WAVES - SOUND

IB PHYSICS | COMPLETED NOTES

Simple Harmonic Motion

IB PHYSICS | WAVES - SOUND

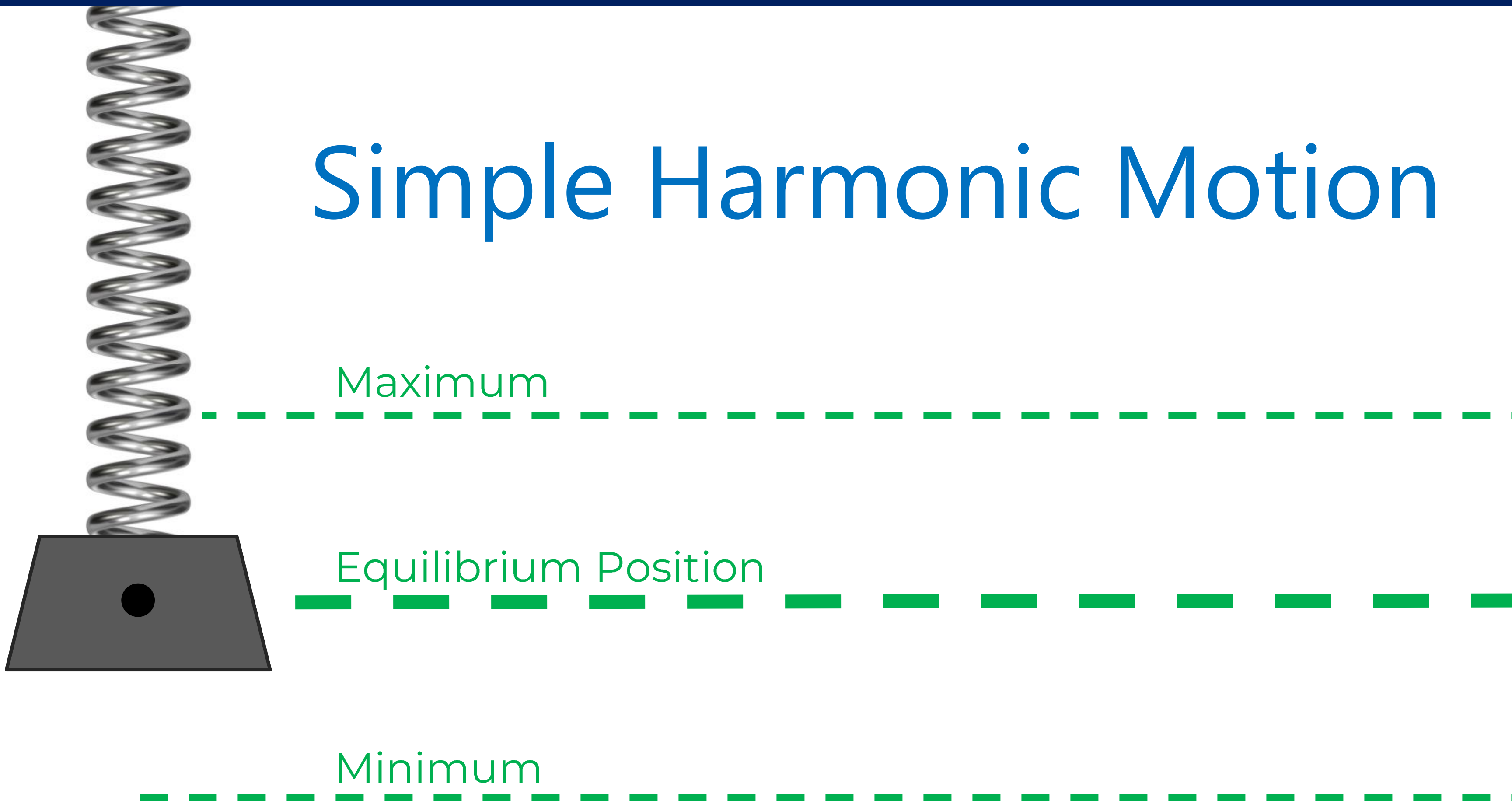
Warm up

What words would you use to describe the motion of a bobble head doll?

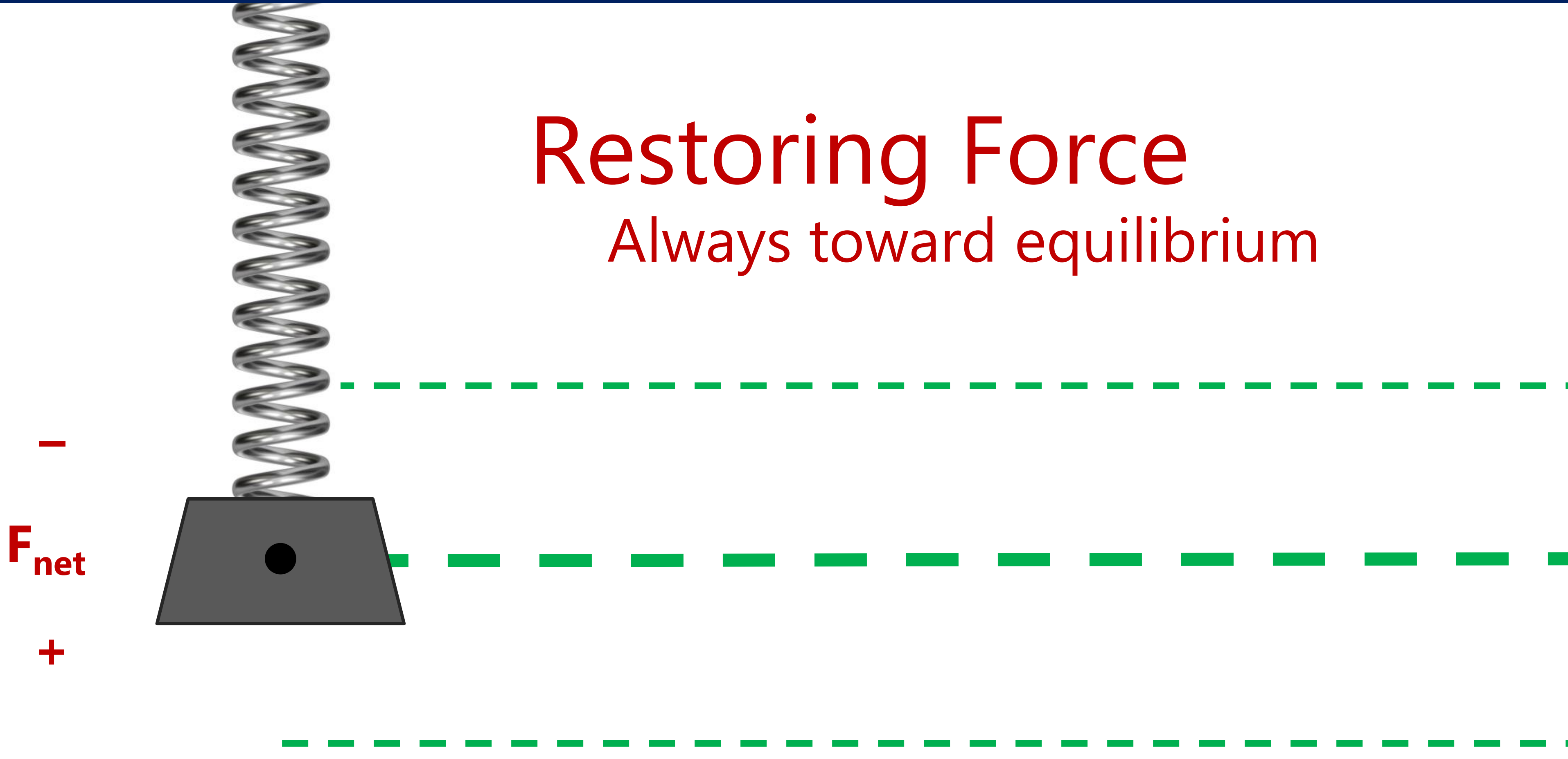
- Oscillating
- Back and Forth
- Repeating
- Etc.

A Mass on a Spring

Simple Harmonic Motion



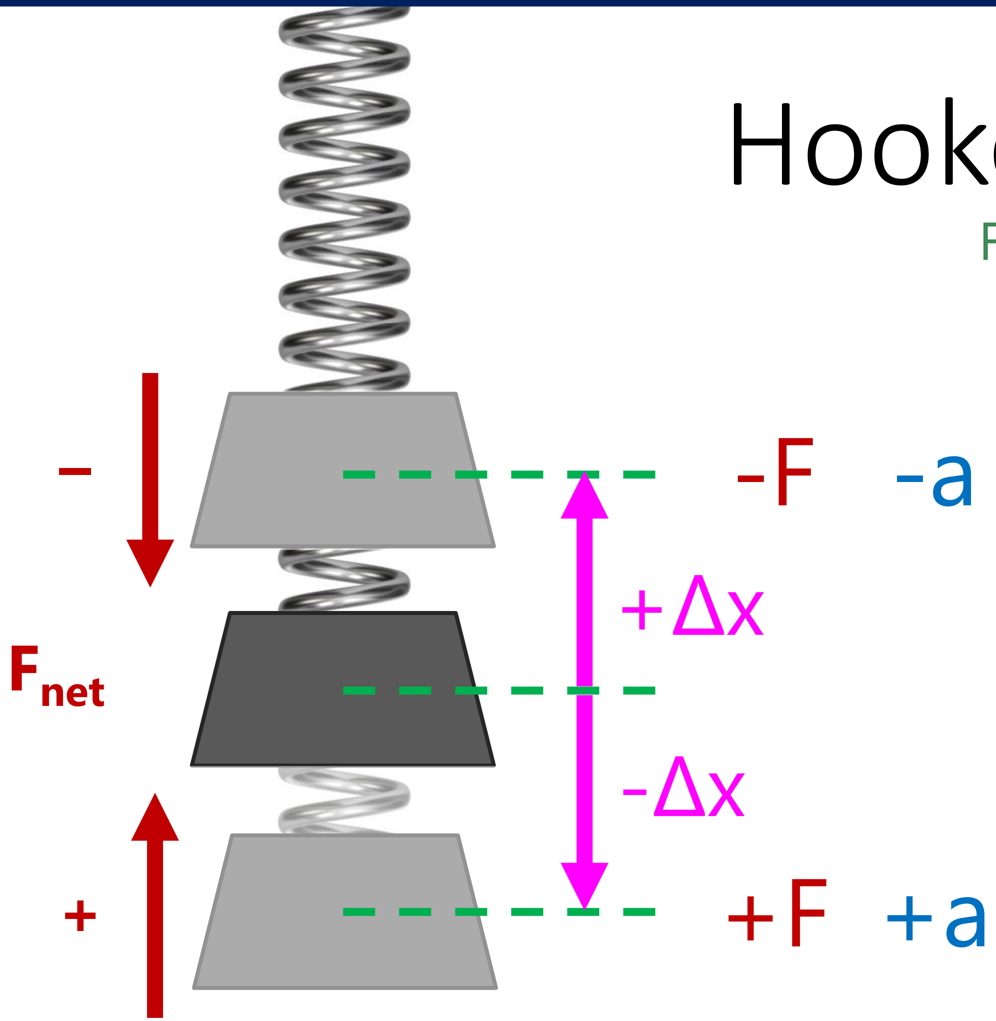
Let’s look at the forces…



Restoring Force

Always toward equilibrium

Force and Displacement



Hooke's Law: $F = -k\Delta x$

Force is opposite to the displacement

Acceleration is in the same direction as the force

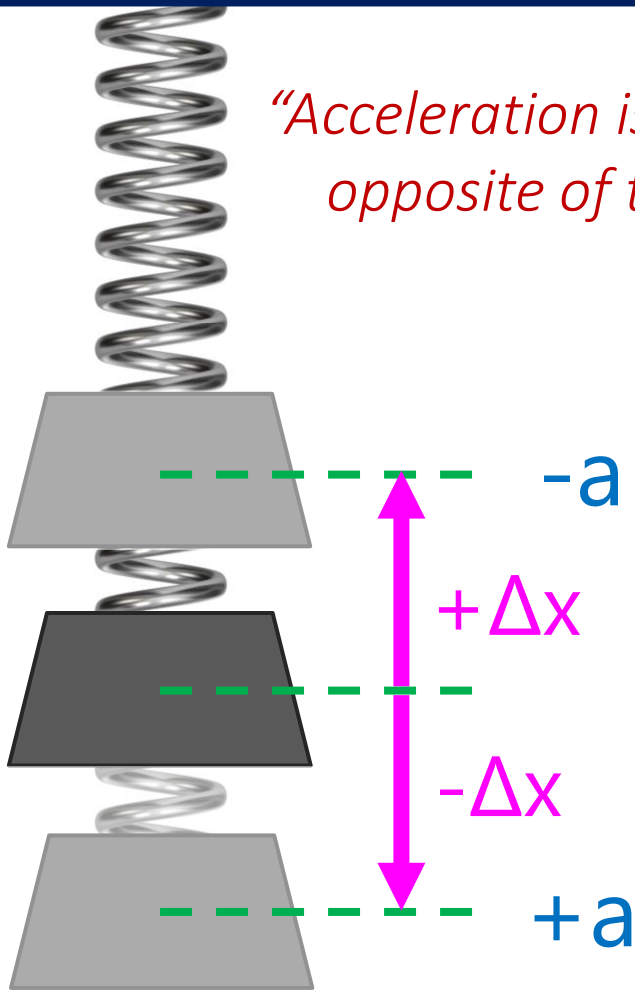
$$F = ma$$

Why the Negative Sign??

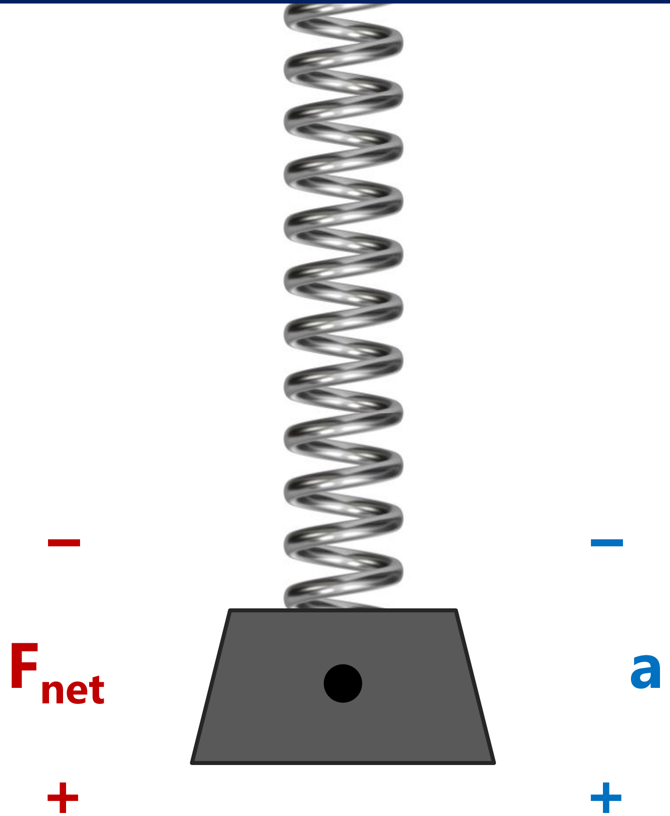
"Acceleration is proportional to the opposite of the displacement"

$$a \propto -x$$

Proportional to



Let's look at this one more time…

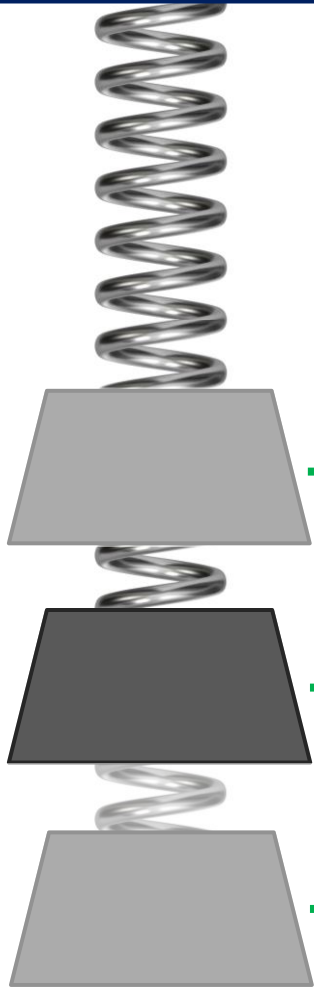


When is the force largest?

When is the acceleration largest?

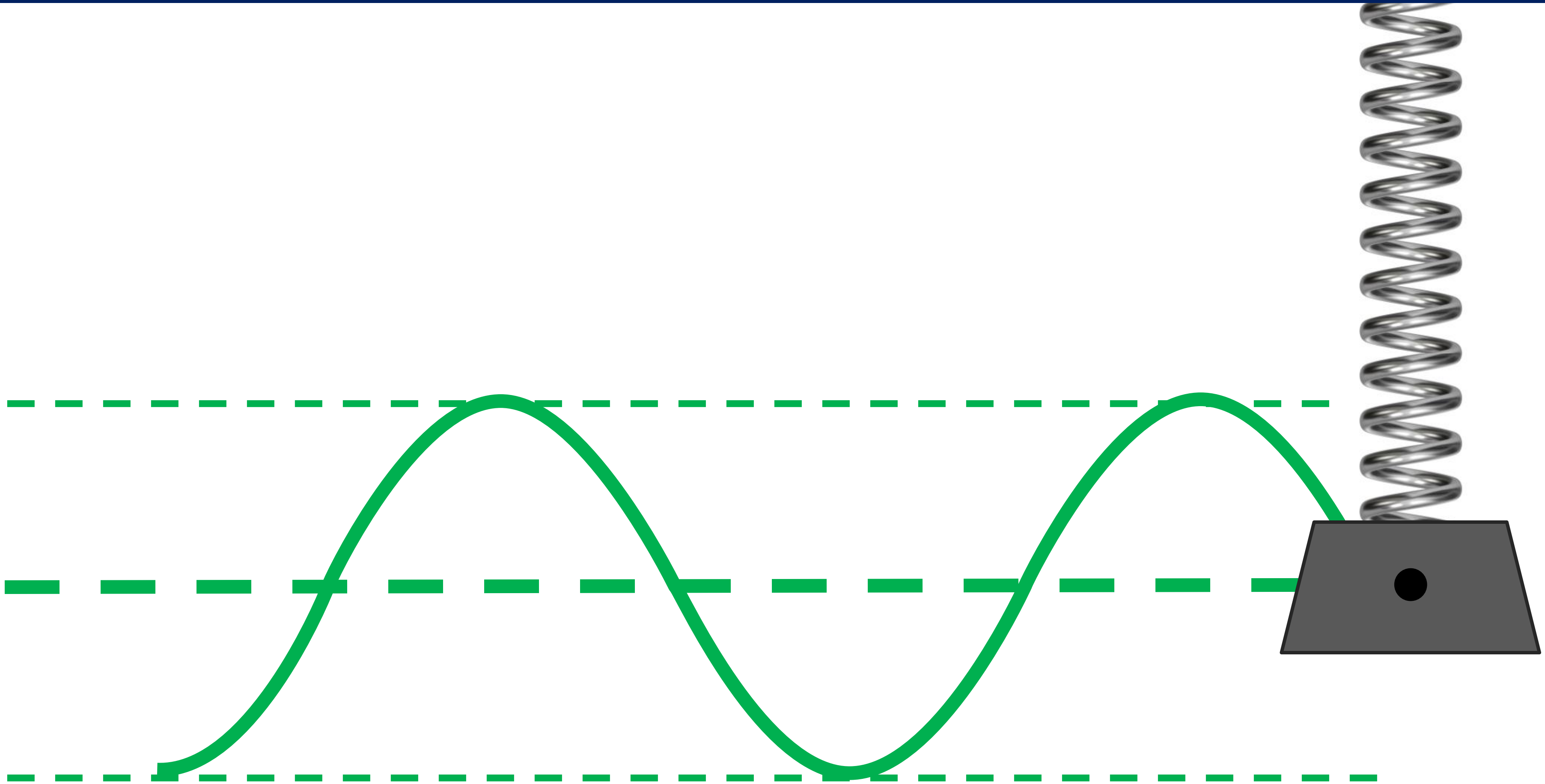
When is the velocity largest?

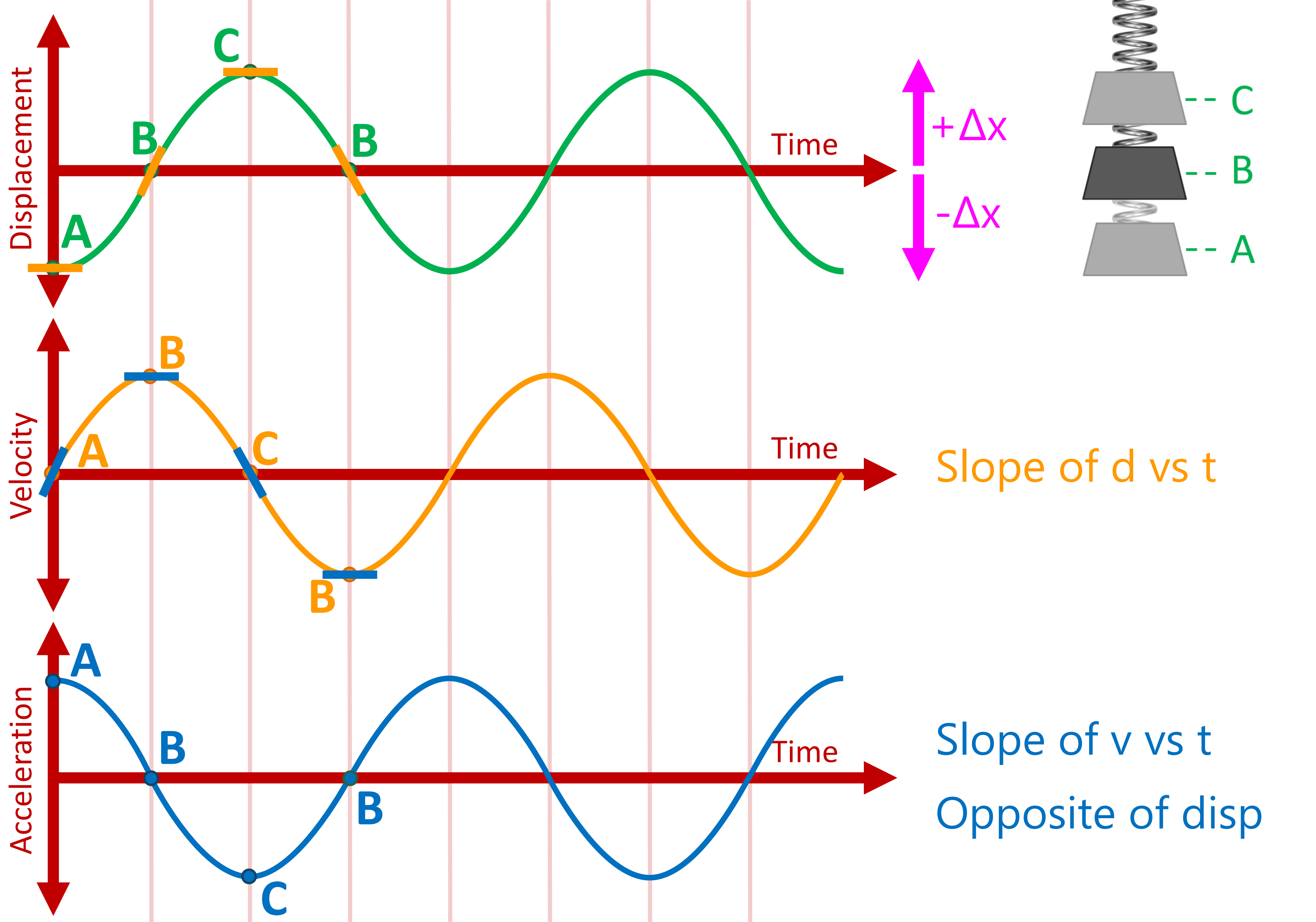
Where is the Greatest...



