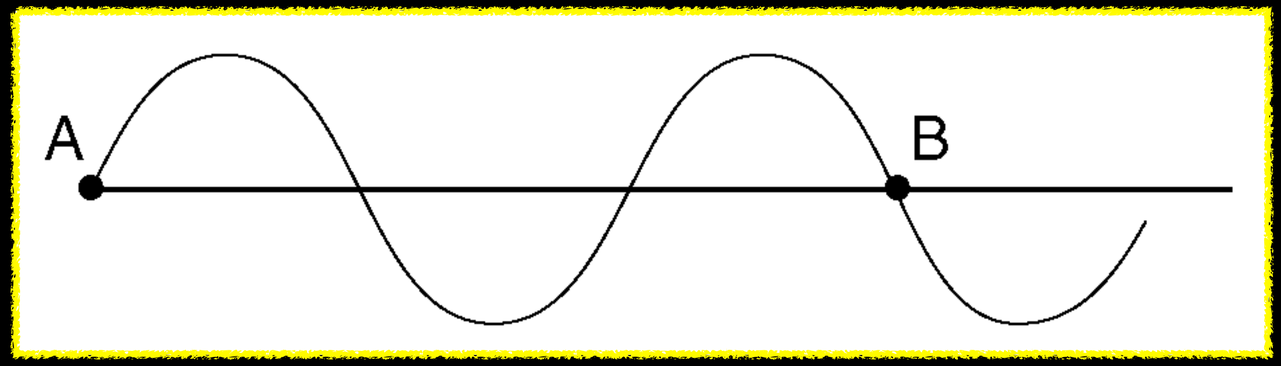
How many wavelengths separate point A and point B?

A. 1.0

B. 1.5

C. 3.0

D. 0.75



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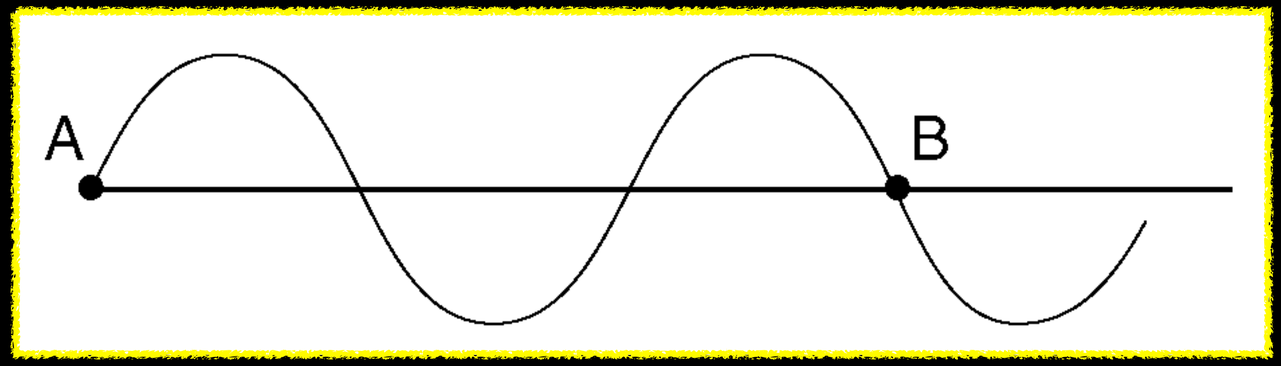


