Harmonic Motion

Harmonic Motion is motion that repeats itself, oscillating back and forth. Eventually it will lose energy (called dampening) and come to rest in the middle, known as its equilibrium position.

Amplitude (A in m, cm, or degrees): maximum distance or angle from the equilibrium (center) position. Wider swing = more energy = more amplitude.

Period (T in sec): length of time for one cycle; how long it takes for one repetition. A slower object has a bigger (longer) period.

Cycle: the repeated part of the motion; must include all of the steps of the motion.

Frequency (f in Hz): number of cycles per second. Motion that repeats more often is more frequent and has a higher frequency.

Harmonic Motion Basics

Amplitude never affects period or frequency! A pendulum with more amplitude moves fast, but travels a long distance. A pendulum with less amplitude moves slow, but only travels a small distance. Either way, the period is the same.

Harmonic Motion Graphs

Imagine a pen attached to the bottom of a pendulum. If a piece of paper is moved beneath the pendulum as it swings, a harmonic motion graph is drawn.

Cycle—from any point on the line to that same point going the same way. This graph shows 2 complete cycles.

Period—measure the time for one cycle between any two identical points on the graph (top-to-top, bottom-to-bottom, etc.).

Frequency—count the number of cycles in 1 second OR find the period and use f = 1/T.

Amplitude—measure the total distance from side-to-side (or top-to-bottom) and divide by two OR measure the distance from the equilibrium position (halfway between the peaks) to one of the peaks.

Position vs. Time

<table>
<thead>
<tr>
<th>Period (in secs)</th>
<th>T = 1 cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>T = 1 sec</td>
<td></td>
</tr>
<tr>
<td>T = 1/2 sec</td>
<td></td>
</tr>
<tr>
<td>T = 1/4 sec</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Frequency (in hertz)</th>
<th>T = 1/f</th>
</tr>
</thead>
<tbody>
<tr>
<td>f = 1 Hz</td>
<td></td>
</tr>
<tr>
<td>f = 2 Hz</td>
<td></td>
</tr>
<tr>
<td>f = 4 Hz</td>
<td></td>
</tr>
</tbody>
</table>

Amplitude is 1/2(side-to-side) = 1/2(3+3) = 1/2(6) = 3 cm

End of 1st cycle = period (T) = 1 sec
1 cycle in 1 sec = frequency (f) = 1 Hz
Harmonic Motion: Yes or No?

<table>
<thead>
<tr>
<th></th>
<th>Pendulum:</th>
<th>A bouncing ball:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ocean waves:</td>
<td></td>
<td>A ruler pulled from one side and released:</td>
</tr>
<tr>
<td>A child on a swing:</td>
<td></td>
<td>A person jumping up and down:</td>
</tr>
<tr>
<td>Jumping Jacks:</td>
<td></td>
<td>A spinning ball:</td>
</tr>
<tr>
<td>Bouncing spring:</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Period, Frequency, or Amplitude?

- Doesn’t change period.
- More of this means more energy.
- Increases as a pendulum swings back and forth faster.
- Measured in cycles per second.
- Measured in meters or centimeters.
- This decreases with a smaller swing.
- If the frequency increases, this decreases.
- Measured in Hertz.
- Measured in seconds.
- 4. If it swings back and forth slower, this decreases.
- 5. As it dampens, this decreases.

A moving spring

- Where is its equilibrium position?

If the spring starts at position A, how much of a cycle does it complete from A to C?

If the spring moves 10 cm from C to A (side to side), how big is its amplitude?

Position vs. Time

1 cycle after A is ___; 2 cycles after D is ___.
1/2 cycle after G is ___; 1/4 cycle before M is ___.
# of complete cycles shown is ___.
Period (T) = ___  Frequency (f) = ___
Equilibrium position = ___  Amplitude (A) = ___

Mark 1 cycle of the harmonic motion.
Starting at 1.5 secs, when does the 2nd cycle end:
Number of cycles shown is ___.
Period (T) = ___  Frequency (f) = ___
Equilibrium position = ___  Amplitude (A) = ___
Which of these is Harmonic Motion?

<table>
<thead>
<tr>
<th>Pendulum:</th>
<th>Y</th>
<th>A bouncing ball:</th>
<th>N</th>
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<td>N</td>
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</tbody>
</table>

1. Period D
2. Equilibrium position F
3. Amplitude C
4. Damping G
5. Frequency A
6. Cycle E
7. Hertz B

A. The number of cycles per second.
B. A unit of one cycle per second.
C. The size or strength of a cycle.
D. Time it takes to complete one cycle.
E. A part of motion that repeats over and over with a set series of events.
F. Halfway between the two sides and where the motion comes to rest.
G. The motion dying out over time.