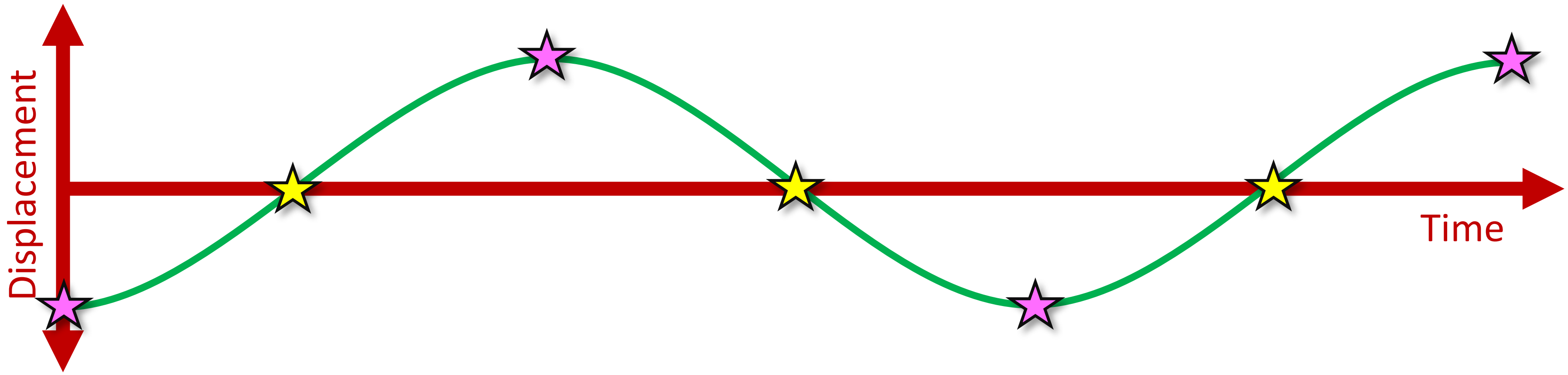
	Displacement	Velocity	Acceleration
C	X		X
B		X	
A	X		X

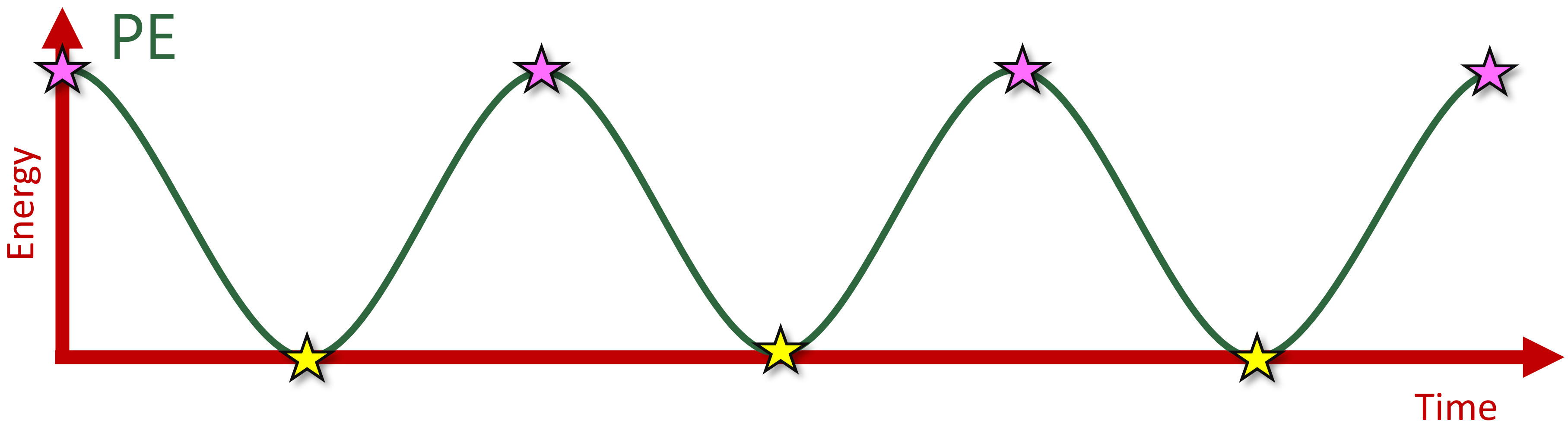
Graphing Displacement vs Time



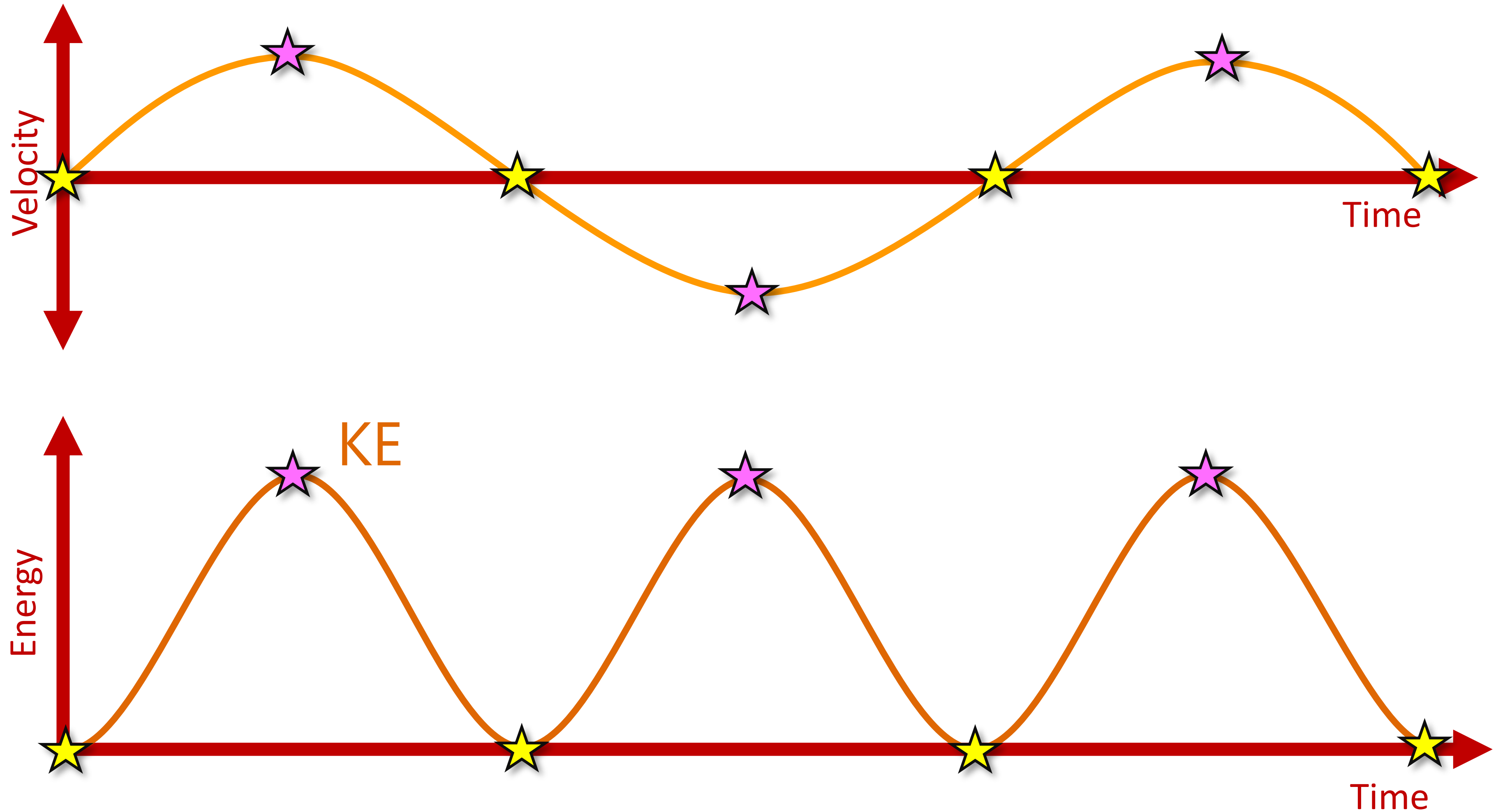

Displacement
Time
A
B
C
B
+Δx
-Δx
C
B
A
Velocity
Time
A
B
C
B
Slope of d vs t
Acceleration
Time
A
B
C
B
Slope of v vs t
Opposite of disp