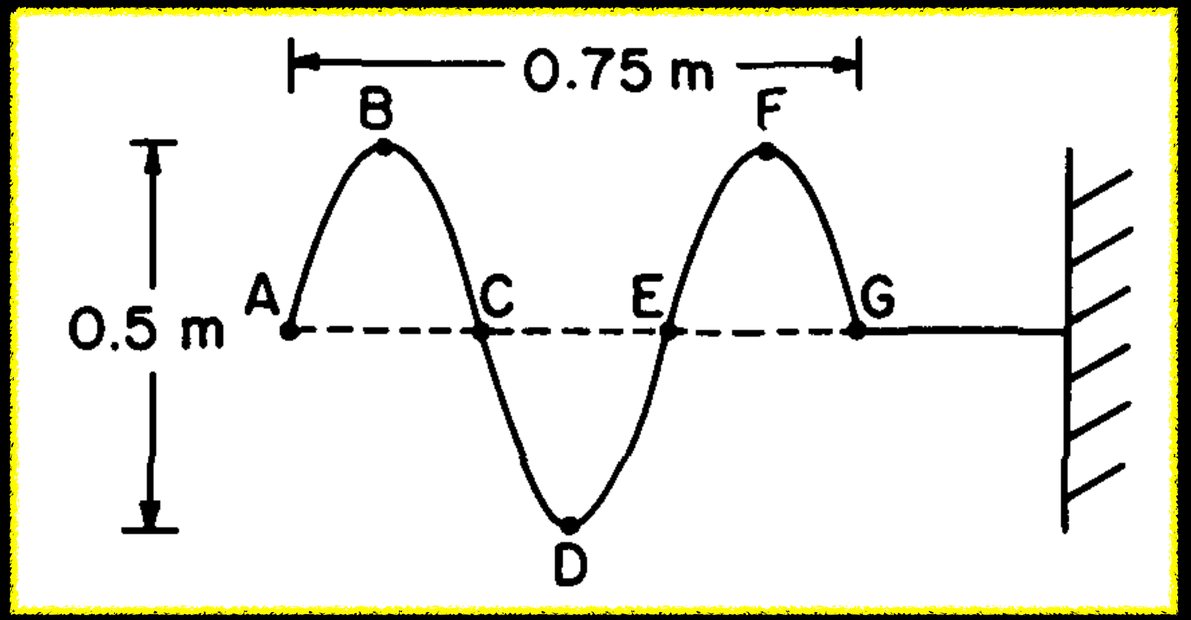
What is the amplitude of the wave traveling to the right along an elastic medium?

A. 1.0 m

B. 0.75 m

C. 0.50 m

D. 0.25 m



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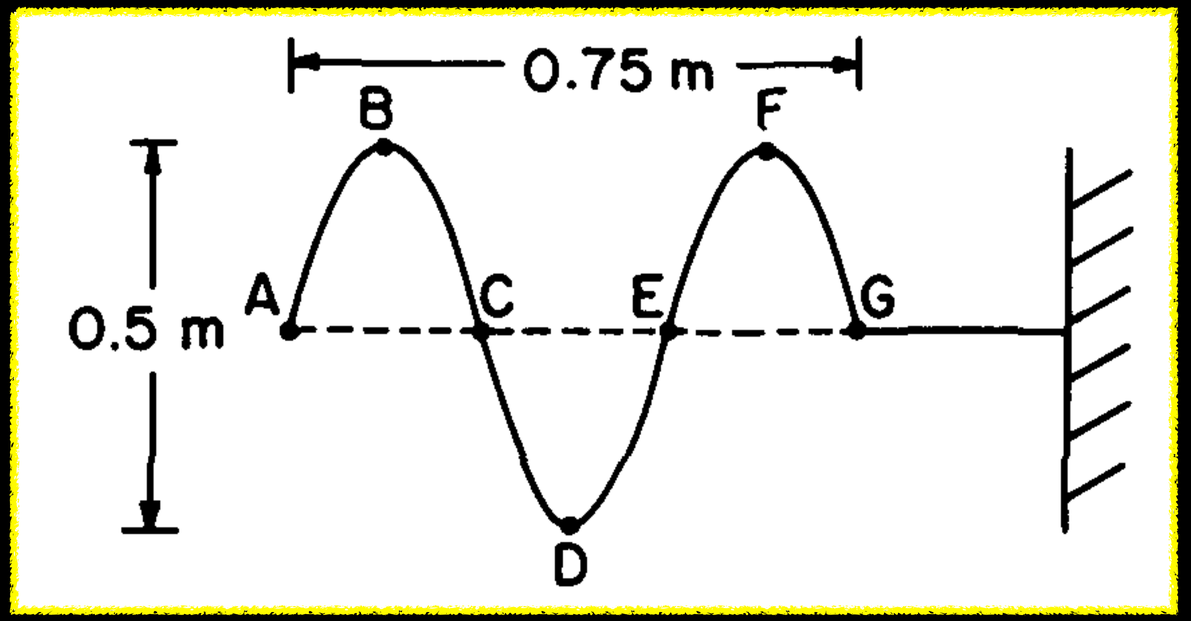