**Period, Frequency, or Amplitude?**

- A. Doesn’t change period.
- B. More of this means more energy.
- C. Increases as a pendulum swings back and forth faster.
- D. Measured in cycles per second.
- E. Measured in meters or centimeters.
- F. Measured in Hertz.
- G. Measured in seconds.
- H. If the frequency increases, this decreases.
- I. As it dampens, this decreases.

If the pendulum starts at C going to the right, where does 1 cycle end? C going right.

From letter A to letter C, would be the amplitude or C to E.

If the pendulum starts at A, how many times does it pass point C in 1 cycle? Two times.

An spring has a period of 4 seconds. What is its frequency?

\[ T = \frac{1}{4} \text{ sec} \]  \[ f = \frac{1}{T} = \frac{1}{4} = 0.25 \text{ Hz} \]

A pendulum has a frequency of 3 Hz. What is its period?

\[ f = 3 \text{ Hz} \]  \[ T = \frac{1}{f} = \frac{1}{3} = 0.33 \text{ sec} \]

A pendulum takes 10 seconds to complete 2 cycles.

A) What is its period? \[ 5 \text{ sec} \]
B) What is its frequency?

\[ f = \frac{1}{5} = 0.2 \text{ Hz} \]

Where is its equilibrium position?

2 T B

If the spring starts at position A, how much of a cycle does it complete from A to C? Half cycle

If the spring moves 10 cm from C to A (side to side), how big is its amplitude? 5 cm

**Position vs. Time**

1 cycle after A is E: 2 cycles after D is I:

1/2 cycle after G is J: 1/4 cycle before M is J.

# of complete cycles shown is 3.

Period (T) = 1 sec  Frequency (f) = \[ \frac{1}{T} = 1 \text{ Hz} \]

Equilibrium position = 0 cm  Amplitude (A) = 6 cm

Mark 1 cycle of the harmonic motion.

Starting at 1.5 secs, when does the 2nd cycle end? 1.5 sec

Number of cycles shown is 2.5 cycles.

Period (T) = 2.5 sec  Frequency (f) = \[ \frac{1}{T} = \frac{2.5}{2.5} = 0.83 \text{ Hz} \]

Equilibrium position = 1 cm  Amplitude (A) = 3 cm
Waves are harmonic motion that moves thru a medium (matter). Water is the medium for water waves; a slinky is the medium when you shake a slinky. The particles in the medium vibrate, but do not move. Only the energy of the wave moves, transferring the energy. This is why waves seem to go thru things, like sound moving thru air.

### Types of Waves

**Longitudinal (compression) waves** vibrate parallel to (same direction as) the direction of motion. Sound is a longitudinal wave: a speaker vibrates in and out pushing the sound forward. Only longitudinal waves can move thru fluids (liquids and gases).

**Transverse waves** vibrate perpendicular (90º) to the direction of motion. Because the energy moves forward while the vibration is up and down, water waves look like transverse waves, but are actually surface waves, which occur between materials (air and water).

### Wavelength (λ)

The wavelength—λ [lambda] (in m) is the length of one wave between any two identical points on the wave (crest-to-crest or trough-to-trough, etc).

### Wave Speed (v)

Because waves move, it is obvious that they must have a speed. However, you may be surprised to know that amplitude, frequency, and wavelength don’t change speed: only the medium it travels thru.

The speed of a wave changes only if the medium changes. Sound moves faster in more elastic substances. Sound is faster in colder water and in solids (rather than liquids) because the molecules are closer. The wave on a slinky moves faster if the slinky is pulled tighter. Yet, if the medium stays the same, the speed stays the same. Different waves will have the same speed in the same medium.

**Closer Molecules—Faster Wave**

- A push: giving energy (starts the wave)
- Close dominos will fall quickly because they hit each other quickly.

**Faster: Tighter Solids**

**Slower: Looser Liquids**

**More Distant Molecules—Slower Wave**

- Dominos that are farther apart will fall slower because they take more time to hit each other.

### Earthquakes (seismic waves)

Earthquakes are made up of both types of waves. Longitudinal waves are the fastest and hit first, so they are called primary waves (P waves). Transverse (T) waves are slower, but do more damage because the up and down break thing by shearing (cutting), so are called S-waves. Only the P waves travel thru the earth’s center, which proves the earth has a liquid center.
1. Transverse wave
   A. A wave where the oscillation is perpendicular to the direction of motion.