Energy for SHM

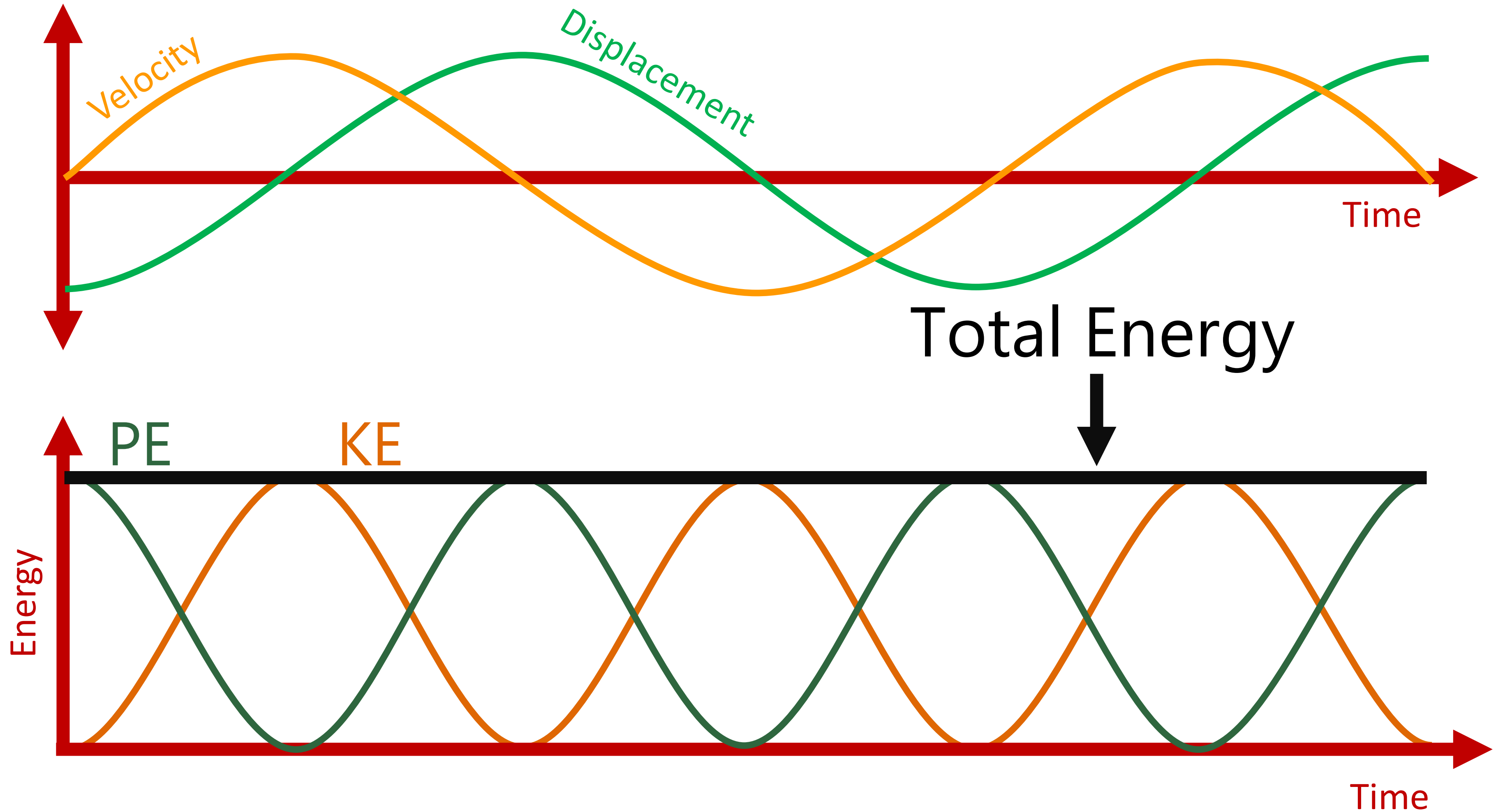




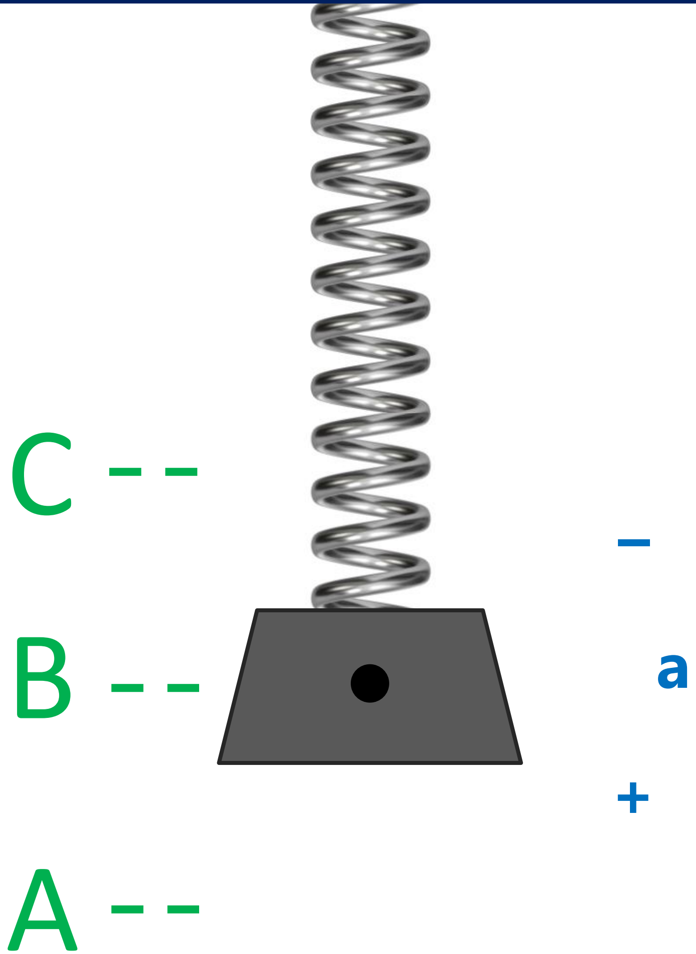
Energy for SHM

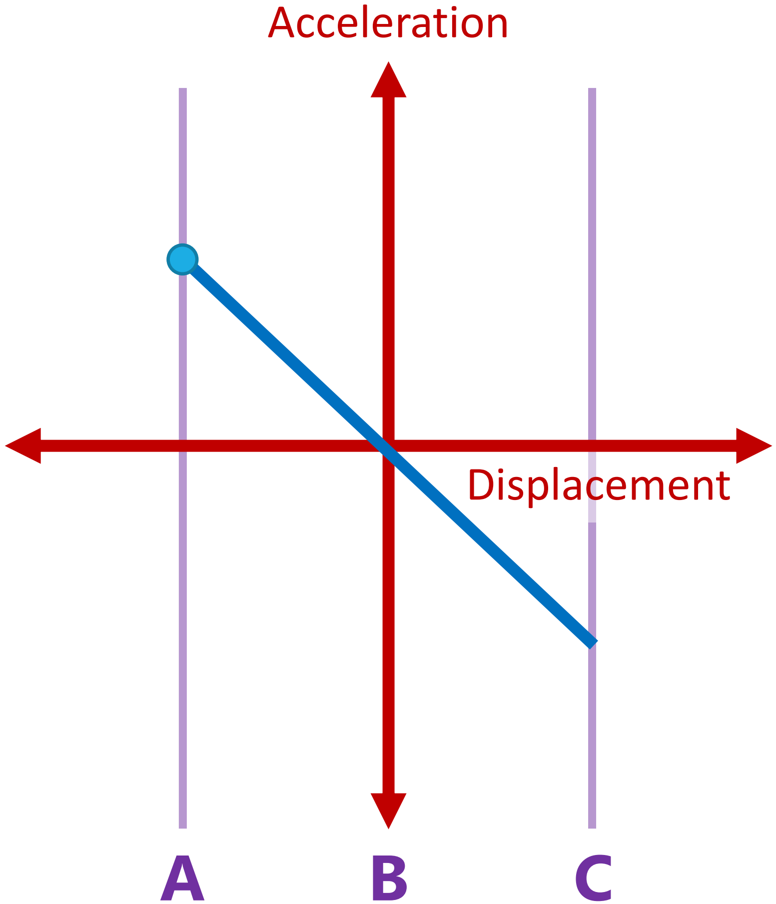


Energy for SHM

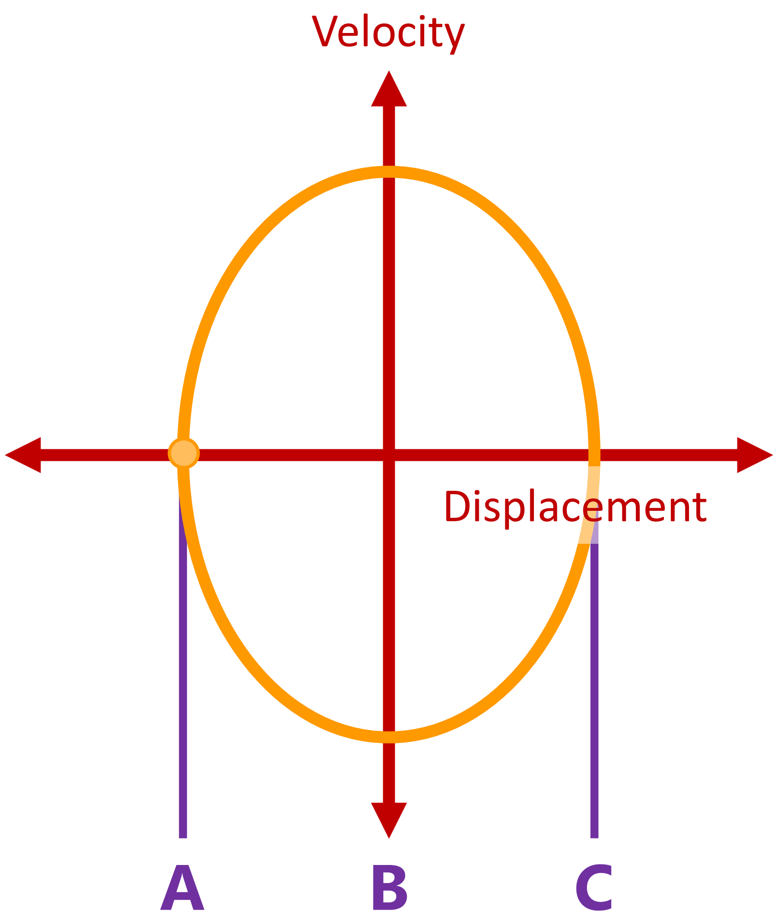


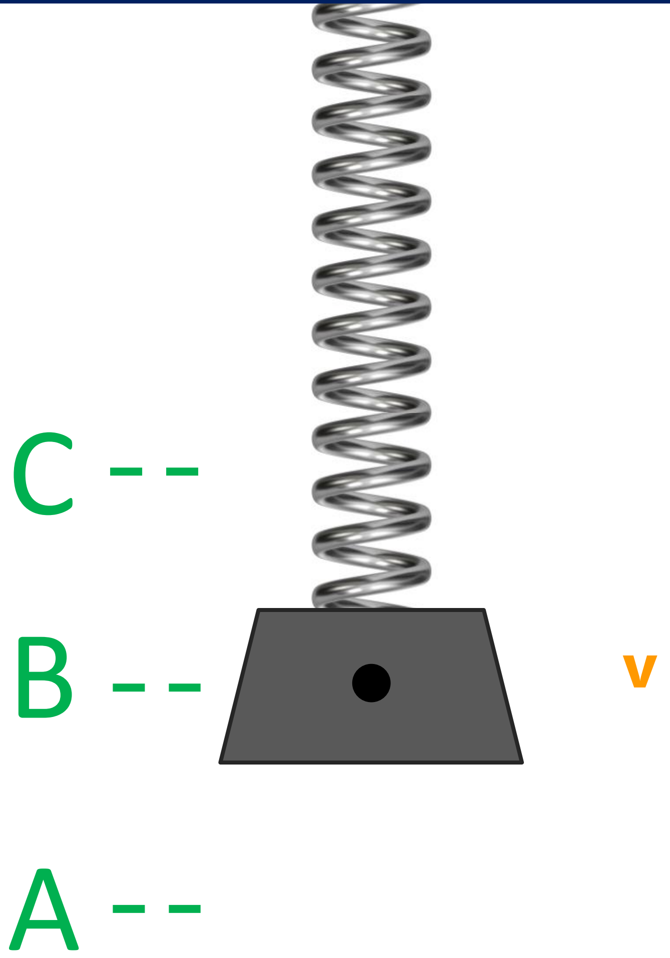
Acceleration vs Displacement



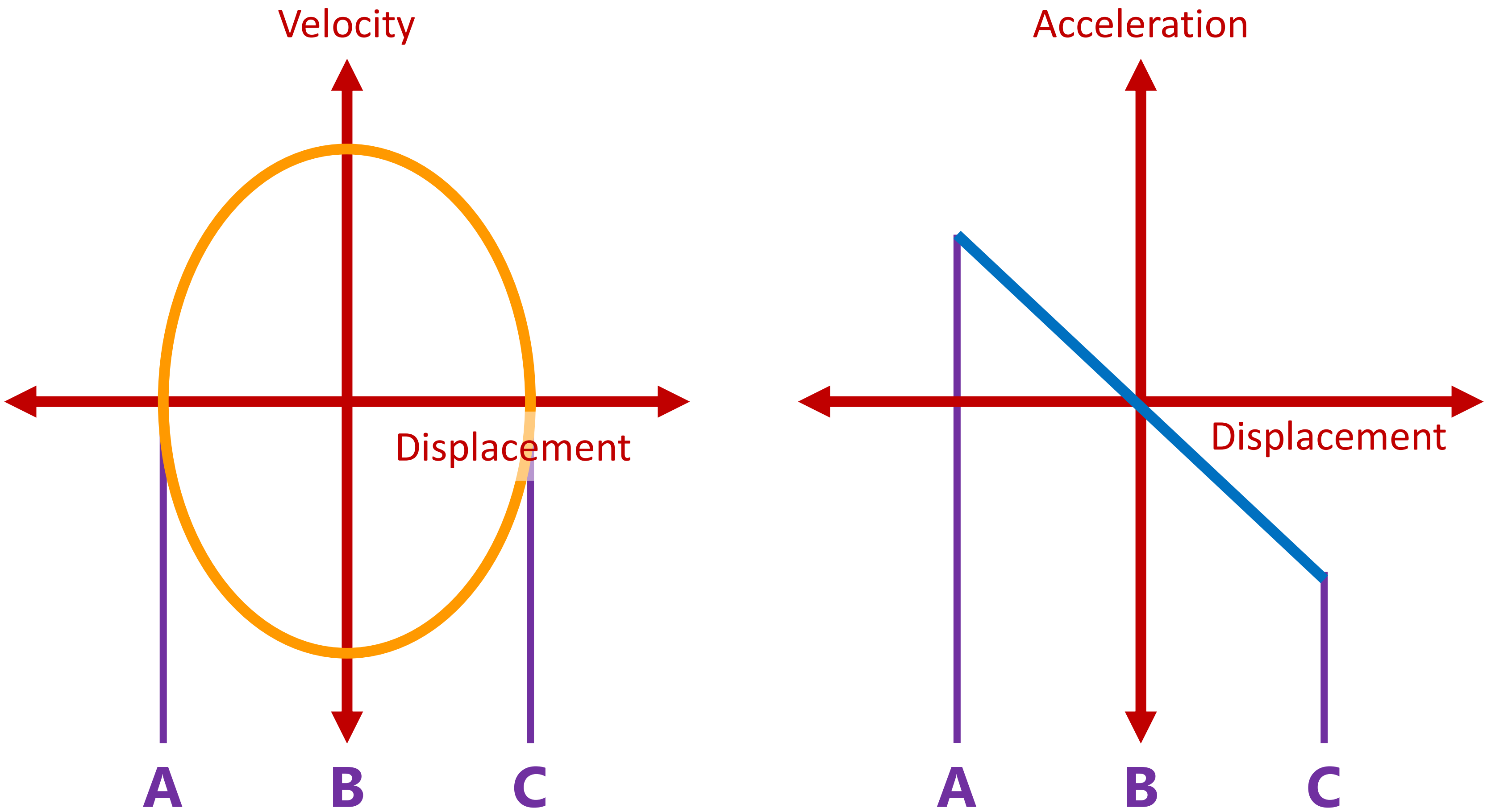


Velocity vs Displacement

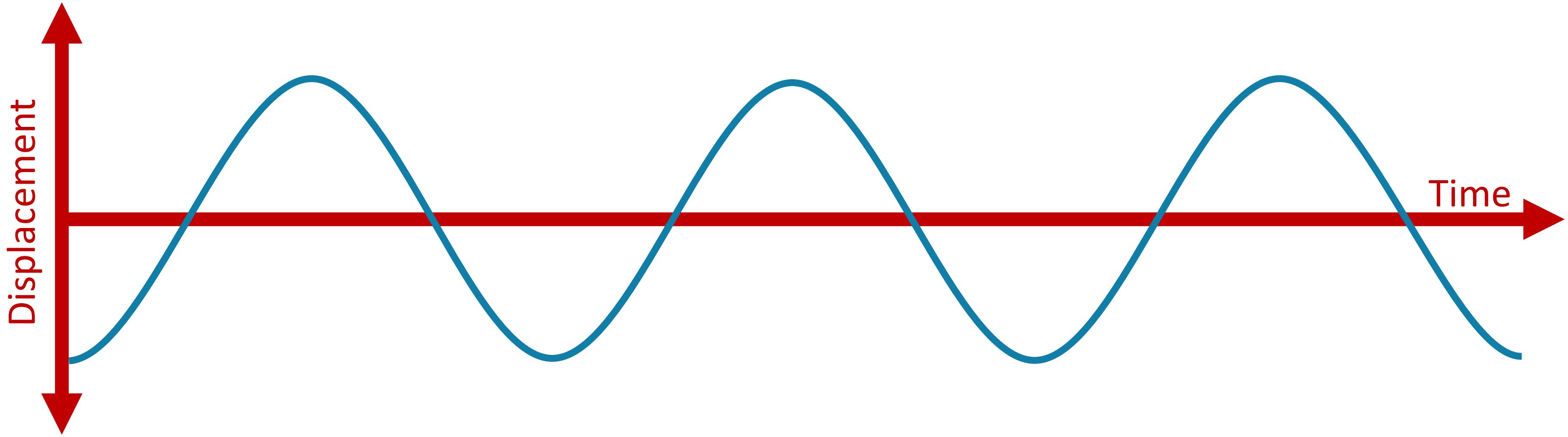




______ vs Displacement



Properties of SHM

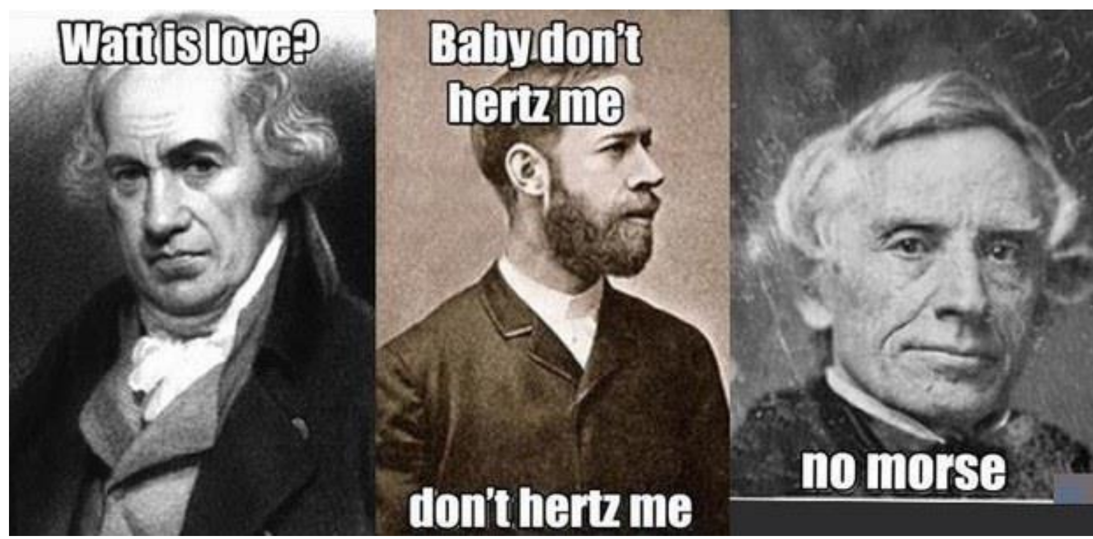


Property	What is it?	Symbol	Unit
Period	Time per cycle	T	[s]
Frequency	Cycles per second	f	[Hz]

Period is related to Frequency

Period = 1 / Frequency

Sub-topic 4.1 – Oscillations
$\boxed{T = \frac{1}{f}}$
Sub-topic 4.2 – Travelling waves
$c = f\lambda$
Sub-topic 4.3 – Wave characteristics
$I \propto A^2$ $I \propto x^{-2}$ $I = I_0 cos^2\, \theta$



Period is related to Frequency

Period = 1 / Frequency

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

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

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

Try this...

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

Taylor Swift's song Shake it Off has a tempo of 160 beats per minute (2.67 Hz) how many seconds are in between each beat (the **period**)

$f = 2.67\ Hz$

$T = ??$

$$T = \frac{1}{f} = \frac{1}{2.67\ Hz} = \mathbf{0.37\ s}$$

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

Try this...

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

You are standing on the beach with your feet in the water and notice that a new wave comes crashing in every 4 seconds, what is the **frequency** of these waves?

$T = 4\ s$

$f = ??$

$$f = \frac{1}{T} = \frac{1}{4\ s} = \mathbf{0.25\ Hz}$$

A little harder…

You are pushing your younger brother on a swing and you end up pushing 12 times in one minute. What is the period and frequency of the swing?

$$T = \frac{60\ seconds}{12\ times} = \mathbf{5\ s}$$

$$f = \frac{1}{T} = \frac{1}{5\ s} = \mathbf{0.2\ Hz}$$

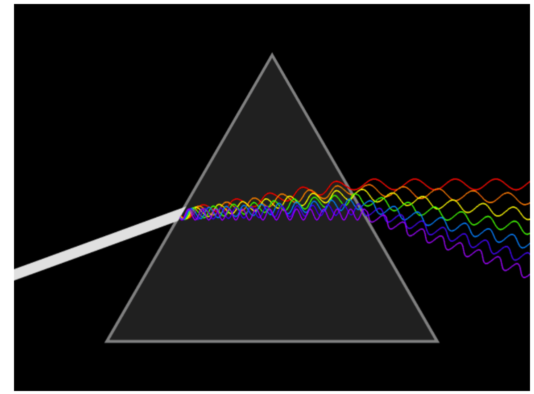
Lesson Takeaways

- ❑ I can relate the acceleration of an object in simple harmonic motion to its position
- ❑ I can graph the displacement, velocity, and acceleration vs time for simple harmonic motion
- ❑ I can describe and relate the properties of period and frequency
- ❑ I can calculate period and frequency from a scenario

Properties of Traveling Waves

IB PHYSICS | WAVES - SOUND

What is a Wave?



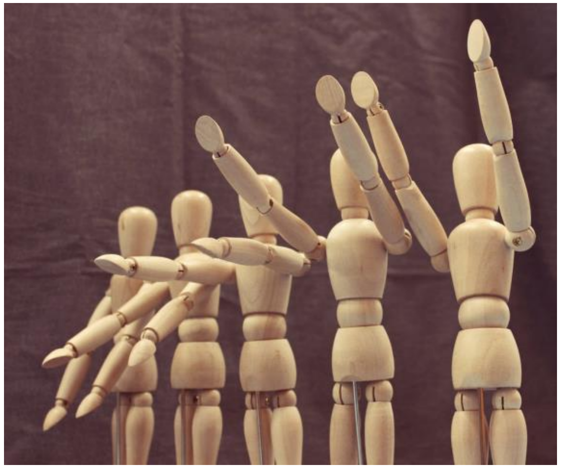
What is a Wave?

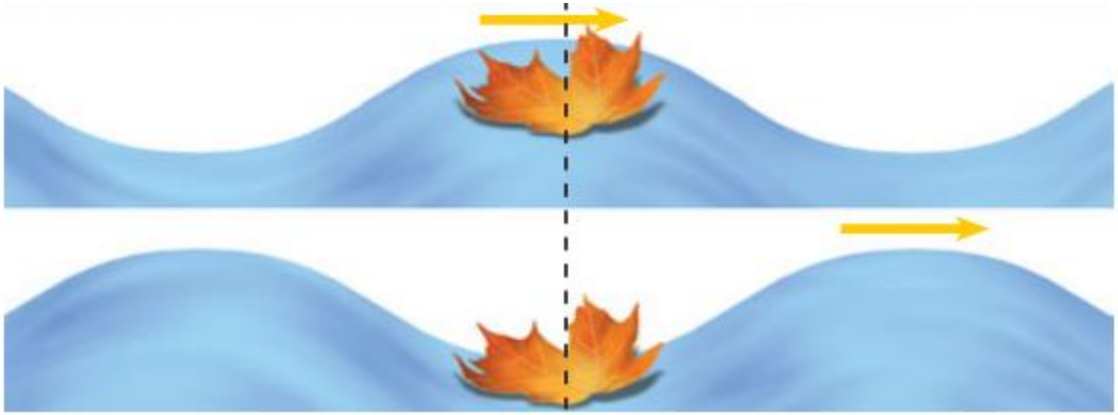
A wave is a disturbance that carries ____energy____ through matter or space

matter through which a wave travels → medium

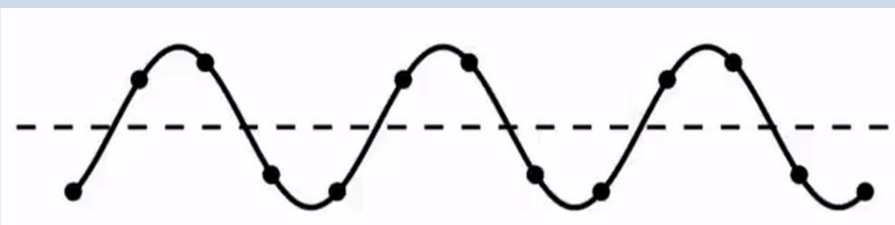
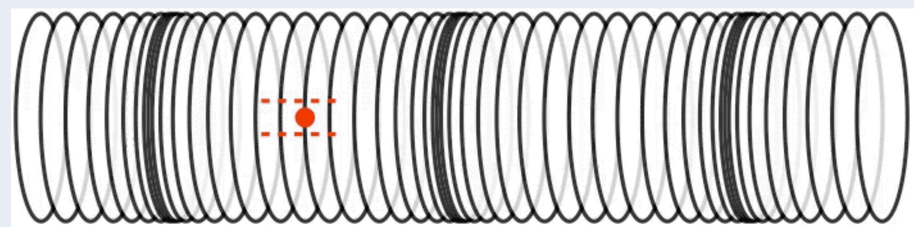
Is the Medium Moving?

The medium particles oscillate back and forth

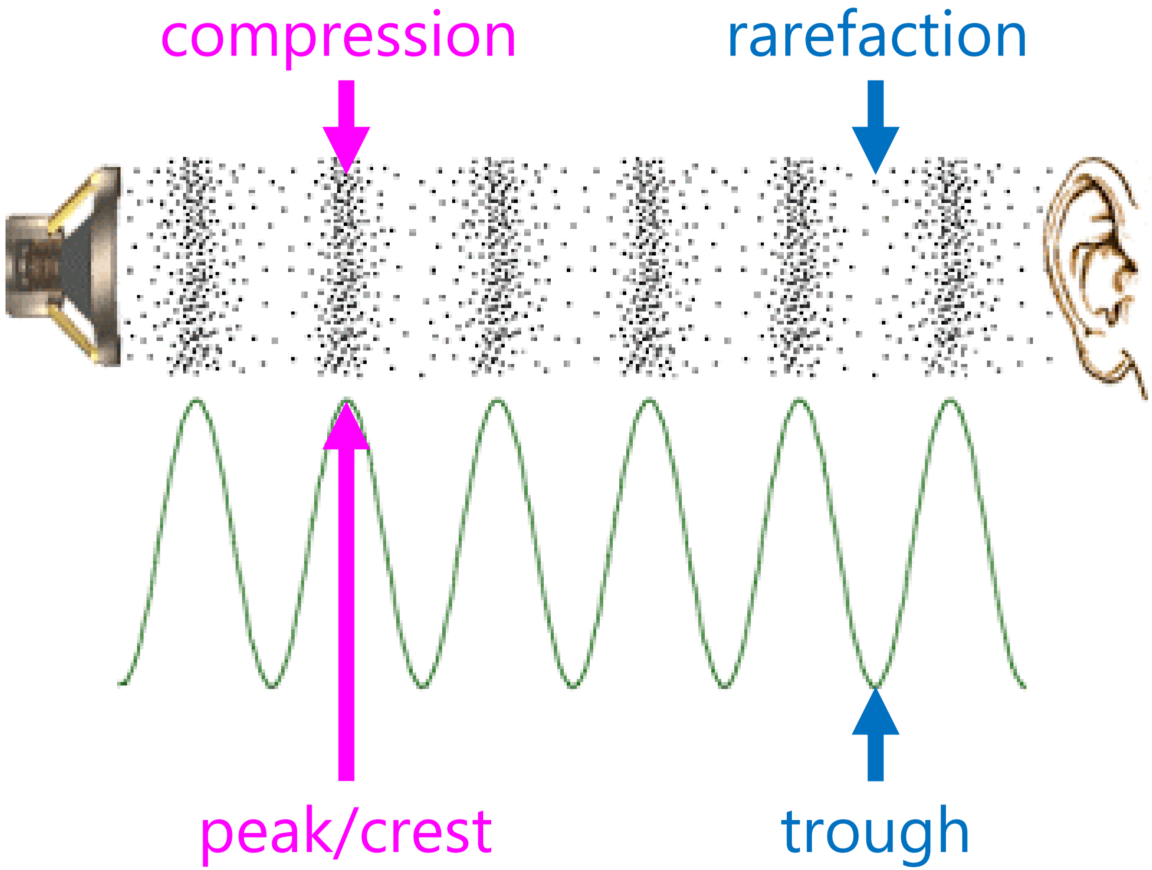




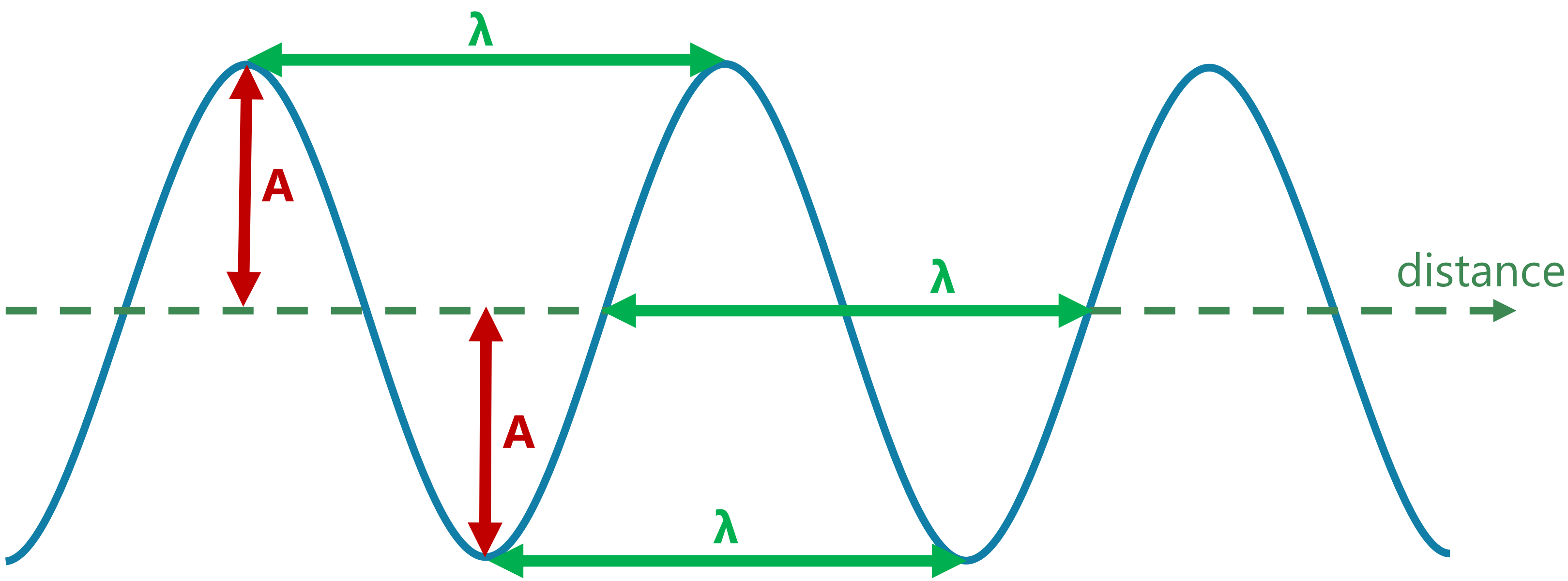
Two Types of Waves

Transverse	Longitudinal
Particles move **perpendicular** to the wave's motion	Particles move **parallel** to the wave's motion
	
Examples: • Ripples in a pond • Light Waves  	Examples: • Sound Waves • Earthquake Waves

Properties of a Wave

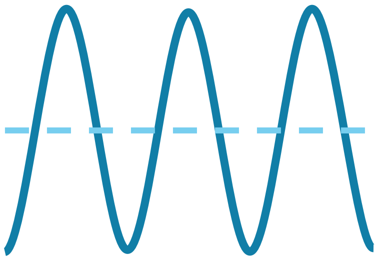


Properties of a Wave



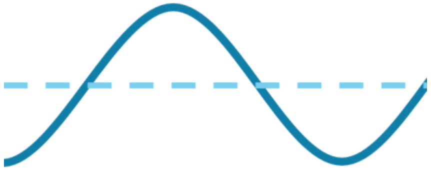
Property	Symbol	Unit
Amplitude	**A**	**[m]**
Wavelength	**λ**	**[m]**

Waves and Energy

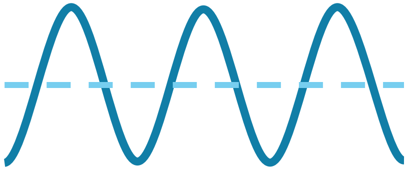


↑ Amplitude = ↑ Energy

↓ Amplitude = ↓ Energy



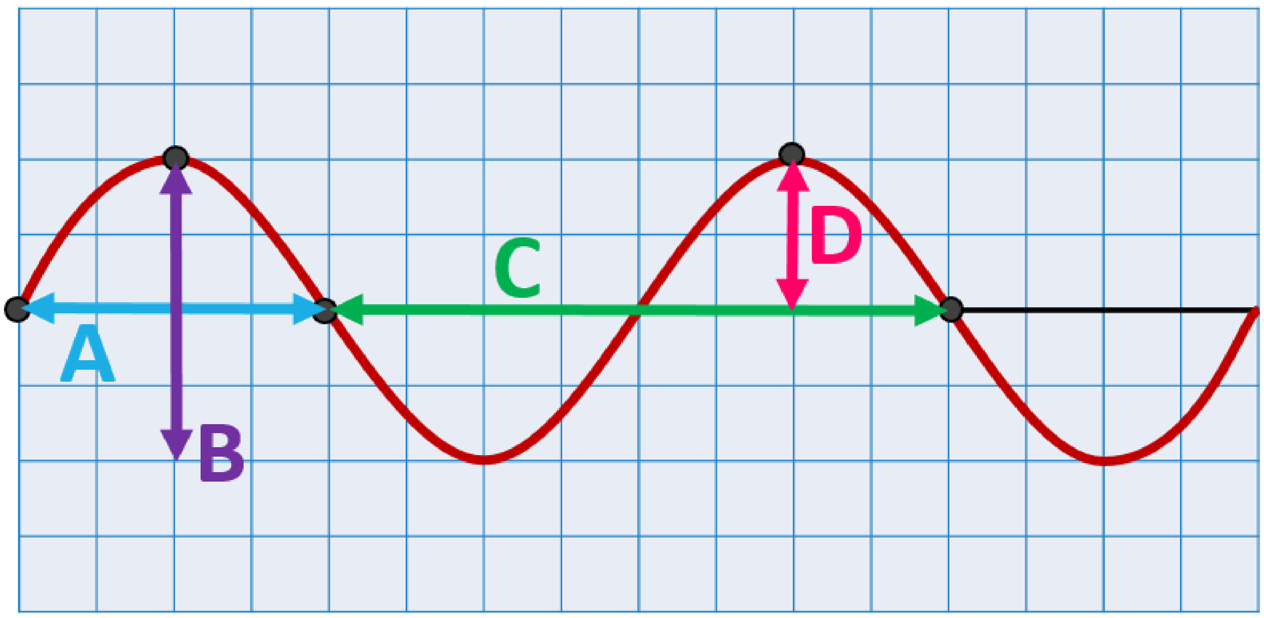
↑ Wavelength = ↓ Energy



↓ Wavelength = ↑ Energy

Label this wave

Can you identify the wave properties from this diagram?