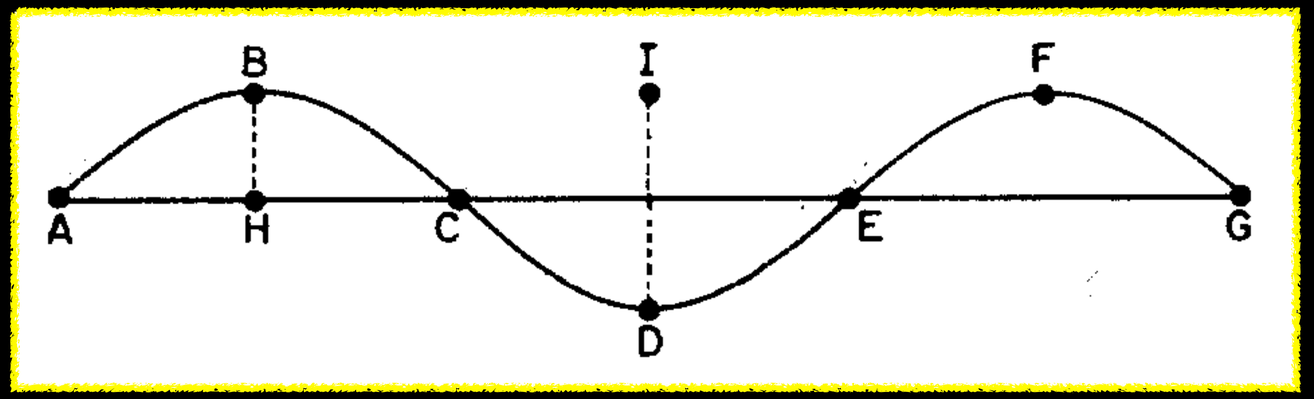
A wavelength is the distance between points

A. *A* and C

B. *A* and E

C. *B* and H

D. *I* and D



A wavelength is the distance between points

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B. *A* and E

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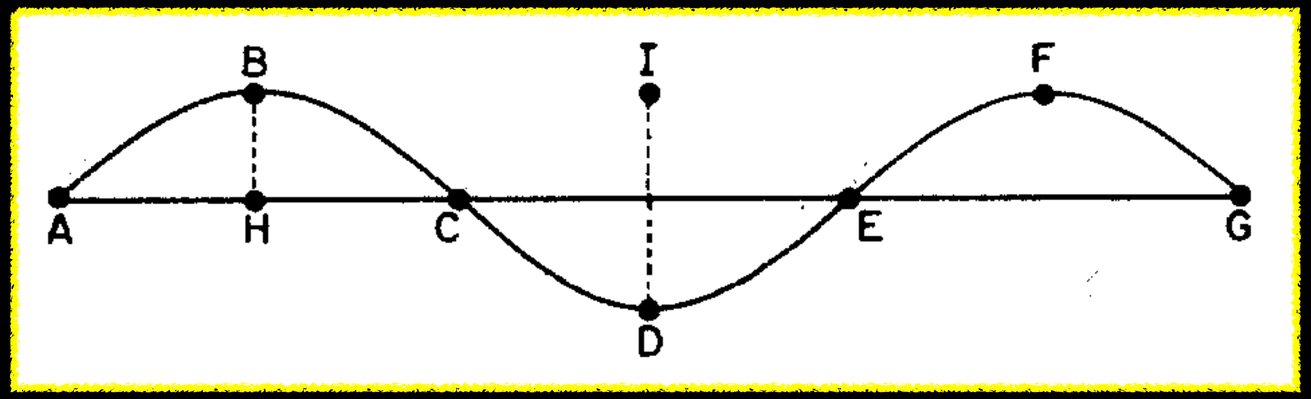
D. *I* and D