2. Longitudinal wave
   B. The bottom of a wave.
   C. The top of a wave.

3. Crest
   D. A wave where the oscillation is in the same direction (parallel) as the motion.

4. Trough
   E. The length of one wave cycle.

5. Wavelength

Wave Motion, Yes or No?

FM radio: ________________  Music: ________________
A car going 70 m/s: ________  A bulldozer: ______________
Clock pendulum: __________  Earthquakes: ______________
Ocean waves: _____________  Cellphones: ______________

Transverse or Longitudinal Waves?
A. _____ You move the slinky left and right.
B. _____ You push the slinky forward.
C. _____ Sound, if a radio’s speaker moves in and out.
D. _____ Earthquakes.
E. _____ Vibrates up and down and moves to the right.

A wave is 8 meters long and has a frequency of 3 Hz. Find speed.

Wave A has a wavelength of 2 meters and a frequency of 1.5 Hz. Calculate the wave’s speed.

Wave B has a frequency of 18 Hz in the same medium. What is Wave B’s speed?

Calculate Wave B’s wavelength.

So, as f increases in the same medium, λ ______________.

Displacement vs. Position

Mark 1 cycle of the wave.
Starting at 0.75 m, where does the 2nd cycle end:
Number of complete cycles: ________
Wavelength: ________
Amplitude: ________
If f = 4 Hz, find speed:

Displacement vs. Position

Mark 1 cycle of the harmonic motion.
Starting at 1.5 secs, when does half a cycle end:
Number of complete cycles: ________
Number of troughs: ________
Wavelength: ________
Amplitude: ________
If f = 50 Hz, find speed:

f is the variable for ___________ and is measured in _____.
λ is the variable for ___________ and is measured in _____.
T is the variable for ___________ and is measured in _____.
v is the variable for ___________ and is measured in _____.

Which number shows:
A. _____ Double the amplitude
B. _____ Amplitude
C. _____ Wavelength
D. _____ Half λ

Faster or slower wave speed?
A. _____ The medium gets colder.
B. _____ The amplitude gets bigger.
C. _____ A slinky gets looser.
D. _____ The medium turns from solid to liquid.
E. _____ The wavelength gets shorter.

Wave 1: f = 25 Hz; Wave 2: f = 40 Hz. Which one will be faster in water?

Which number shows:
A. _____ Double the amplitude
B. _____ Amplitude
C. _____ Wavelength
D. _____ Half λ
### Unit 10: Waves

#### Wave Motion, Yes or No?

<table>
<thead>
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</tr>
<tr>
<td>Cellphones</td>
<td>Yes</td>
</tr>
</tbody>
</table>

#### Transverse or Longitudinal Waves?
- You move the slinky left and right: Transverse
- You push the slinky forward: Longitudinal
- Sound, if a radio’s speaker moves in and out: Transverse
- Both Earthquakes: Longitudinal
- Vibrates up and down and moves to the right: Transverse

#### Faster or slower wave speed?

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<th>Speed of Wave</th>
<th>Explanation</th>
</tr>
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<td>Faster</td>
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</tr>
<tr>
<td>Slower</td>
<td>The amplitude gets bigger.</td>
</tr>
<tr>
<td>Slower</td>
<td>A slinky gets looser.</td>
</tr>
<tr>
<td>Faster</td>
<td>The medium turns from solid to liquid.</td>
</tr>
<tr>
<td>Slower</td>
<td>The wavelength gets shorter.</td>
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</table>

#### Wave 1: f = 25 Hz, Wave 2: f = 40 Hz. Which one will be faster in water?

```
<table>
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<tr>
<th>Speed of Wave</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Same</td>
<td>Both waves move with the same speed.</td>
</tr>
<tr>
<td>Wave 2</td>
<td>Wave 2 will have shorter wavelength.</td>
</tr>
</tbody>
</table>
```

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**Wave Equation:**

\[
\text{Speed} = \text{Frequency} \times \text{Wavelength} = f \lambda
\]

**Sample Problems:**

1. **A wave is 8 meters long and has a frequency of 3 Hz. Find speed.**
   - \[v = f \lambda = 3 \times 8 = 24 \text{ m/s}\]

2. **A wave has a wavelength of 2 meters and a frequency of 1.5 Hz. Calculate the wave's speed.**
   - \[v = f \lambda = 1.5 \times 2 = 3 \text{ m/s}\]