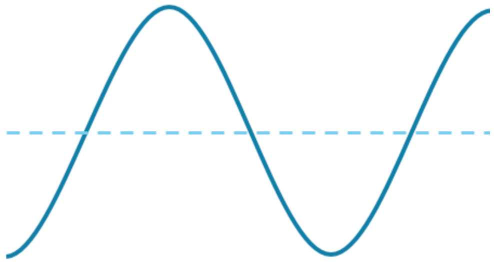


Amplitude? **D**

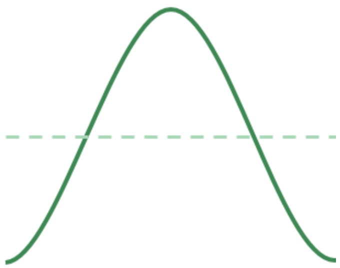
Wavelength? **C**

How Many Waves?

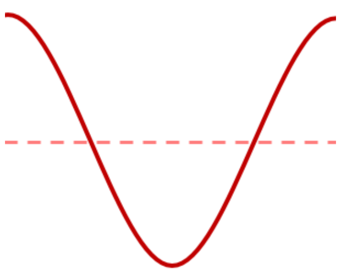
1.5



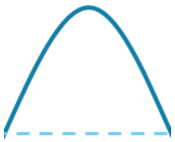
1



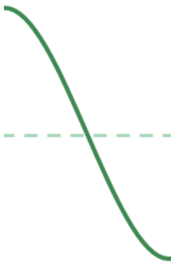
1



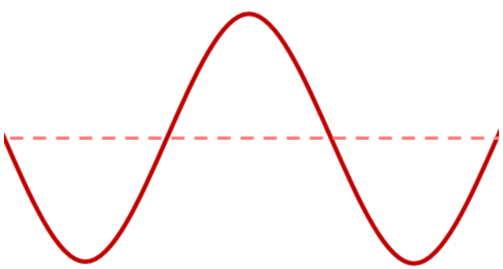
0.5



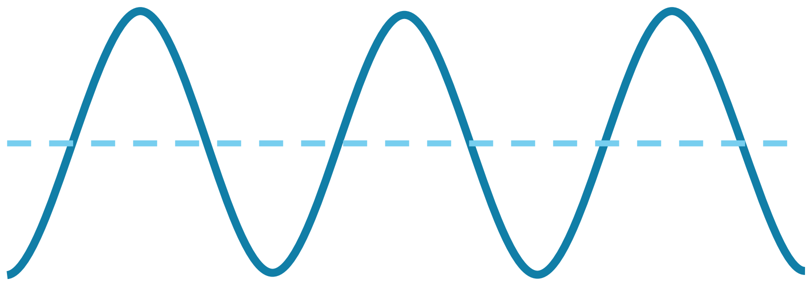
0.5



1.5

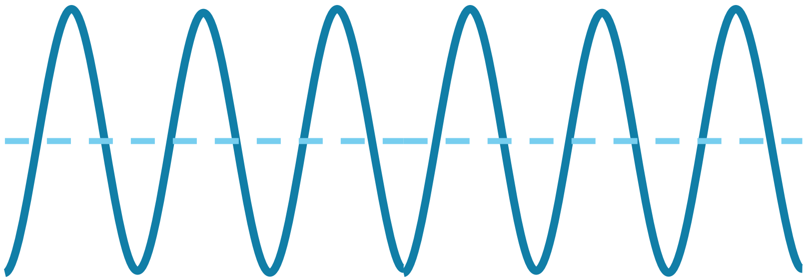


Wavelength is related to frequency



Longer wavelength

Lower frequency



Shorter wavelength

Higher frequency

Wave Speed Equation

Speed = Frequency × Wavelength

Symbols	v	$=$	f	$\times$	λ
Units	[m s^{-1}]	$=$	[Hz]	$\times$	[m]
			[s^{-1}]		

IB Physics Data Booklet

Sub-topic 4.1 – Oscillations	Sub-topic 4.4 – Wave behaviour
$T = \frac{1}{f}$	$\frac{n_1}{n_2} = \frac{\sin\theta_2}{\sin\theta_1} = \frac{v_2}{v_1}$ $s = \frac{\lambda D}{d}$ Constructive interference: path difference $= n\lambda$ Destructive interference: path difference $= (n + \frac{1}{2})\lambda$
Sub-topic 4.2 – Travelling waves	
$\boxed{c = f\lambda}$	
Sub-topic 4.3 – Wave characteristics	
$I \propto A^2$ $I \propto x^{-2}$ $I = I_0 cos^2\,\theta$	

*Note: "c" represents the speed of light but the relationship is the same for all wave speeds

Try this…

A piano string vibrates with a frequency of 262 Hz. If these sound waves have a wavelength in the air of 1.30 m, what is the speed of sound?

$f = 262\ Hz$

$\lambda = 1.30\ m$

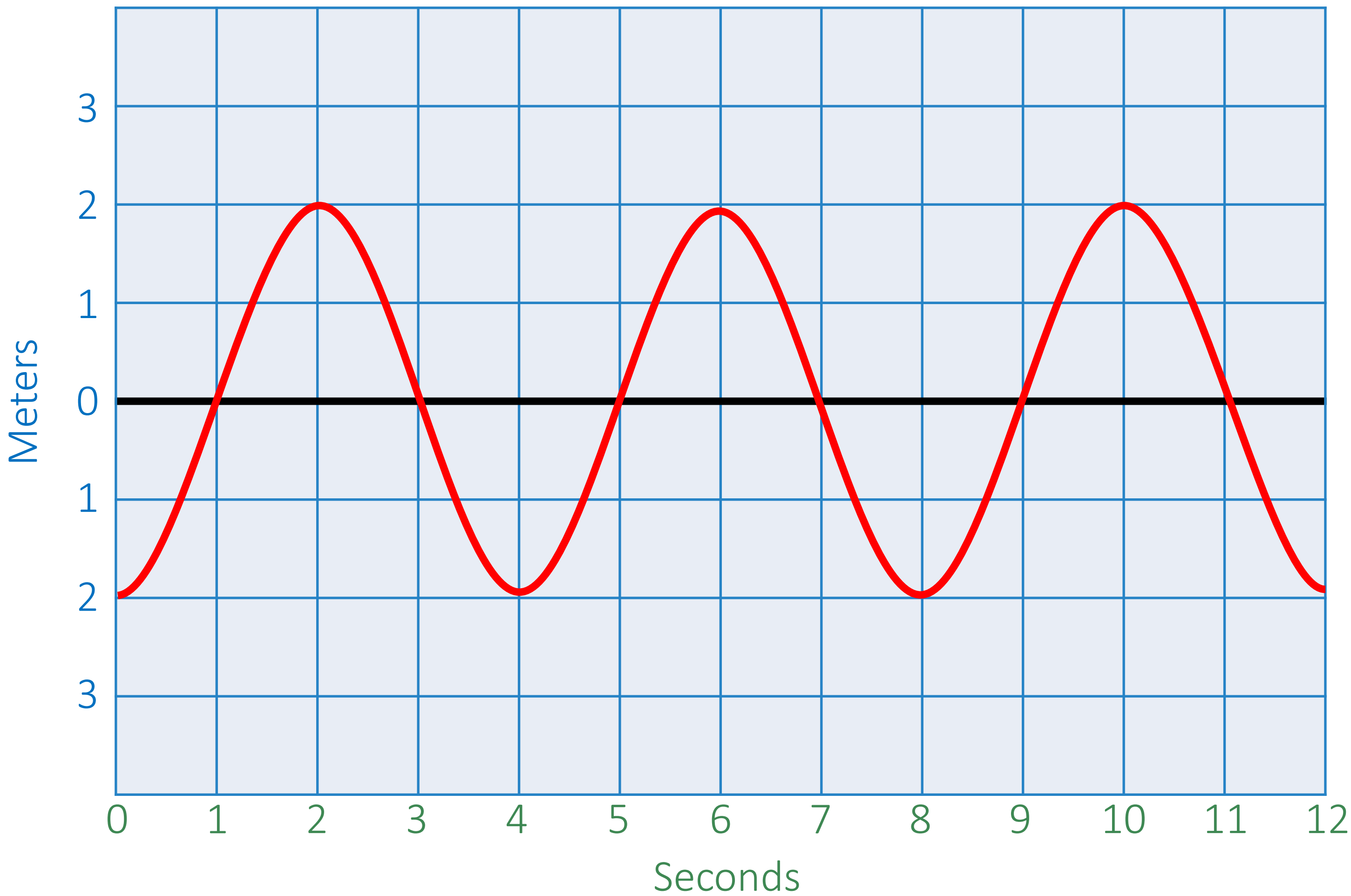
$v = ??$

$$v = f\lambda = (262)(1.30) = 340.6\ m/s$$

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

Read a Wave #1

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

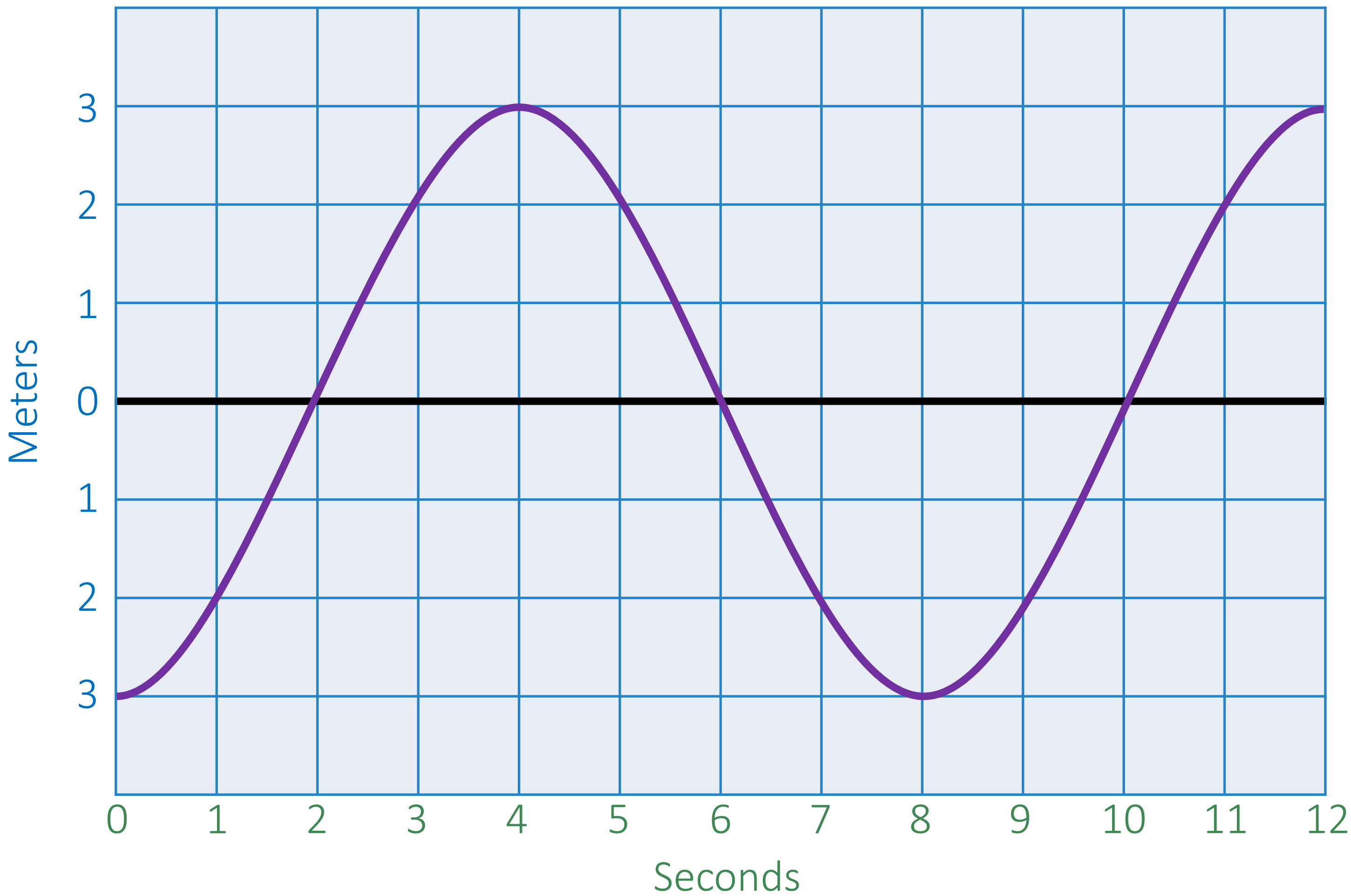


of Waves
3
Period
4 s
Amplitude
2 m
Frequency
0.25 Hz

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

Read a Wave #2

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



# of Waves	**1.5**
Period	**8 s**
Amplitude	**3 m**
Frequency	**0.125 Hz**

One Final Question…

The crests of waves passing into a harbor are 2.1 m apart and have an amplitude of 60 cm. 12 waves pass an observer every minute.

What is their frequency?	What is their speed?
$\frac{12\ waves}{1\ \cancel{min}} \times \frac{1\ \cancel{min}}{60\ s} = 0.2\ \frac{waves}{s}$ $\downarrow$ $f = \mathbf{0.2\ Hz}$	$v = f\lambda$ $= (0.2)(2.1)$ $= \mathbf{0.42\ m\ s^{-1}}$

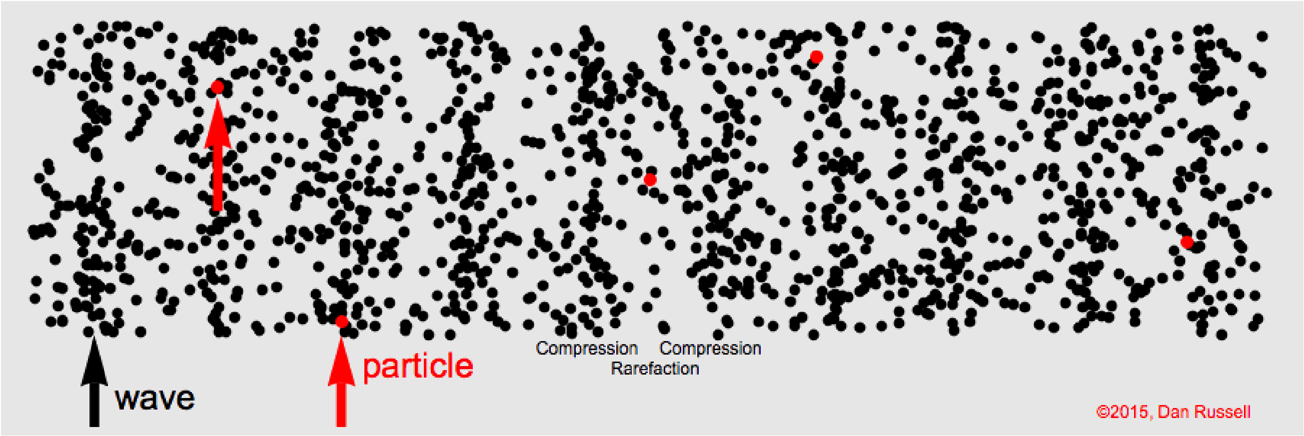
Lesson Takeaways

- ❑ I can describe how waves carry energy through a medium
- ❑ I can compare the properties of transverse and longitudinal waves
- ❑ I can read a wave's amplitude, wavelength, period, and frequency from a graph
- ❑ I can describe the number of complete wavelengths represented in a picture
- ❑ I can use the wave speed equation to mathematically relate speed, wavelength, and frequency

Sound and Standing Waves

IB PHYSICS | WAVES - SOUND

Sound Waves start as Vibrations

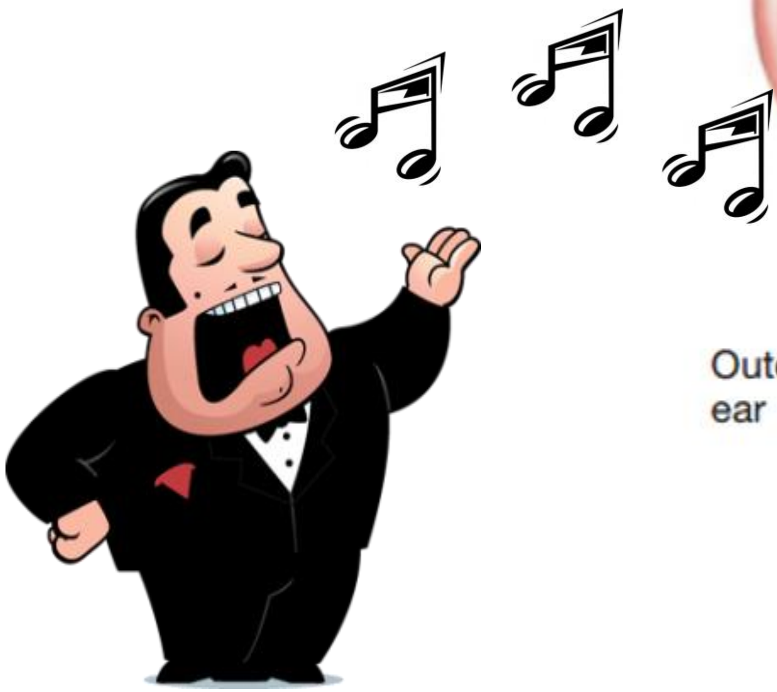


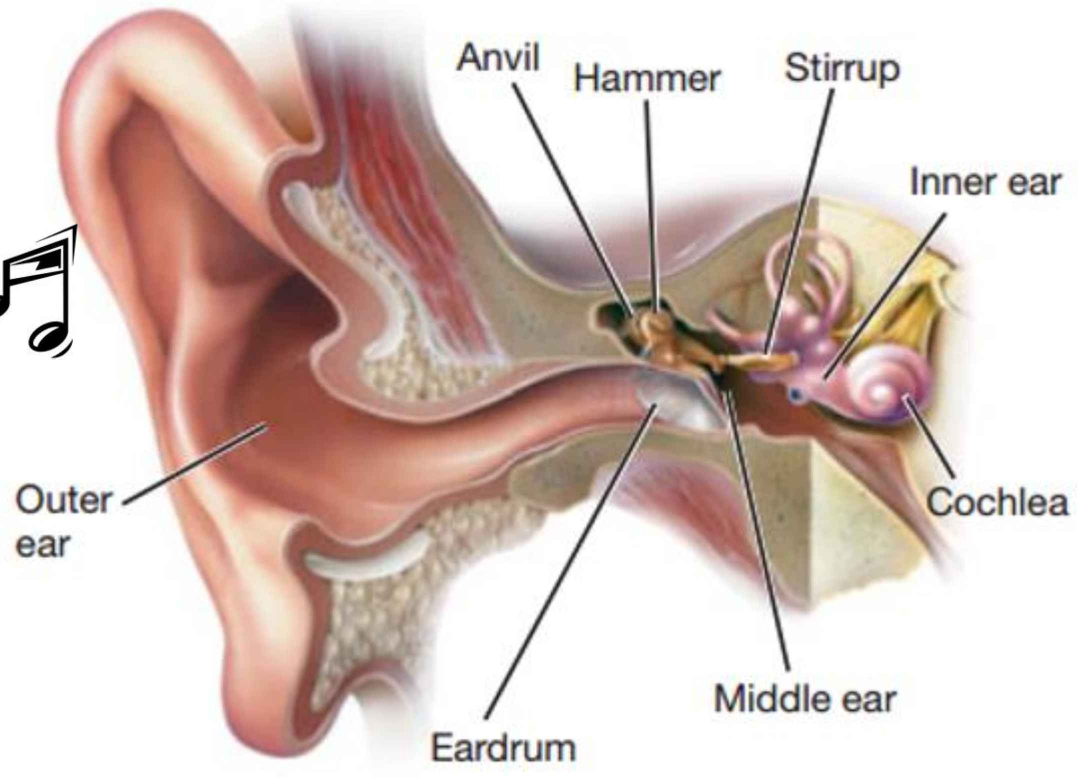
What kind of wave is sound?

Longitudinal

Sound is Pressure

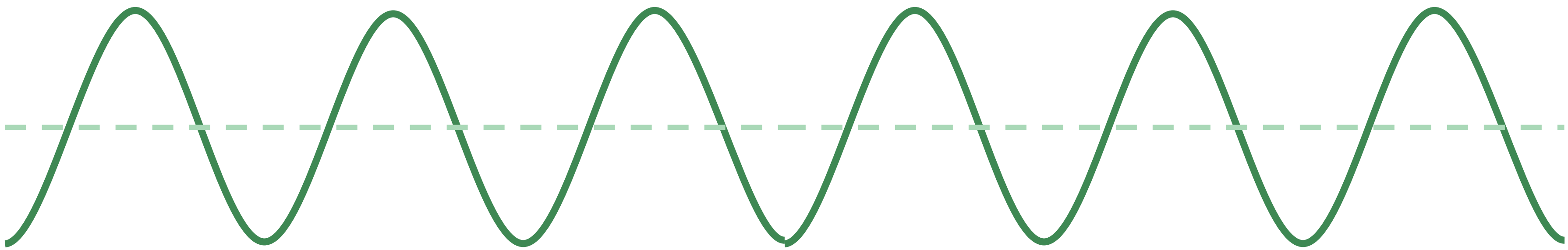
Vibrations pressurize the air molecules and those pressure waves cause our ears to vibrate too!