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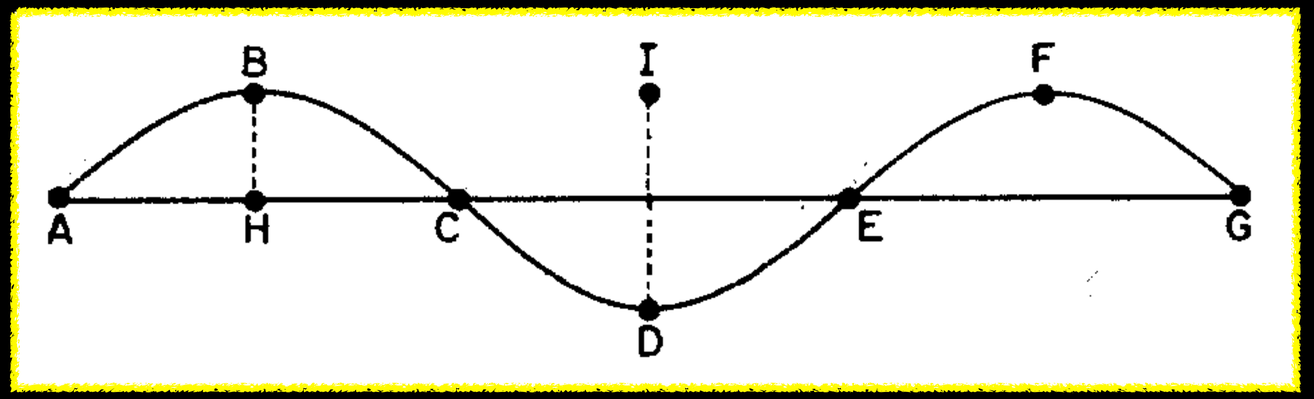
A. *A* and C

B. *A* and E

C. *B* and H

D. *I* and D



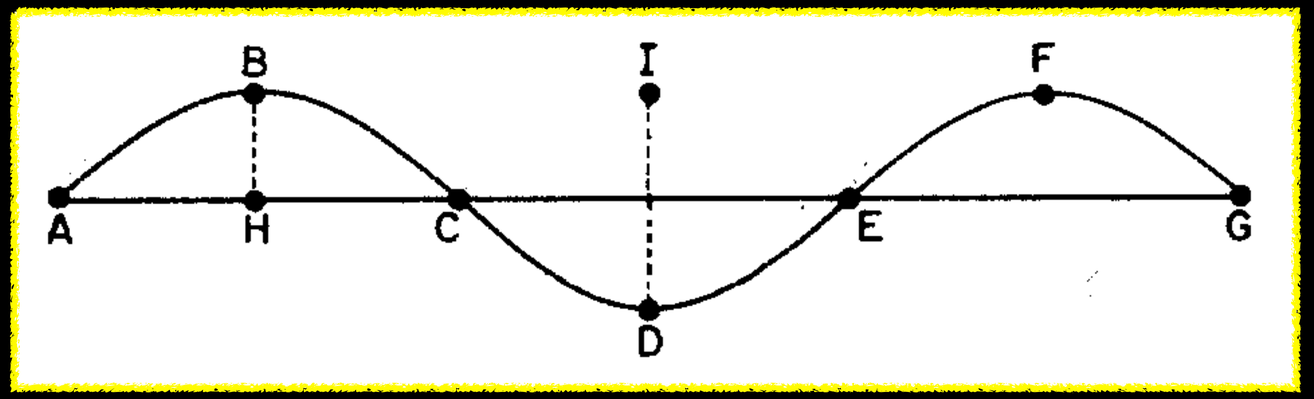
The amplitude of the wave is the distance between points