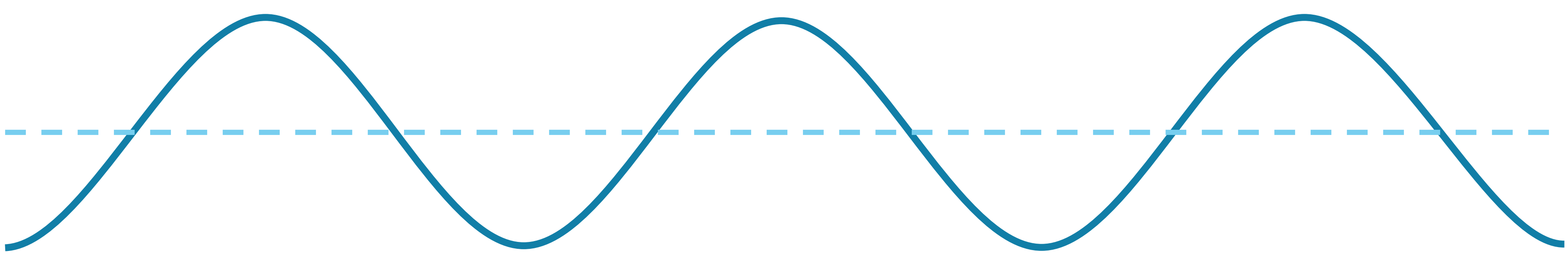


Pitch is Related to Frequency

High pitched sounds have ___**high**___ frequencies



Low pitched sounds have ___**low**___ frequencies

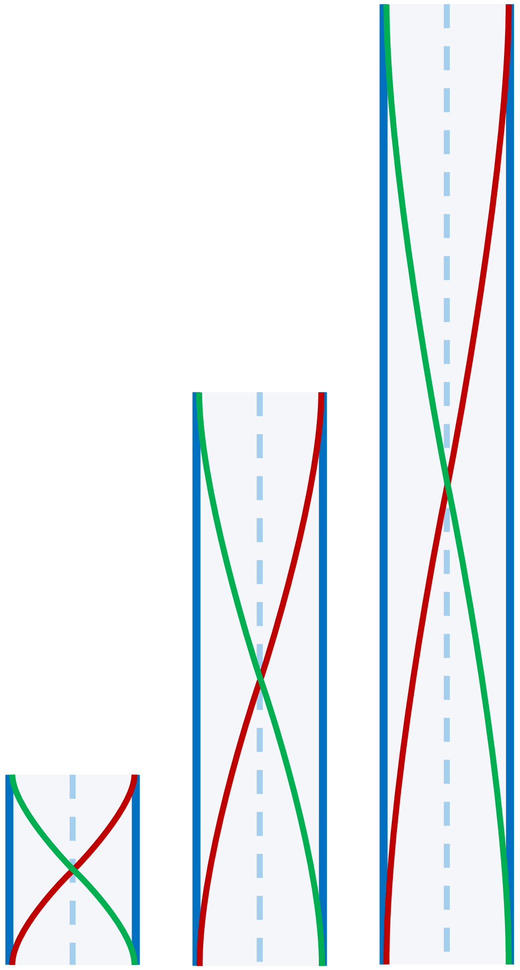


Sensing Pitch

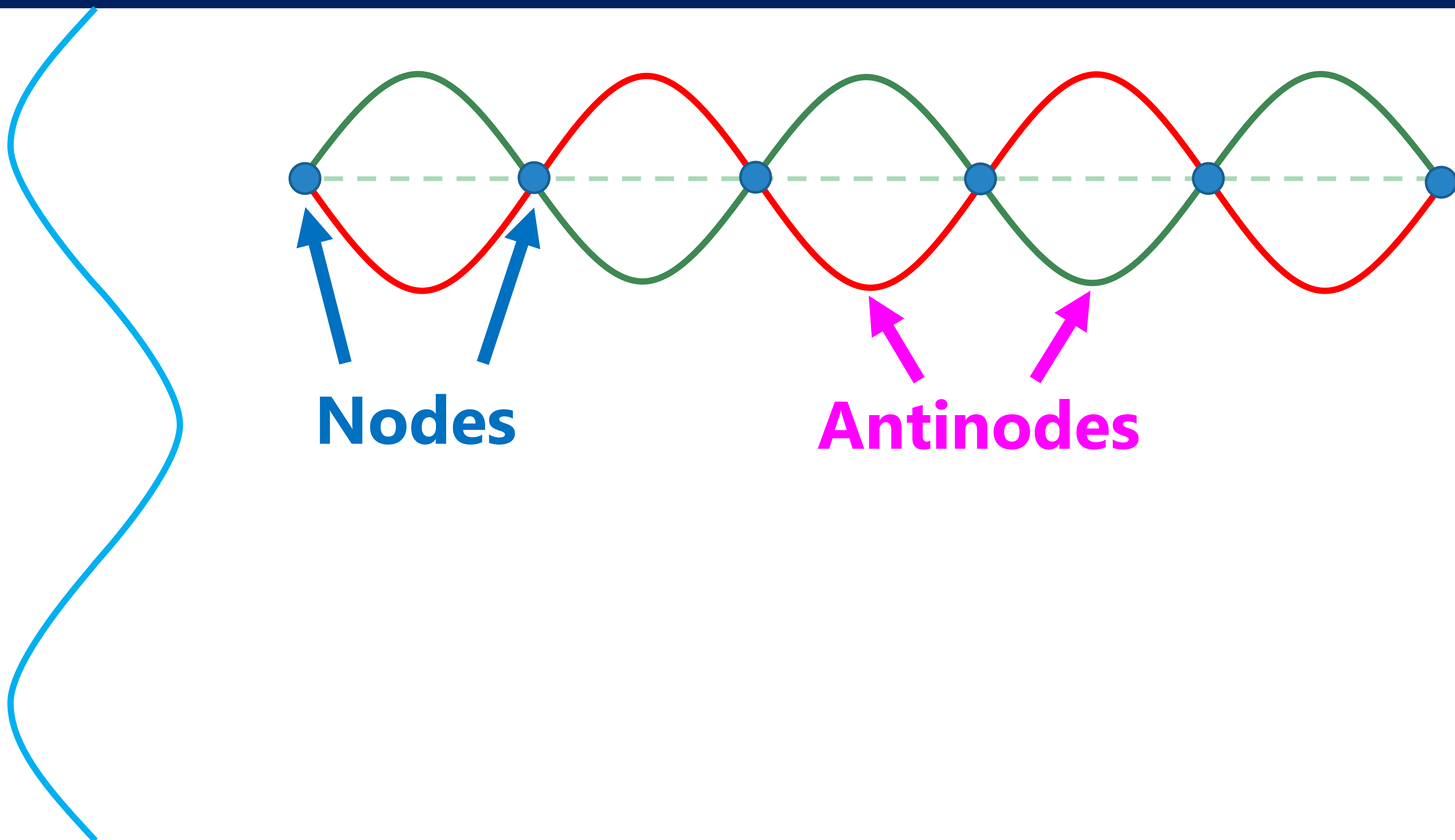
Sadly, the range of frequencies that we can hear diminishes with age…

Frequency
8,000 Hz
10,000 Hz
12,000 Hz
14,000 Hz
16,000 Hz
18,000 Hz
20,000 Hz

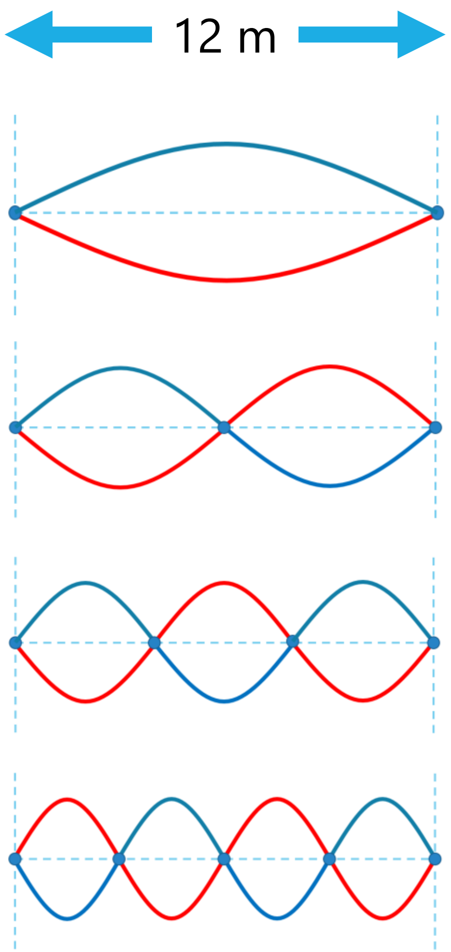
What do you notice from the video?



Standing Waves

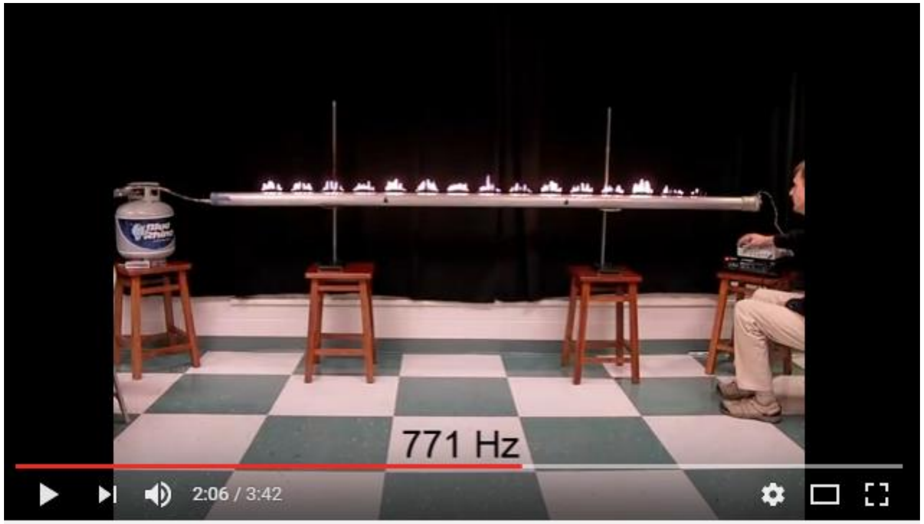


Standing Waves

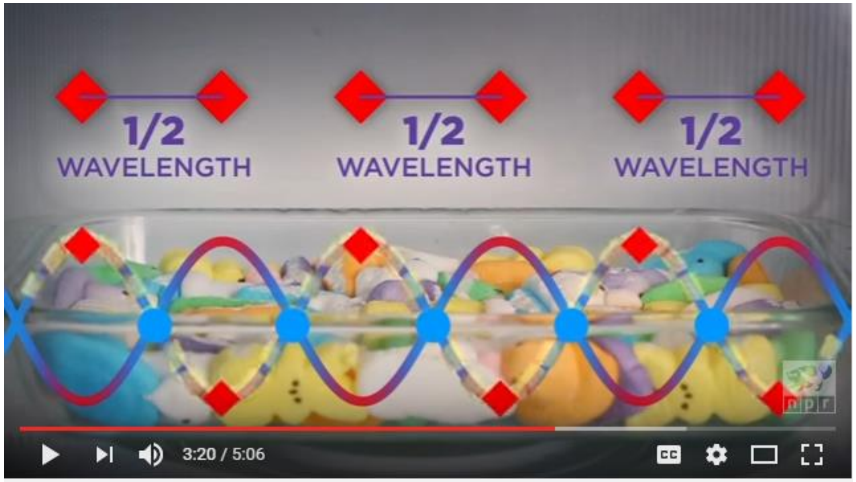


# of Standing Waves	# of Wavelengths	Wavelength (m)
1	0.5	24
2	1	12
3	1.5	8
4	2	6

"Seeing" Standing Waves



The Rubens' Flame Tube: Seeing Sound Through Fire



Finding The Speed Of Light With Peeps | SKUNK BEAR

Lesson Takeaways

- ❑ I can relate the pitch of a sound to the frequency of the sound wave
- ❑ I can identify and label the node and antinodes on a standing wave diagram

Calculating Harmonics and Instruments

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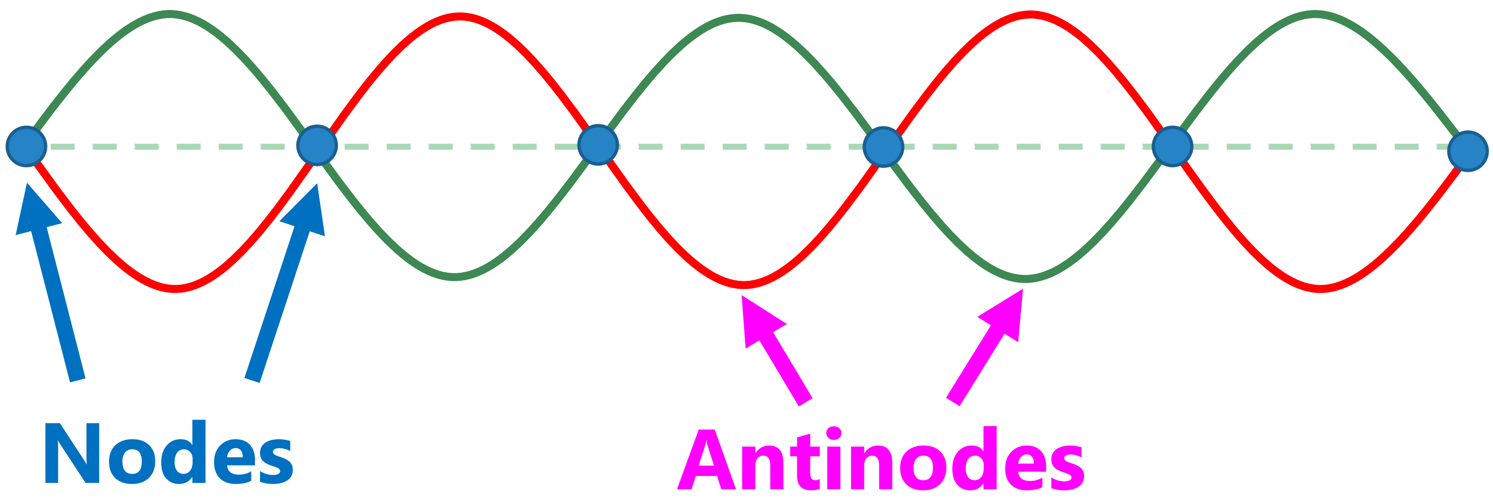
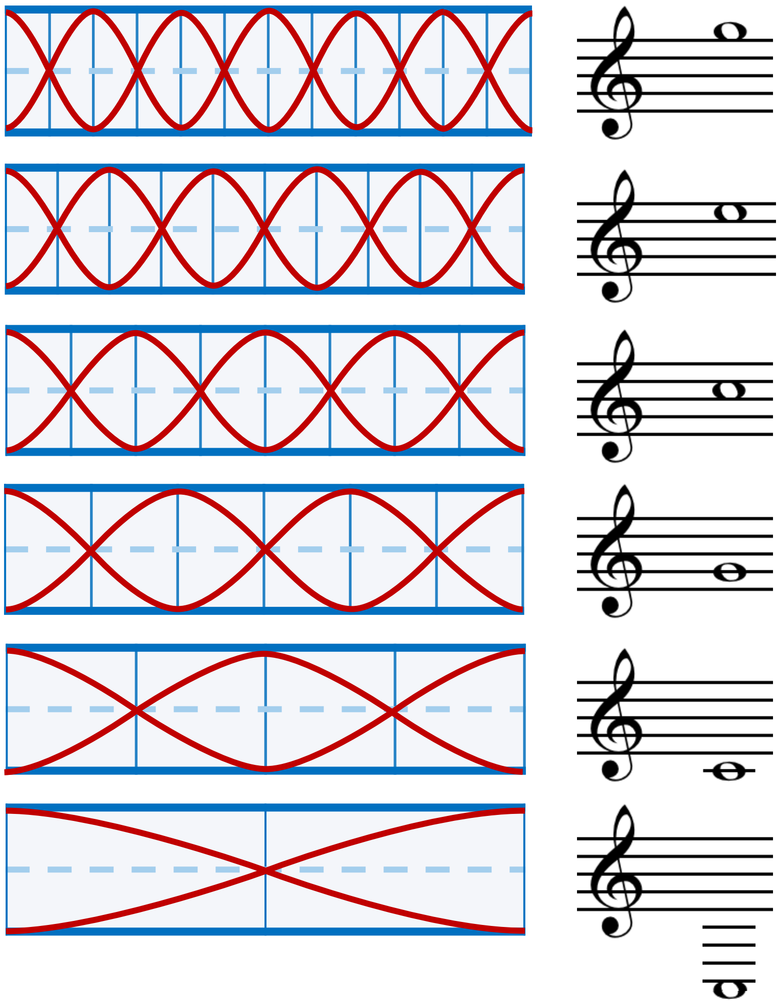
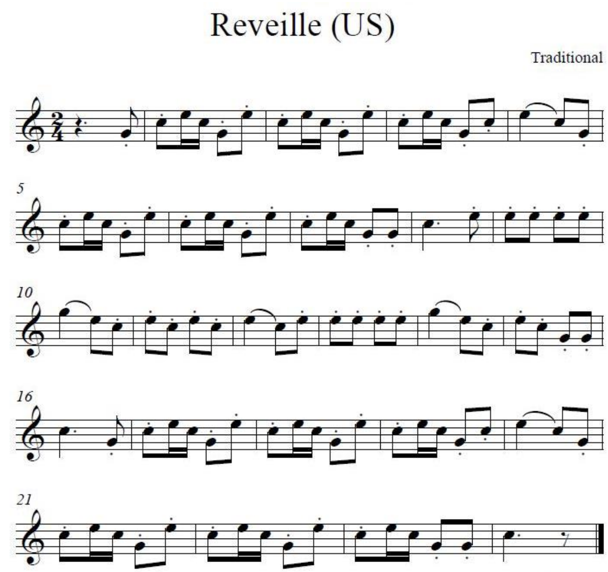
Standing Waves Review

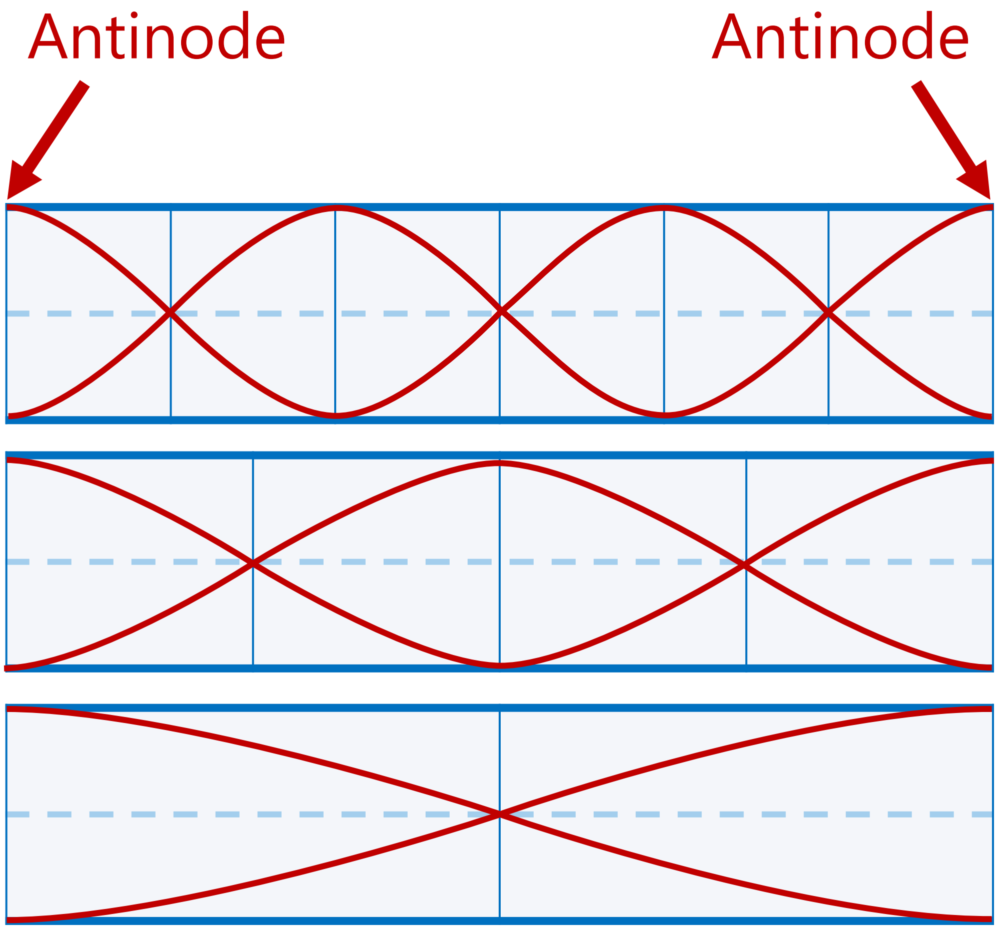


Harmonics



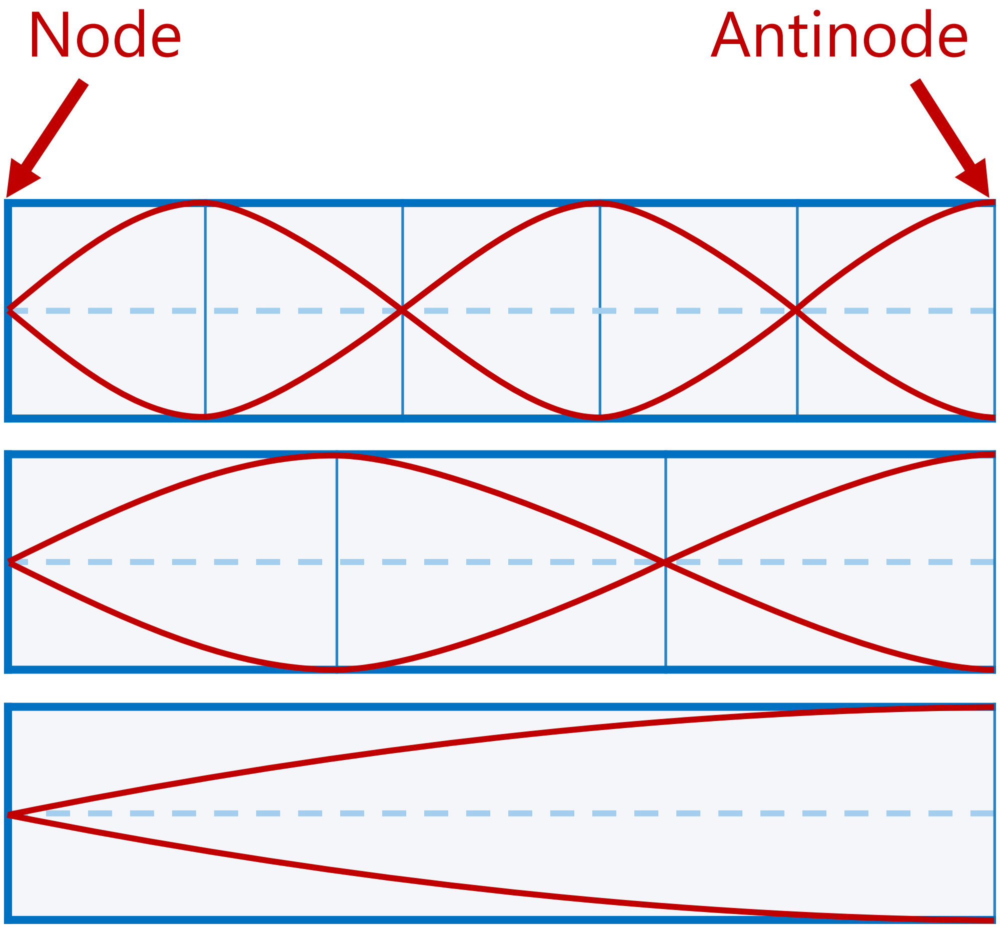


Open Pipe Resonance



L =
$\frac{3}{2}\lambda$
1λ
$\frac{1}{2}\lambda$

Closed Pipe Resonance



L =
$\frac{5}{4}\lambda$
$\frac{3}{4}\lambda$
$\frac{1}{4}\lambda$

Strings make sound too!

wave speed

____

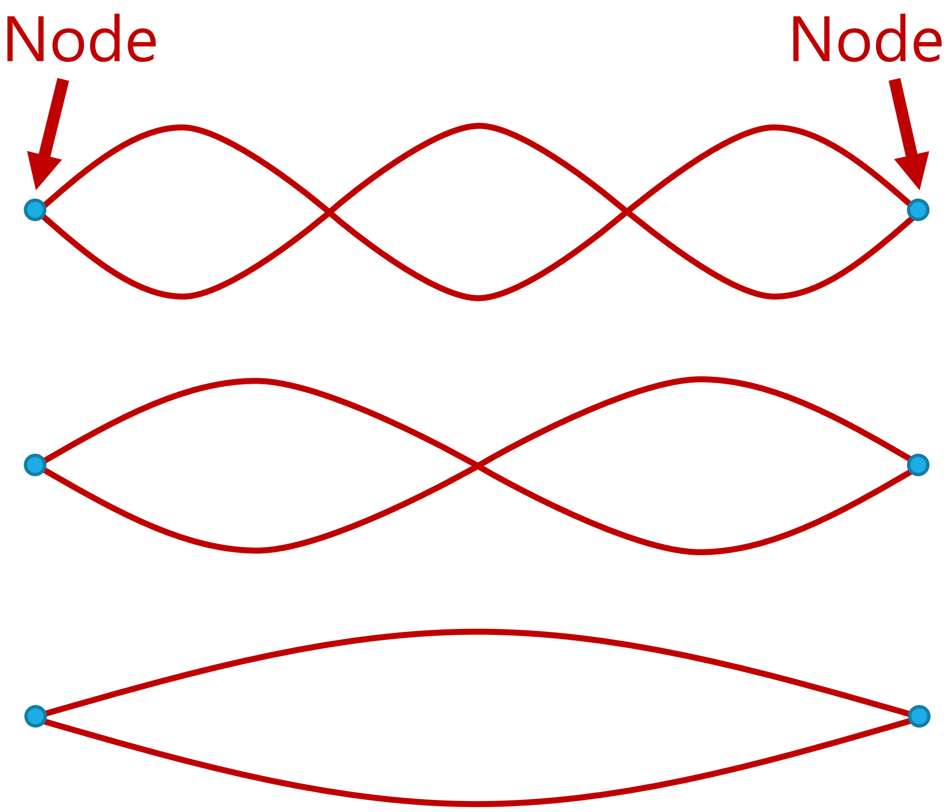
changes depending on the string tension

Two ways to increase frequency in string:

increase tension

decrease length

String Resonance

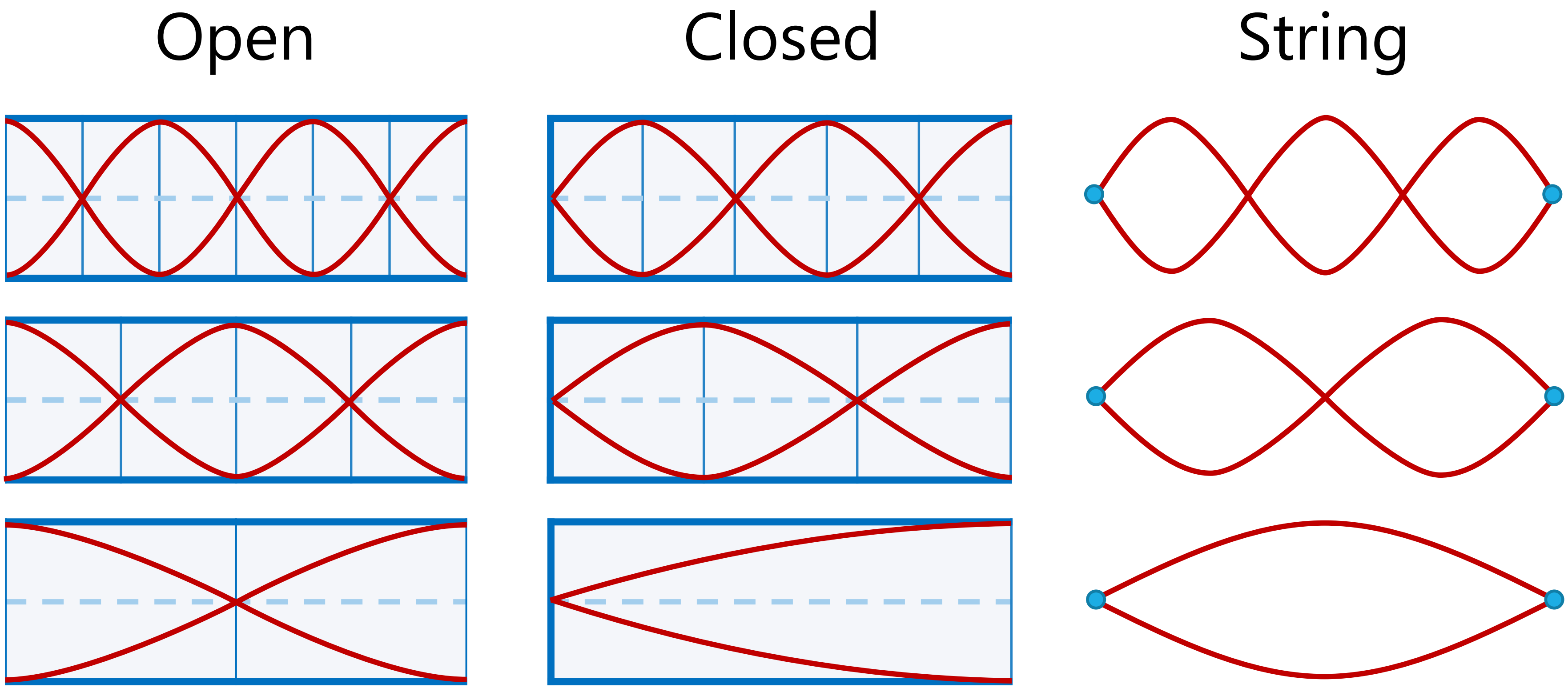


$L =$
$\frac{3}{2}\lambda$
1λ
$\frac{1}{2}\lambda$

Review of End Conditions

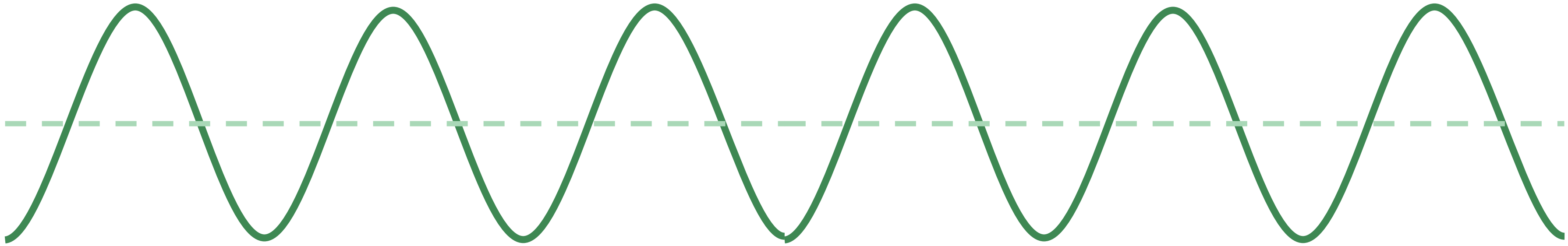
Closed Pipe	Node	Antinode
Open Pipe	Antinode	Antinode
String	Node	Node

All the Harmonics!

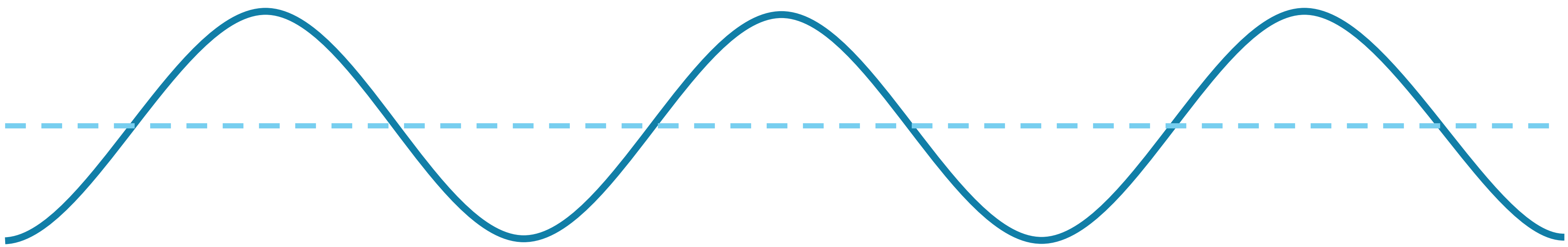


Remember Pitch and Frequency

High pitched sounds have high frequencies

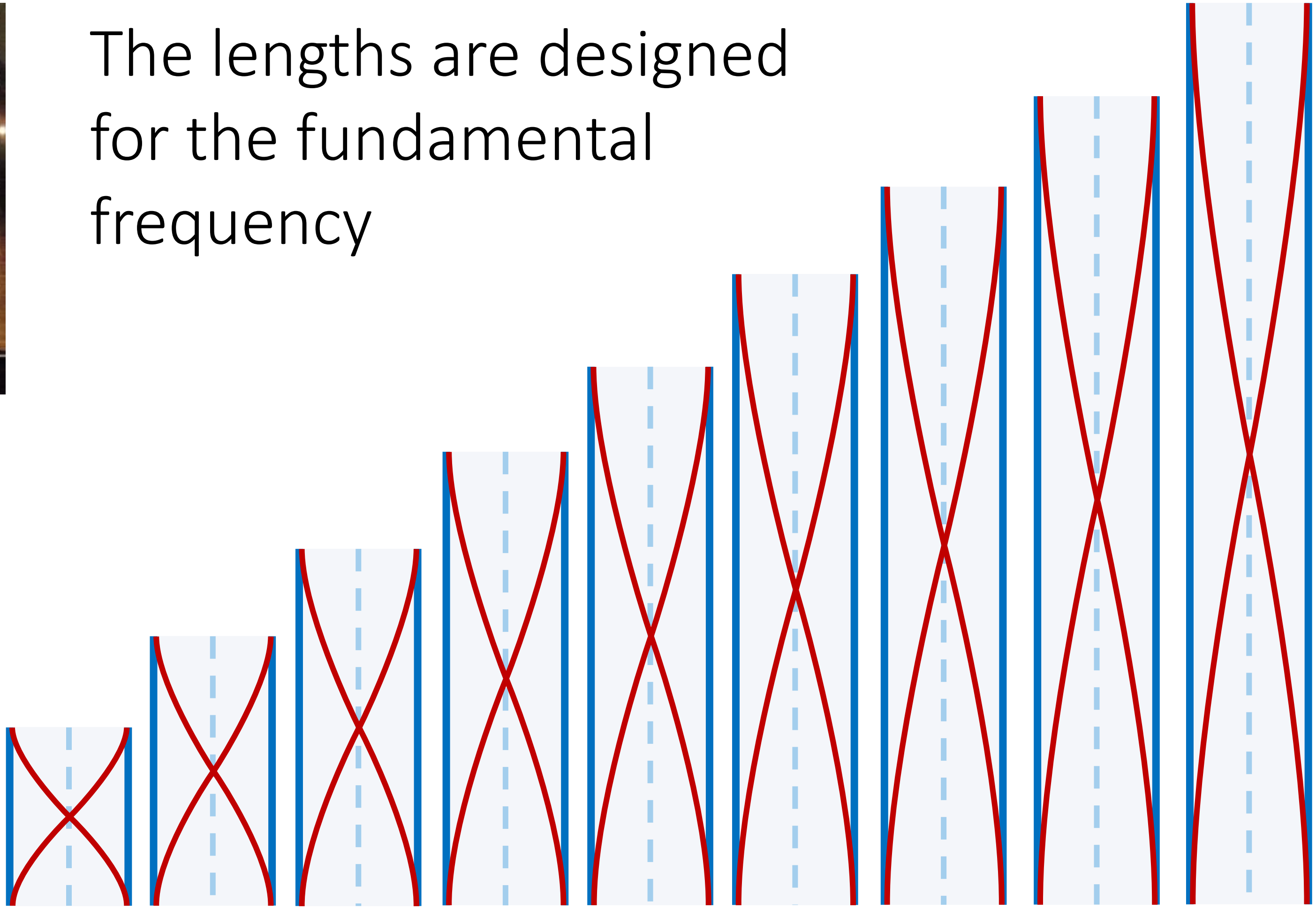


Low pitched sounds have low frequencies



Making Different Pitches

The lengths are designed for the fundamental frequency



Calculating Frequency | Open Pipes

An open organ pipe is $\overset{L}{\boxed{2.1\ m}}$ long and the speed of sound in the pipe is 341 m/s. What is the fundamental frequency of the pipe?

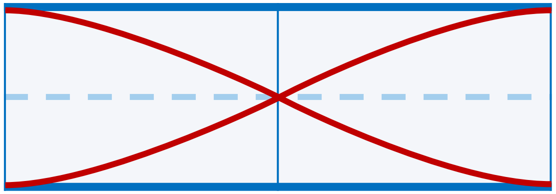
$$v = f\lambda \longrightarrow f = \frac{v}{\lambda} = \frac{341}{4.2}$$

$$f = ?$$

$$v = 341\ m\ s^{-1}$$

$$\lambda = 4.2\ m$$

$$= \boxed{\mathbf{81.2\ Hz}}$$



$$L = \frac{1}{2}\lambda \longrightarrow \lambda = 2L = 2(2.1) = 4.2\ m$$

Resonant String Practice

The note produced on a violin string of length 40 cm produces a wave speed of 250 m/s. What is the first harmonic of this note?

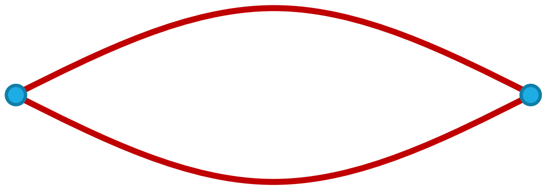
$$v = f\lambda \longrightarrow f = \frac{v}{\lambda} = \frac{250}{0.8}$$

$f = ?$

$v = 250\ m\ s^{-1}$

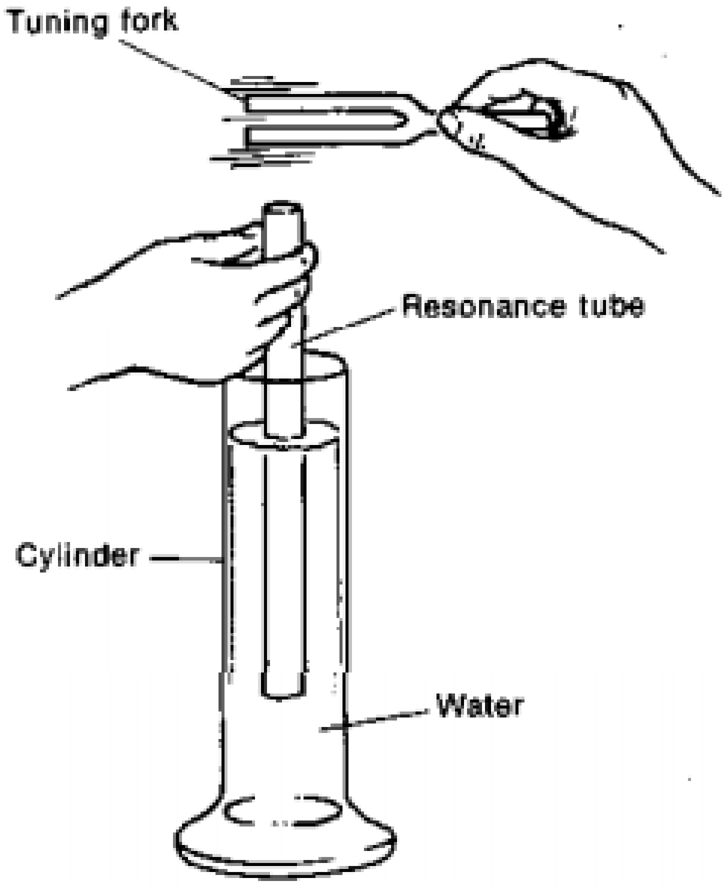
$\lambda = 0.8\ m$

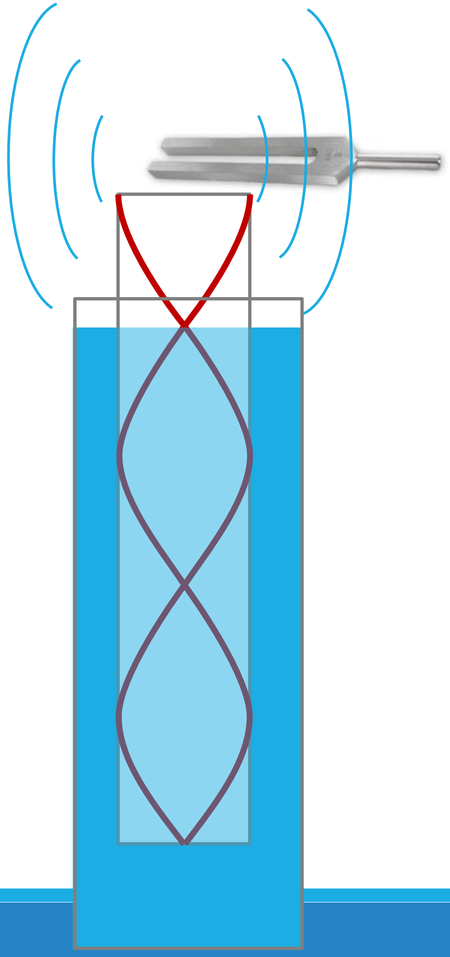
$$= \boxed{\mathbf{312.5\ Hz}}$$



$$L = \frac{1}{2}\lambda \longrightarrow \lambda = 2L = 2(0.4) = 0.8\ m$$

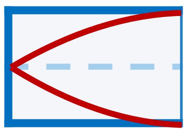
Finding Resonance





Calculating Frequency | Closed Pipes

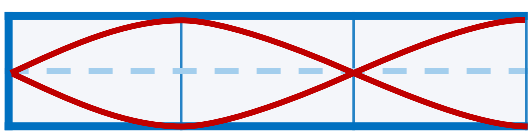
You found an unmarked tuning fork in your collection. You notice that the smallest length for resonance is **12 cm**. If the speed of sound is **345 m/s**, what is the tuning fork frequency?



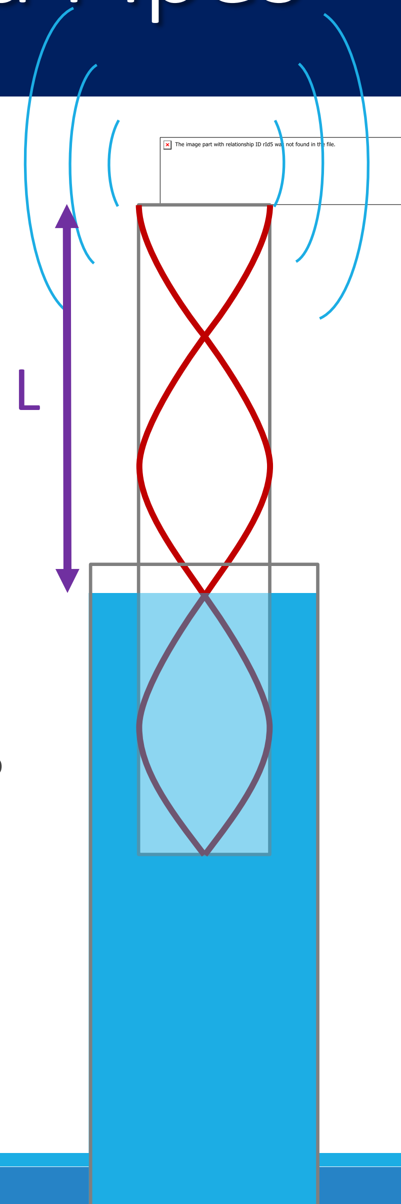
$$L = \frac{1}{4}\lambda \longrightarrow \lambda = 4L = 4(0.12) = \boxed{0.48\ m}$$

$$f = \frac{v}{\lambda} = \frac{345}{0.48} = \mathbf{718.75\ Hz}$$

What should the length of the tube be for the 2nd resonant position?



$$L = \frac{3}{4}\lambda = \frac{3}{4}(0.48) = \mathbf{0.36\ m}$$



Lesson Takeaways

- ❑ I can identify and label the node and antinodes on a standing wave diagram
- ❑ I can describe the end conditions and nodes/antinodes for open/closed pipes and vibrating strings
- ❑ I can calculate the wavelength or instrument length of a standing wave for different harmonics

Speed of Sound

IB PHYSICS | WAVES - SOUND

Speed of Sound Depends on Medium

Medium	Speed of sound (m/s)	Medium	Speed of sound (m/s)
Gases		**Liquids at 25 °C**	
Air (0 °C)	331	Water	1,490
Air (25 °C)	346	Sea water	1,530
Air (100 °C)	386	**Solids**	
Helium (0 °C)	972	Copper	3,813
Hydrogen (0 °C)	1,290	Iron	5,000
Oxygen (0 °C)	317	Rubber	54

Air (25 °C)

760 mph

0.21 miles/sec

Speed of Sound for Air (at any temp)

$$v = 331\ \mathrm{m\ s^{-1}} + 0.6 \times (\text{Temp in °C})$$

Speed of Sound Depends on Medium

Why does Medium Affect Speed?