A. *A* and C

B. *A* and E

C. *B* and H

D. *I* and D



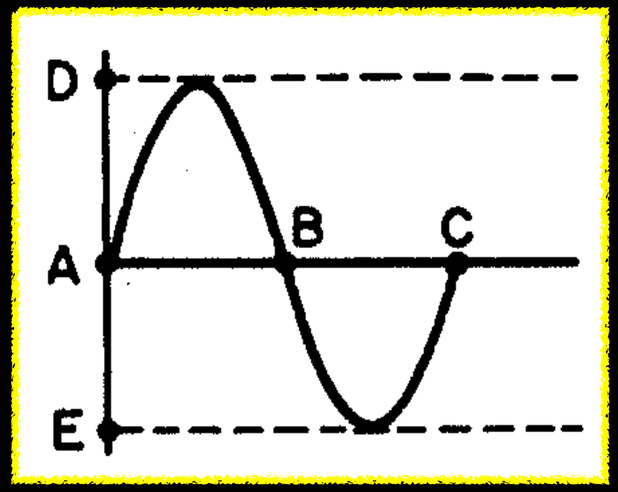
The amplitude of the wave shown below represented by the distance between points

A. *A* and B

B. *A* and C

C. *A* and D

D. *E* and D



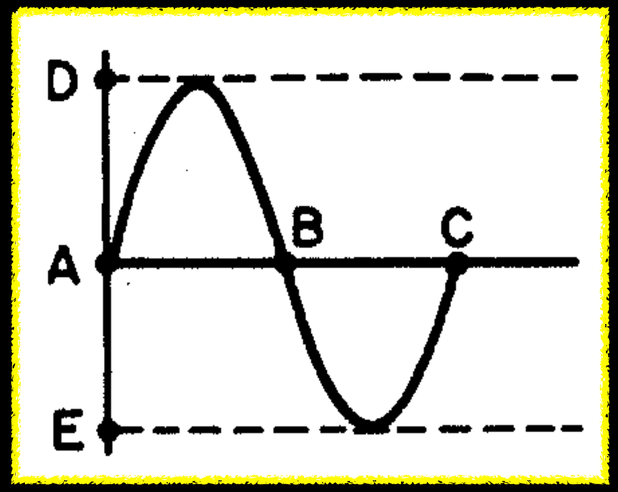
The amplitude of the wave shown below represented by the distance between points

A. *A* and B

B. *A* and C

C. *A* and D

D. *E* and D



The diagram below shows a transverse pulse moving to the right in a string

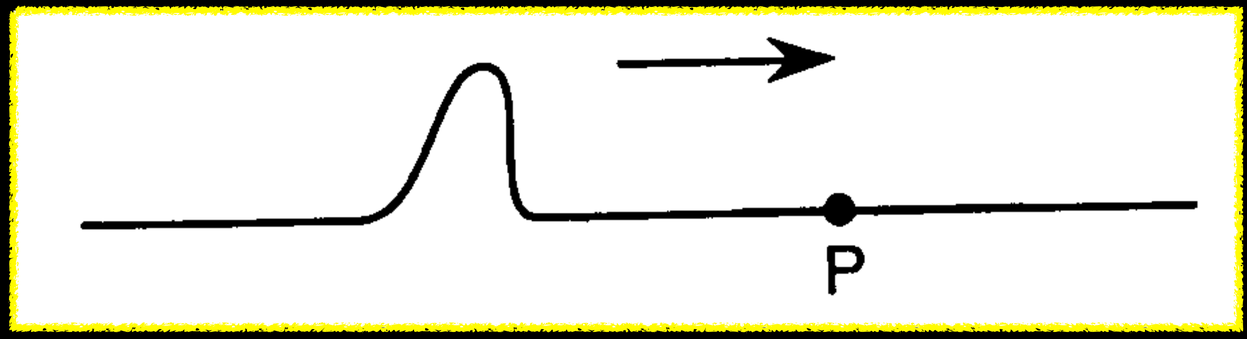
Which diagram best represents the motion of point P as the pulse passes point P?