Medium	Speed of sound (m/s)	Medium	Speed of sound (m/s)
Gases		**Liquids at 25 °C**	
Air (0 °C)	331	Water	1,490
Air (25 °C)	346	Sea water	1,530
Air (100 °C)	386	**Solids**	
Helium (0 °C)	972	Copper	3,813
Hydrogen (0 °C)	1,290	Iron	5,000
Oxygen (0 °C)	317	Rubber	54

molecule spacing

iron

air

Do other factors increase speed?

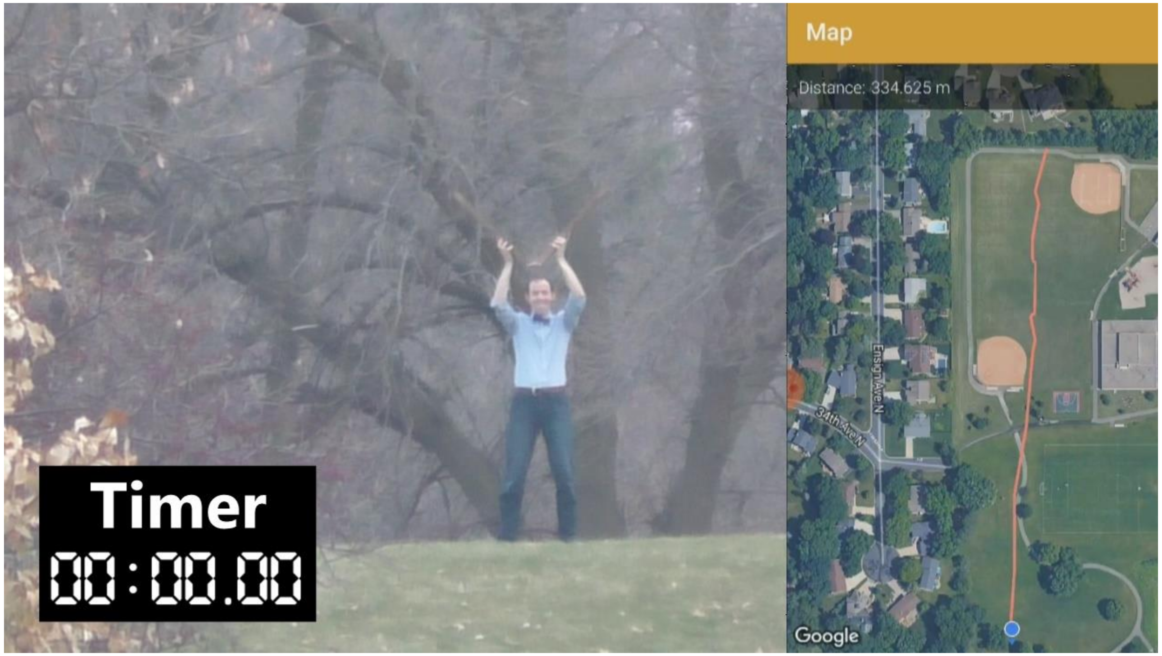
Frequency? No

$$v = f \times \lambda \qquad v = f \times \lambda$$

Amplitude? No

*Independent from all other wave properties

Sound is fast, but not THAT fast…



$$d = 335\ \mathrm{m}$$

$$t = 0.935\ \mathrm{s}$$

$$v = \frac{d}{t} = \frac{335\ \mathrm{m}}{0.935\ \mathrm{s}} = \mathbf{358\ m\ s^{-1}}$$

Using the Speed of Sound

You see lightning strike and immediately start counting, once you get to 7 seconds, you hear the boom of thunder. How far away is the storm?

Air (25 °C)

346 m/s

760 mph

0.21 miles/sec

$$d = vt = (0.21)(7)$$

$$= \mathbf{1.47\ miles}$$

Shortcut for Clocking a Storm

As soon as you see lightning strike, start counting...

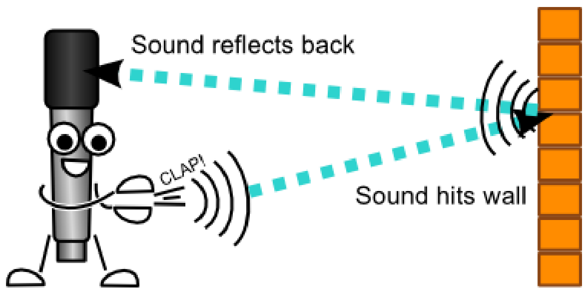
One one thousand, Two one thousand...

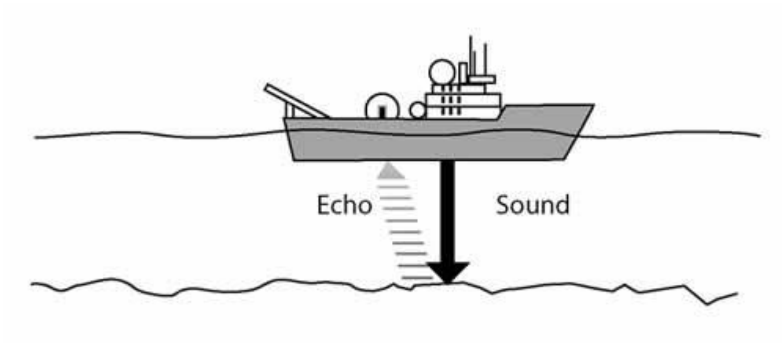
Stop counting as soon as you hear the thunder from that bolt of lightning

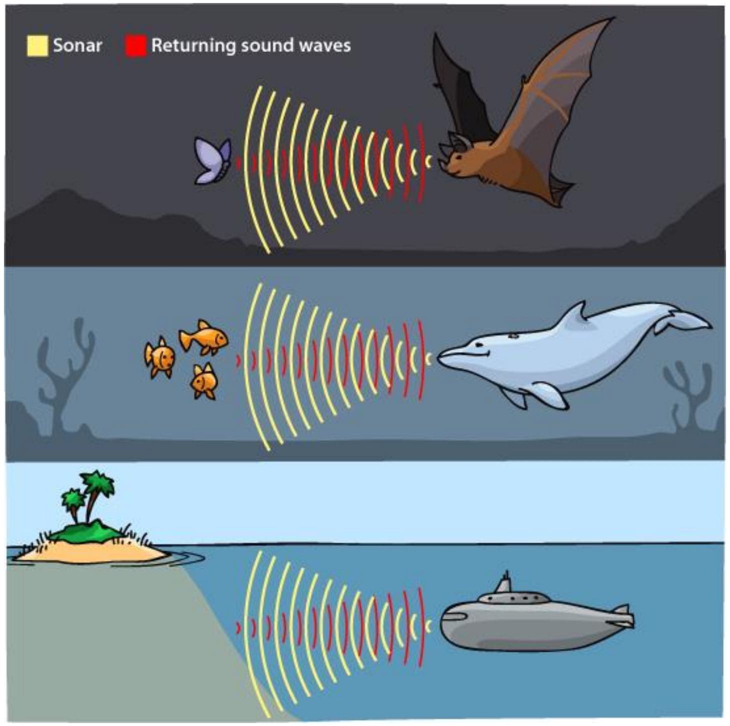
Distance in Miles = Time / 5

ECHO…. Echo…. Echo….

When you hear an echo, you are hearing the sound after it has reflected off of an object and returned to your ear







Calculating Distance from an Echo

A saxophonist plays a duet with himself using the echo of the sound in a long pipe. If the speed of sound is 340 m/s and echo returns 1.3 seconds after the original sound, how long is the pipe?

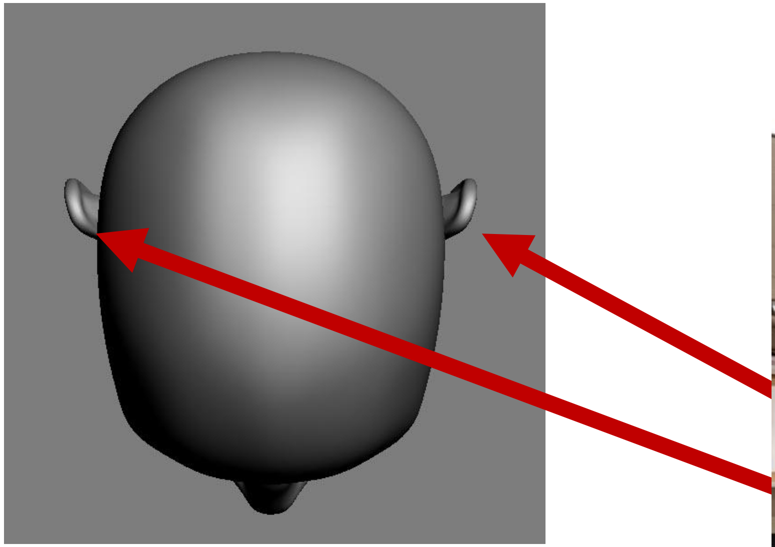
$$v = \frac{d}{t}$$

Only half the time to go one way

$$d = vt = (340)(0.65) = \mathbf{221\,m}$$

How do we locate sounds?

Sound reaches one ear before the other. It also sounds different from different locations due to the shape of our ears.



Lesson Takeaways

- ❑ I can describe why sound travels at different speeds in different media
- ❑ I can calculate how far a distant object is by timing an echo

6

Wave Interference

IB PHYSICS | WAVES - SOUND

Interference

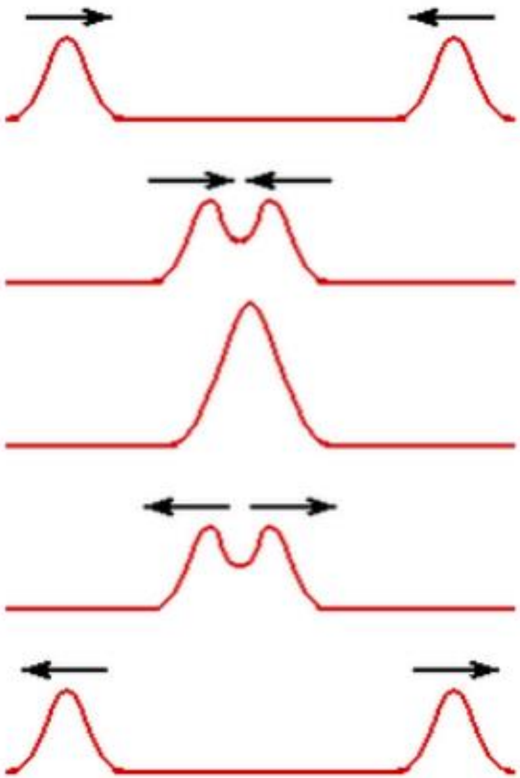
When several waves are in the same location, they combine to produce a new wave that is different from the original waves.

After waves pass by one another continue on

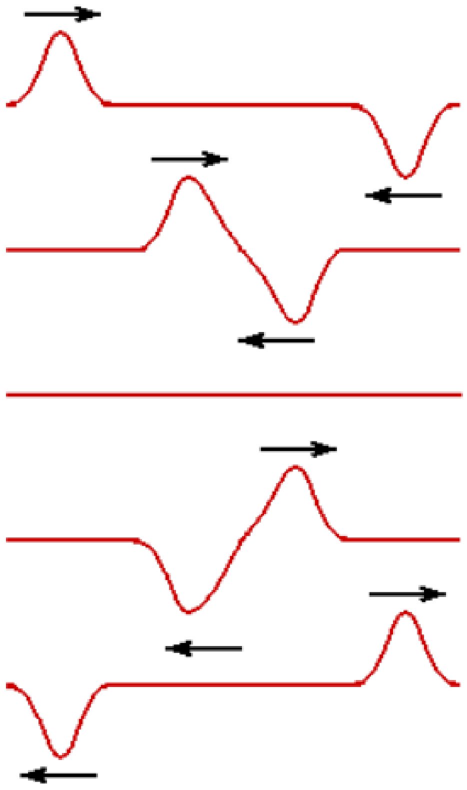
__unchanged__

Name that Interference

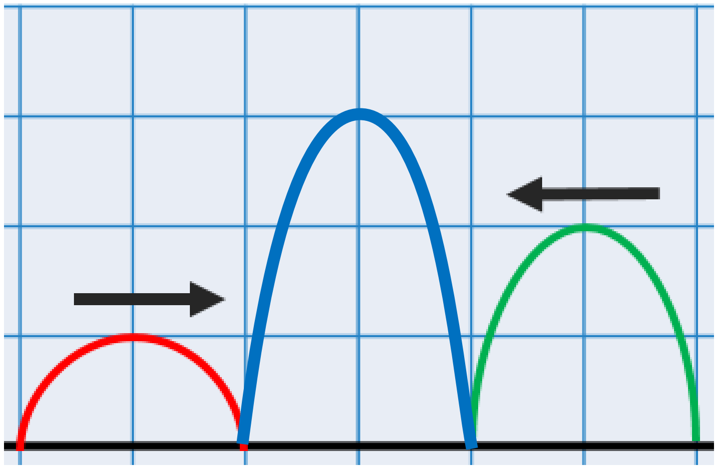
Constructive Interference

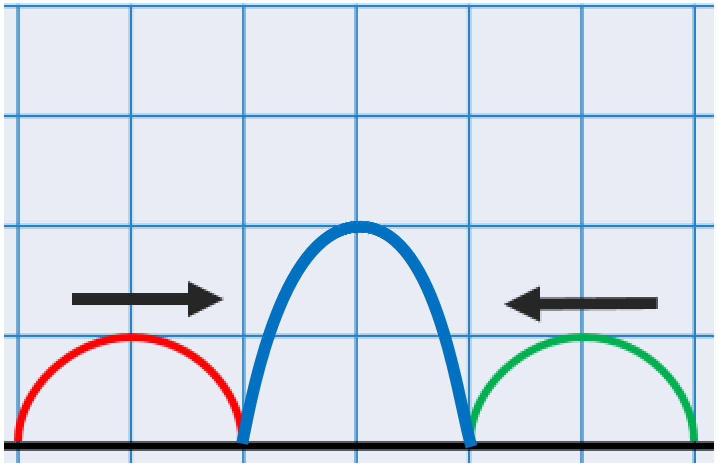


Destructive Interference

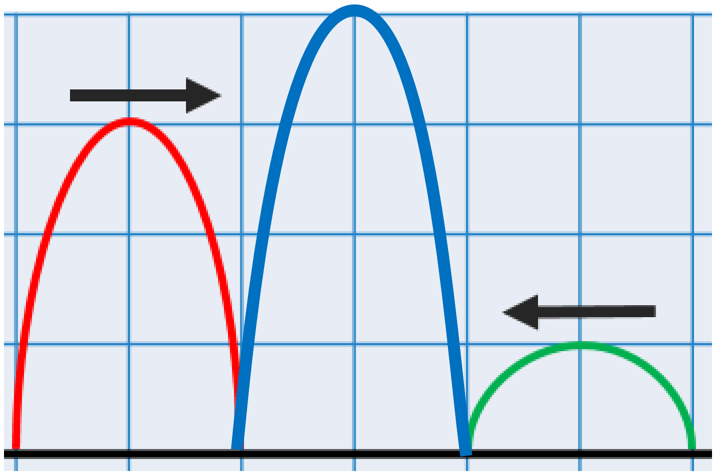


Constructive Interference

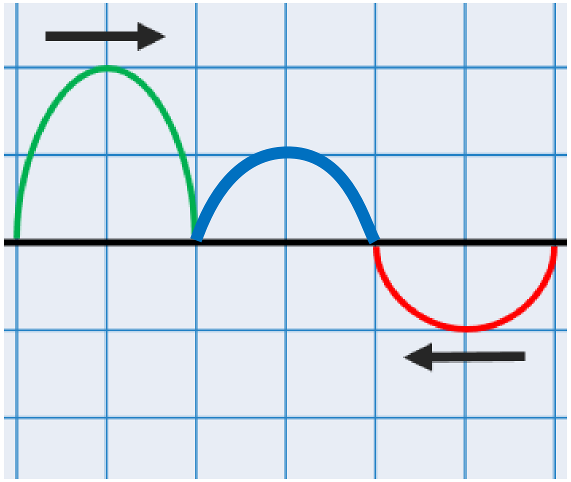


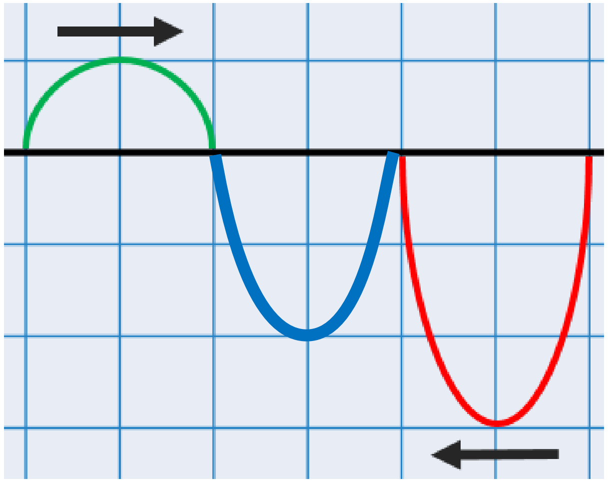


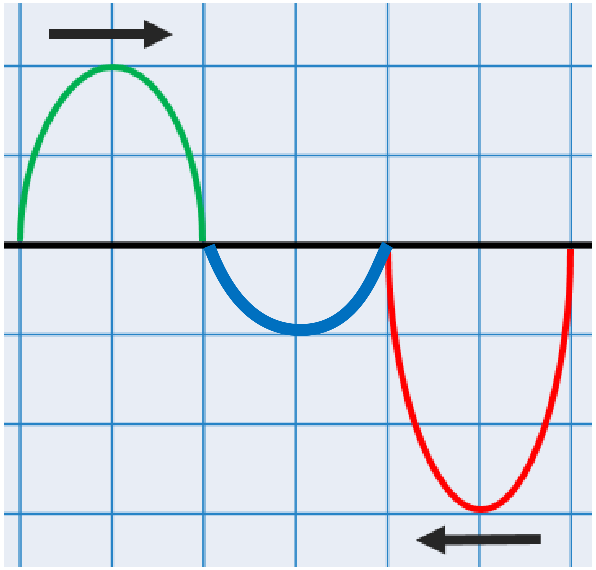
What is the resulting amplitude when these waves meet?



Destructive Interference

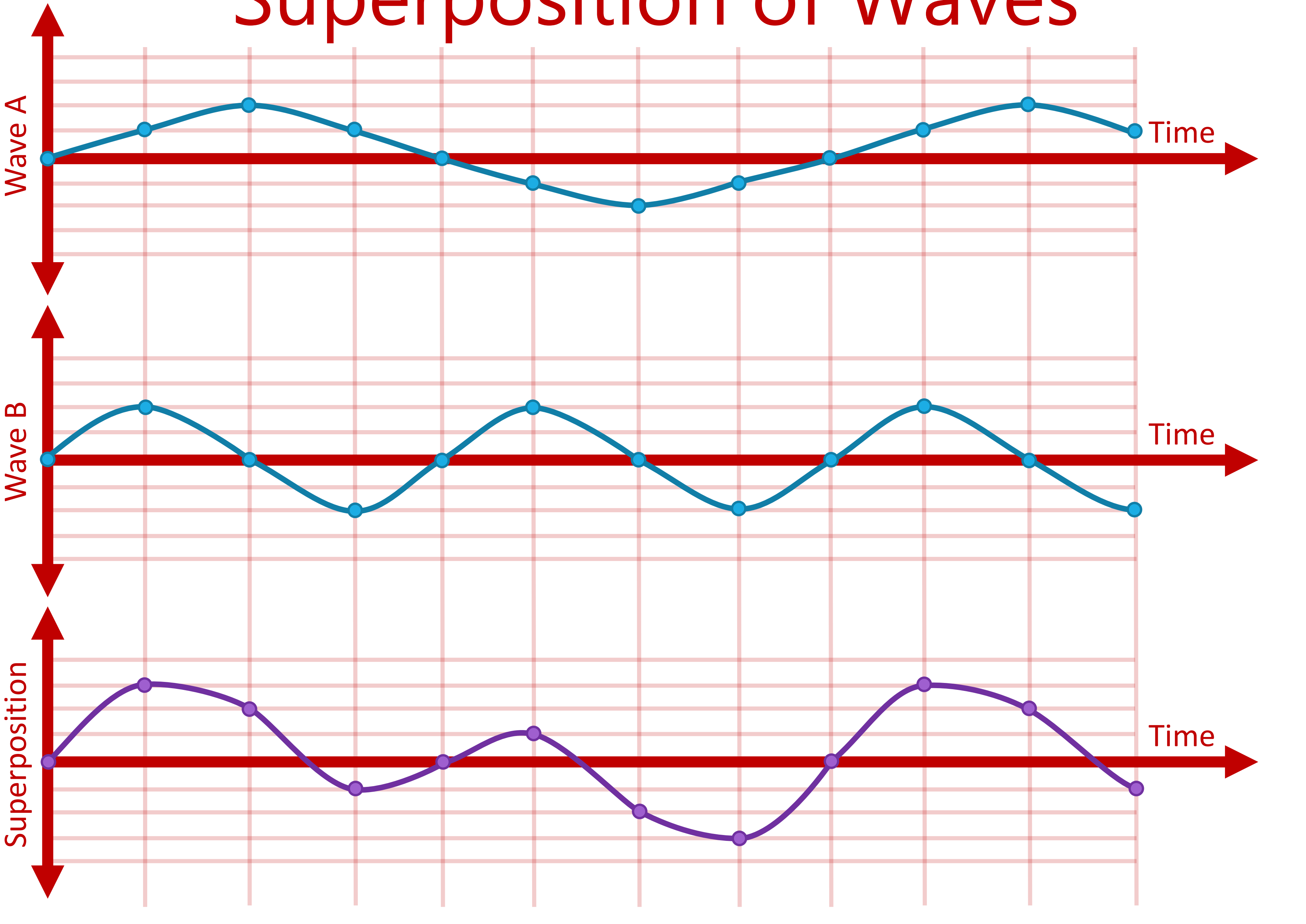






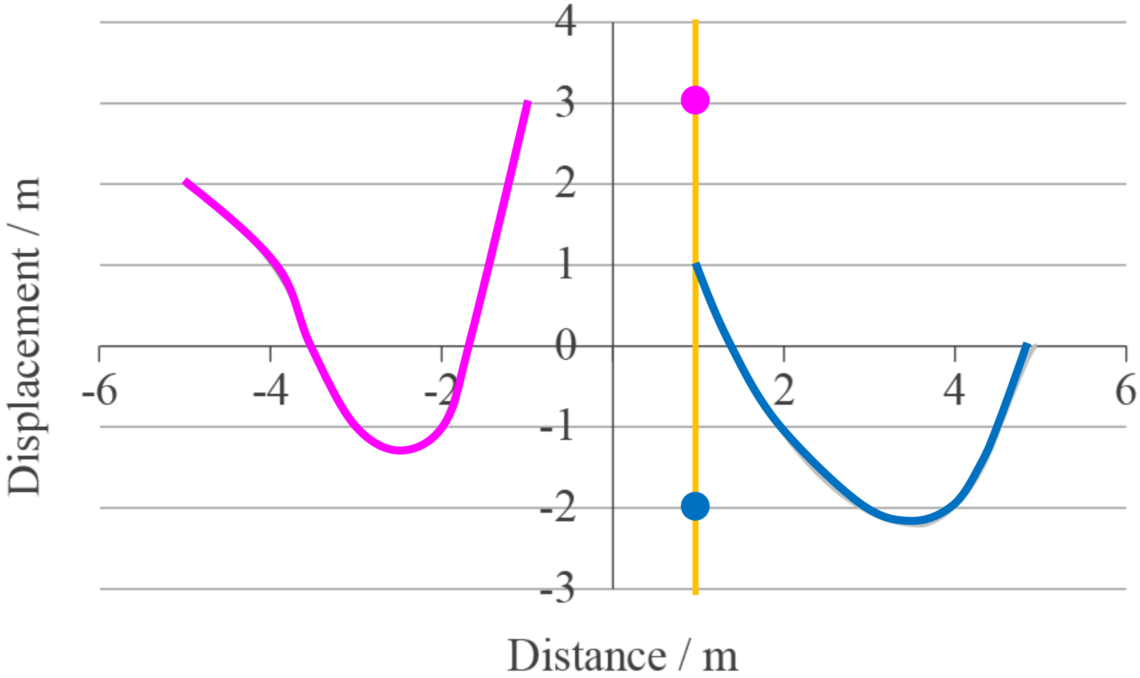
What is the resulting amplitude when these waves meet?