A.

B.

C.

D.



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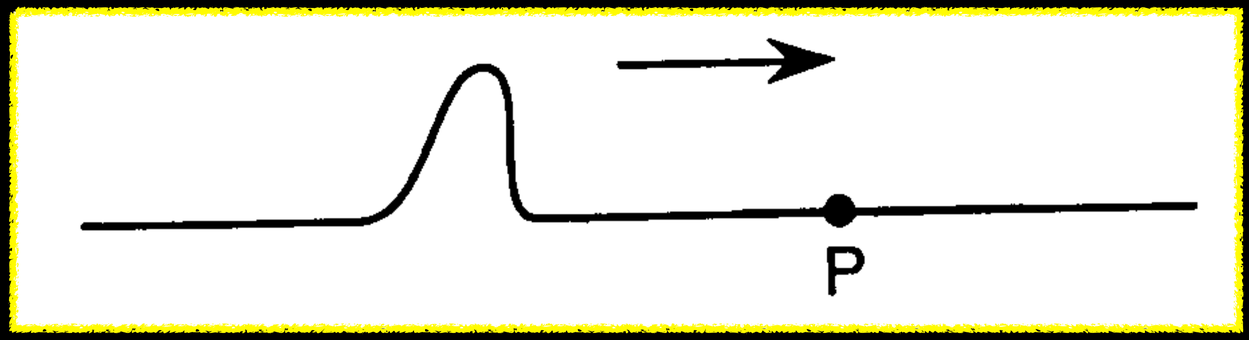

When a transverse wave is moving through a medium, what is the action of the particles of the medium?

A. They travel through the medium with the wave

B. They vibrate in a direction parallel to the direction in which the wave is moving

C. They vibrate in a direction perpendicular to the direction in which the wave is moving

D. They remain at rest

When a transverse wave is moving through a medium, what is the action of the particles of the medium?

A. They travel through the medium with the wave

B. They vibrate in a direction parallel to the direction in which the wave is moving

C. They vibrate in a direction perpendicular to the direction in which the wave is moving

D. They remain at rest

As a longitudinal wave travels horizontally, the particles of the medium vibrate

A. in a circle

B. in a spiral

C. vertically

D. horizontally

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C. vertically

D. horizontally

What is the frequency of a wave if its period is 0.25 second?

A. 1.0 Hz

B. 0.25 Hz

C. 12 Hz

D. 4.0 Hz

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A. 1.0 Hz

B. 0.25 Hz

C. 12 Hz

D. 4.0 Hz

What is the period of a wave whose frequency is 256 cycles per second?

A. 1s

B. 1/256 s

C. 256 s

D. 512 s

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A. 1s

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C. 256 s

D. 512 s

A duck floating on a lake oscillates up and down 5.0 times during a 10.-second interval as a periodic wave passes by

What is the frequency of the duck's oscillations?

A. 0.10 Hz

B. 0.50 Hz

C. 2.0 Hz

D. 50. Hz

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If the amplitude of a wave is increased, the frequency of the wave will

A. decrease

B. increase

C. remain the same

If the amplitude of a wave is increased, the frequency of the wave will

A. decrease

B. increase

C. remain the same

The speed of a transverse wave in a string is 12 meters per second

If the frequency of the source producing this wave is 3.0 hertz, what is its wavelength?

A. 0.25 m

B. 2.0 m

C. 36 m

D. 4.0 m

The speed of a transverse wave in a string is 12 meters per second

If the frequency of the source producing this wave is 3.0 hertz, what is its wavelength?

A. 0.25 m

B. 2.0 m

C. 36 m

D. 4.0 m

The rate at which a wave travels from one point to another determines the wave's

A. frequency

B. period

C. amplitude

D. velocity

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A. frequency

B. period

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D. velocity

Wave motion in a medium transfers

A. energy, only

B. mass, only

C. both mass and energy

D. neither mass nor energy

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