Superposition of Waves



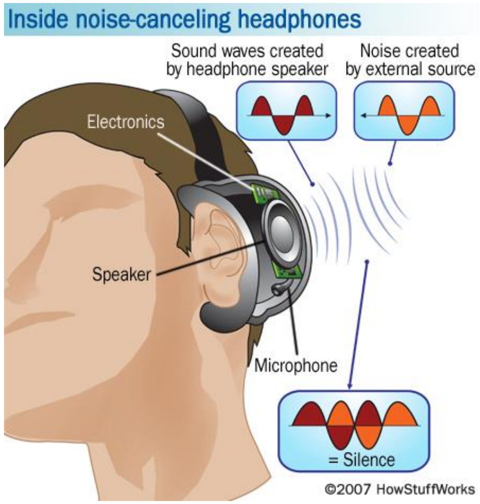
IB Sample Question

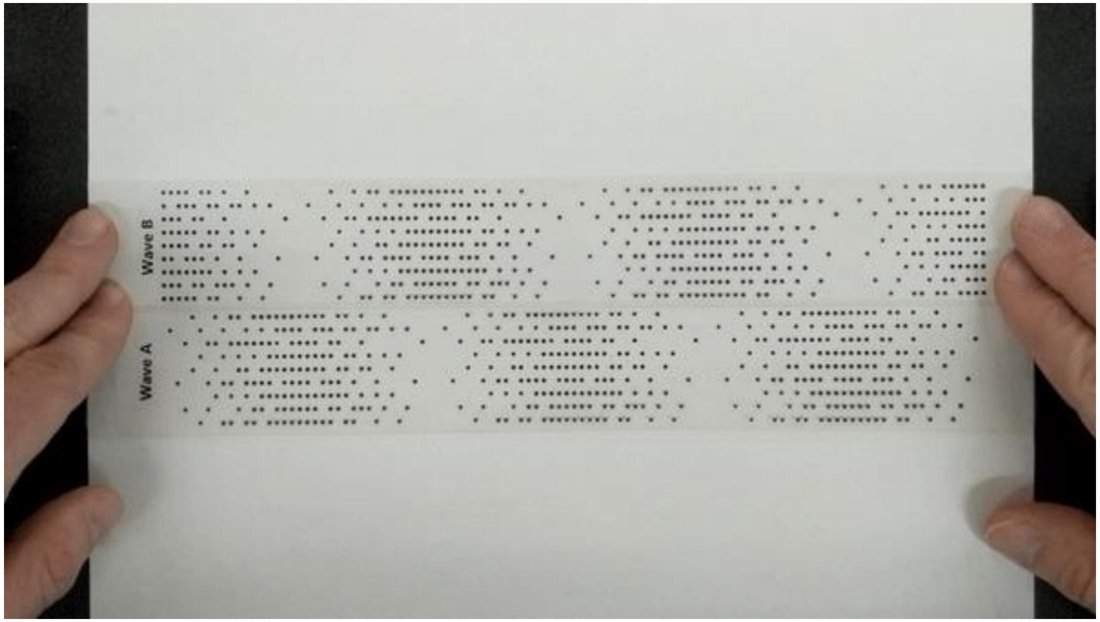
Both the waves below are moving at 0.5 m s^{-1} towards each other. What is the displacement at a distance of 1 m, after 4 s has passed?



$(+3) + (-2) = \mathbf{+1}$

Noise Canceling Headphones



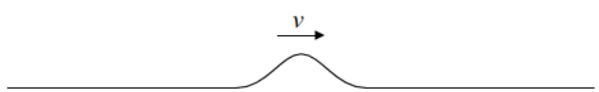


IB Sample Question

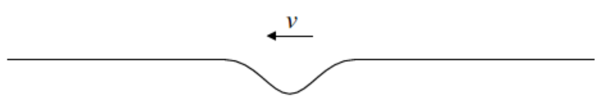
15. Two wave pulses travel along a string towards each other. The diagram shows their positions at a moment in time.

Which of the following shows a possible configuration of the pulses at a later time?

A.



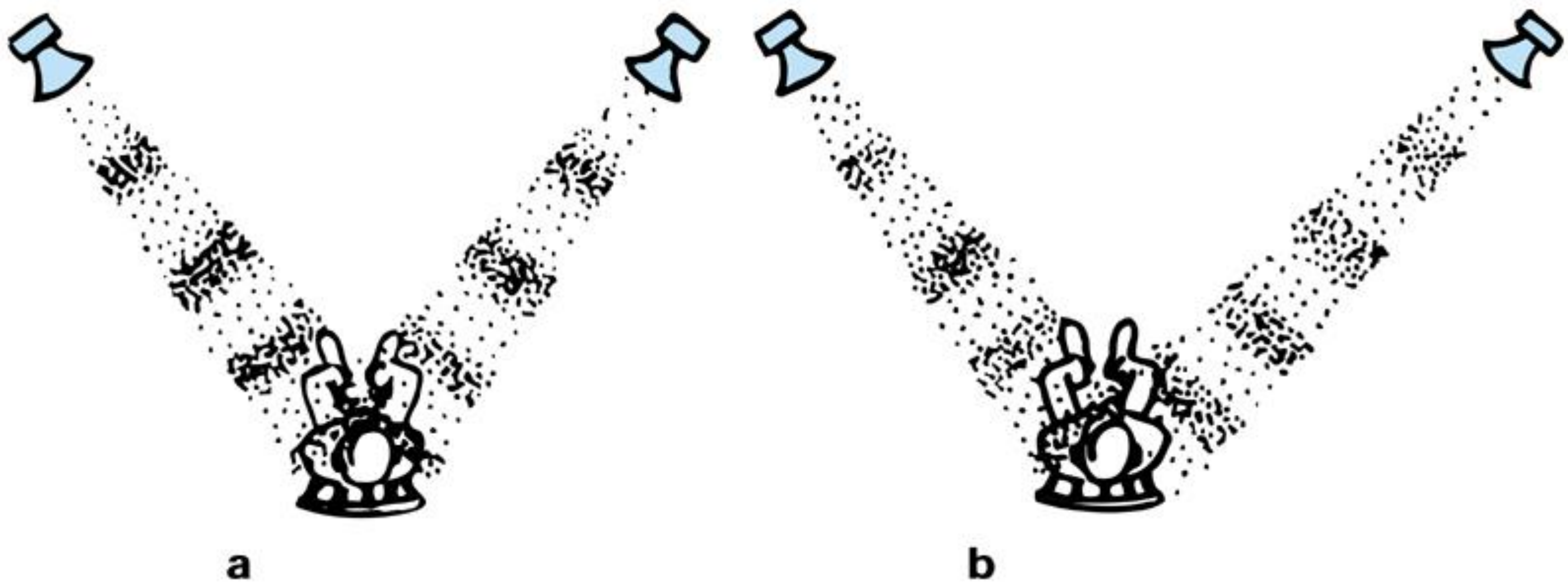
B.



C.

D.

Interference from Multiple Sources



Constructive

Destructive

1D Sound Interference

Path Difference = 0.5λ

0λ	0.5λ	1λ	1.5λ	2λ	2.5λ	
✓		✓		✓		Constructive
	✓		✓		✓	Destructive

Path Difference = $n\lambda$

Path Difference = $(n + \frac{1}{2})\lambda$

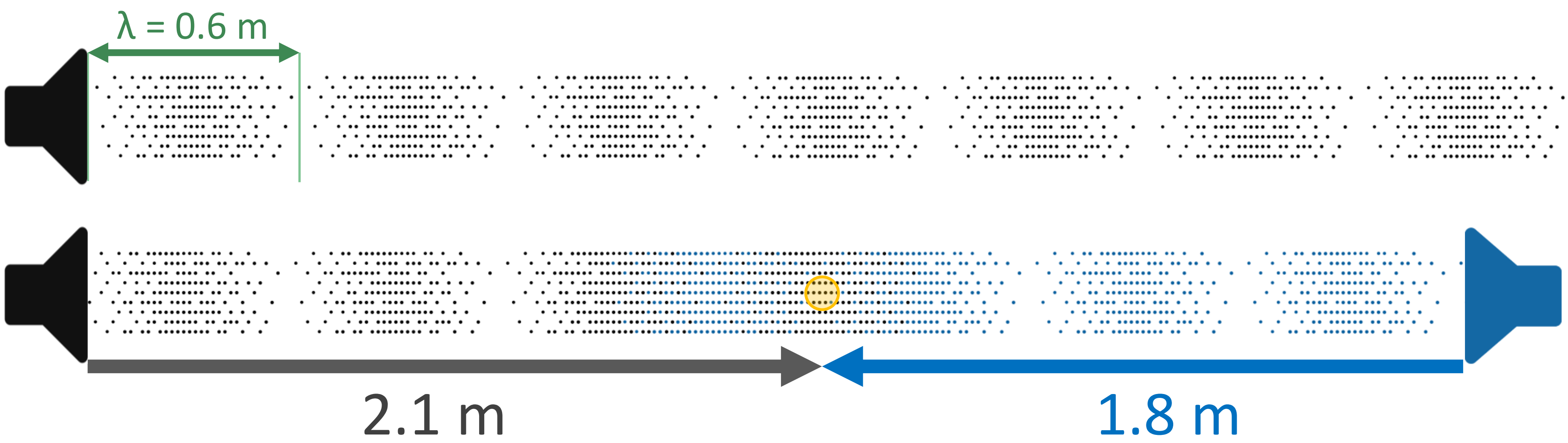
*n is any integer

These are known as "**coherent waves**" because they have the same frequency and a constant phase difference

IB Physics Data Booklet

Sub-topic 4.1 – Oscillations	Sub-topic 4.4 – Wave behaviour
$T = \frac{1}{f}$	$\frac{n_1}{n_2} = \frac{\sin\theta_2}{\sin\theta_1} = \frac{v_2}{v_1}$
Sub-topic 4.2 – Travelling waves	$s = \frac{\lambda D}{d}$
$c = f\lambda$	Constructive interference: path difference $= n\lambda$
Sub-topic 4.3 – Wave characteristics	Destructive interference: path difference $= (n + \frac{1}{2})\lambda$
$I \propto A^2$	
$I \propto x^{-2}$	
$I = I_0 cos^2\,\theta$	

Finding a Minimum



Path Difference = 2.1 – 1.8 = 0.3 m

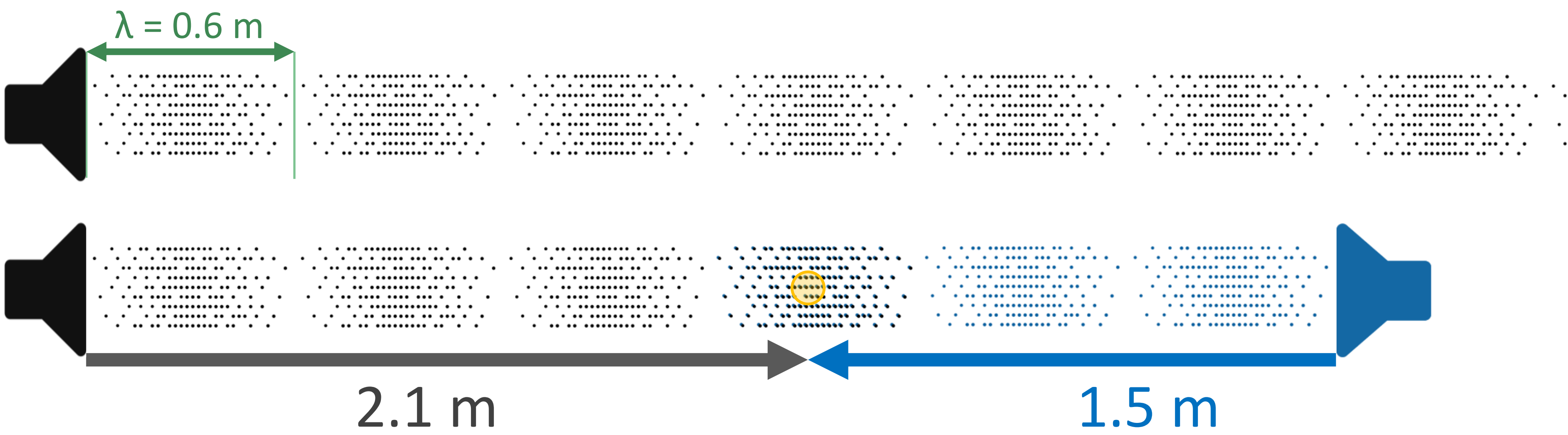
Constructive | Path Difference = $n\lambda$

Destructive | Path Difference = $(n + \frac{1}{2})\lambda$

Path Difference = (   ) × λ

0.3 m = (0.5) × 0.6 m

Finding a Maximum



Path Difference = 2.1 – 1.5 = 0.6 m

Path Difference = (   ) × λ

0.6 m = (1) × 0.6 m

Constructive | Path Difference = $n\lambda$

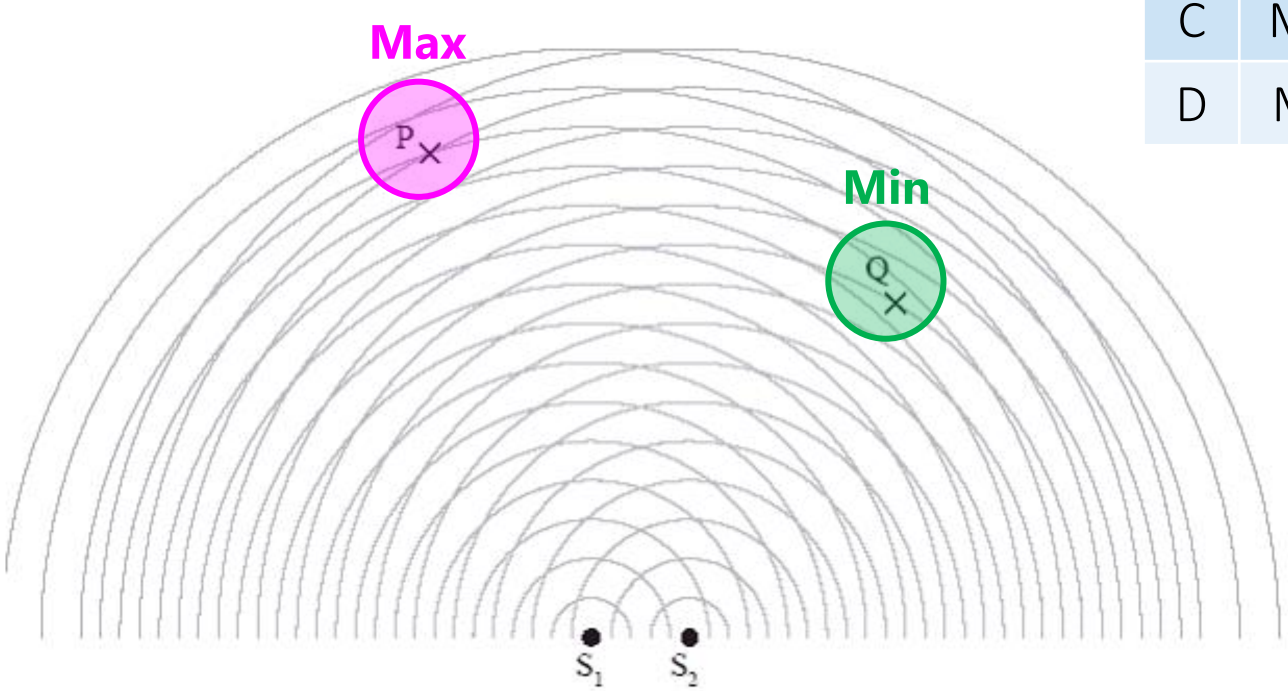
Destructive | Path Difference = $(n + \frac{1}{2})\lambda$

Try This

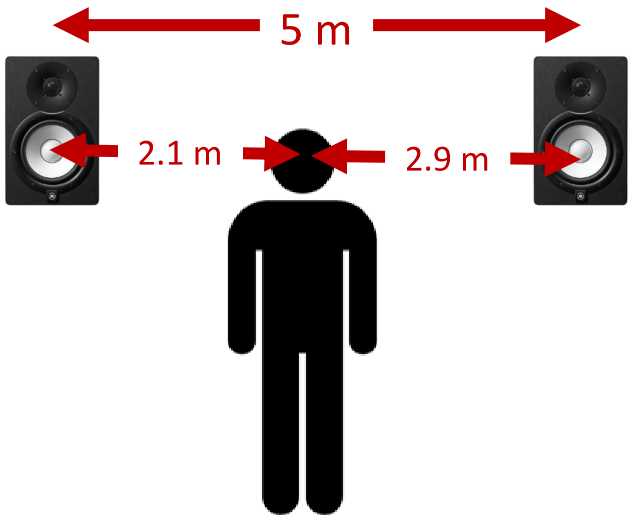
Two coherent point sources S_1 and S_2 emit spherical waves.

Which of the following best describes the intensity of the waves at P and Q?

	P	Q
A	Maximum	Minimum
B	Minimum	Maximum
C	Maximum	Maximum
D	Minimum	Minimum



Try this #1



Two speakers are separated by a distance of 5 meters, if they emit a coherent sound signal of 850 Hz. If the speed of sound is 340 m s^{-1}, is this person in a maximum or minimum location?

$$v = f\lambda$$

$$\lambda = \frac{v}{f} = \frac{340}{850} = 0.4\,m$$

Path Difference

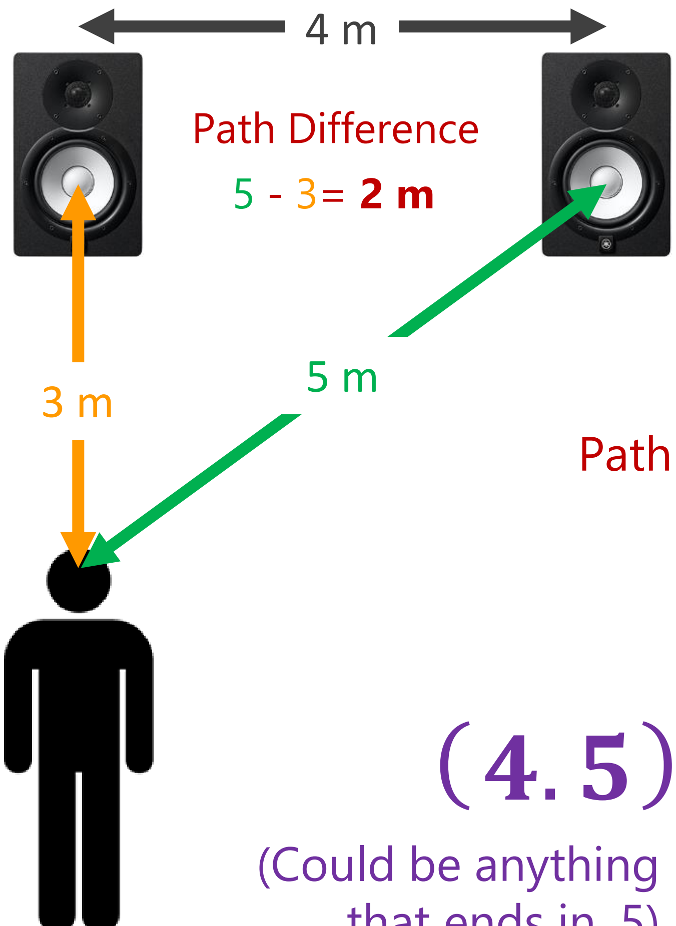
2.9 – 2.1 = **0.8 m**

Path Difference = (___) × λ

$$\frac{0.8}{0.4} = \mathbf{2}$$

Maximum because result is a perfect integer

Try This #2



If these speakers are playing a note with a frequency of 680 Hz, is this person standing at a maximum or minimum spot? Assume a speed of sound of 340 m s^{-2}

$$\lambda = \frac{v}{f} = \frac{340}{680} = 0.5\ m$$

Path Diff. = (   ) × λ

$$\frac{2}{0.5} = 4$$

Maximum because result is a perfect integer

What frequency would result in the opposite effect?

$$(4.5) = \frac{2\text{ m}}{\lambda}$$

(Could be anything that ends in .5)

$$\lambda = 0.44\text{ m}$$

$$f = \frac{v}{\lambda} = \frac{340}{0.44} = \mathbf{773\ Hz}$$

Lesson Takeaways

- ❑ I can qualitatively and quantitatively interpret cases of constructive and destructive interference
- ❑ I can add up two waves with superposition to create a new waveform
- ❑ I can use wavelength and source distance to identify maxima and minima for interference