3. **If a second wave with a frequency of 18 Hz enters the same medium, what will its speed be?**
   - \[v = f \lambda = 3 \times 18 = 54 \text{ m/s}\]

4. **Calculate the second wave's wavelength.**
   - \[\lambda = \frac{v}{f} = \frac{54}{3} = 18 \text{ m}\]

5. **Mark 1 cycle of the wave.**
   - Starting at 0.75 m, where does the 2nd cycle end? 2.75 m
   - Number of complete cycles: 4
   - Mark the third crest.
   - Wavelength: 1 m
   - Amplitude: 2 m
   - If \( f = 4 \text{ Hz} \), find speed: \( v = f \lambda = 4 \times 1 = 4 \text{ m/s} \)
   - If \( f = 50 \text{ Hz} \), find speed: \( v = f \lambda = 50 \times 1 = 100 \text{ m/s} \)

---

**Displacement vs. Position**

Mark 1 cycle of the wave.
- Starting at 0.75 m, where does the 2nd cycle end? 2.75 m
- Number of complete cycles: 4
- Mark the third crest.
- Wavelength: 1 m
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- If \( f = 4 \text{ Hz} \), find speed: \( v = f \lambda = 4 \times 1 = 4 \text{ m/s} \)
- If \( f = 50 \text{ Hz} \), find speed: \( v = f \lambda = 50 \times 1 = 100 \text{ m/s} \)

---

**Displacement vs. Position**

Mark 1 cycle of the harmonic motion.
- Starting at 1.5 secs, when does half a cycle end? 2.5 m
- Number of complete cycles: 2
- Number of troughs: 2
- Wavelength: 2 m
- Amplitude: 3 m
- If \( f = 4 \text{ Hz} \), find speed: \( v = f \lambda = 4 \times 2 = 8 \text{ m/s} \)
- If \( f = 50 \text{ Hz} \), find speed: \( v = f \lambda = 50 \times 2 = 100 \text{ m/s} \)
Teacher explanation:

A teacher asked me some questions that he and I thought would help everyone.

Teacher:
I noticed that on the Waves worksheet you state in your answer key that a clock pendulum is not an example of wave motion. Can you explain why not?

Me:
A pendulum is an example of oscillating, or repeating, motion. Wave motion requires the energy to move, like a water wave or sound. The pendulum doesn't move anywhere. Also, circular motion isn't harmonic either. It repeats, but doesn't follow a path through the "equilibrium position". For a pendulum, the equilibrium position is where it comes to rest.

Teacher:
That makes sense when you talk about energy moving. Initially I was thinking differently since when you graph a pendulum it takes a wave-like form but I understand what you are saying. Thanks.

Me:
Yes, the graphs for SHM (pendulums, springs) and waves look the same.

For SHM it is possible to have a position vs time graph, where position is for the back and forth motion, centered at the equilibrium point. Think of a pendulum with a pen attached. To make this graph you would have to pull the paper one direction to signify time.

For wave motion you could make the same graph, but this time the back and forth of the pendulum would be the up and down of the amplitude of the wave motion (like the top of a wave going up and down) over time.

But for wave motion you could also make a graph of position vs location (or displacement vs position). Here position would be the up and down and the location would be how far away from your starting position. In this case the distance between two crests gives the wavelength.

All of the above graphs are sinusoidal (sin or cos-like).
Standing Waves

Sometimes waves are trapped in boundaries. If the length of a wave matches the space it is in, resonance occurs, causes maximum amplitude. The wave seems to stand still. Standing waves occur only at certain frequencies.

A jump rope looks like a standing wave, but is not because it moves in a circle and can exist at any frequency (you can speed up a little at a time). A standing wave can’t exist at any frequency.

Resonance—When an object vibrates sympathetically and amplifies the energy of a wave.

Guitar strings would be quiet without the resonance (amplification) of the guitar’s body.

Natural Frequency

When a string is plucked it will vibrate with only one anti-node. This is known as the natural frequency and always equals one half of a wavelength. The natural frequency is also called the fundamental frequency (f₁) or harmonic one (H₁).

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Harmonics

Harmonics are standing waves that fit in the same boundaries as the fundamental (natural frequency). As with any wave, changing the frequency does not change the wave speed. So if f changes, \( \lambda \) changes, not v.

First 5 Harmonics of a Vibrating String

<table>
<thead>
<tr>
<th>Fundamental Harmonic</th>
<th>1st Harmonic ( f = f_1 )</th>
<th>2nd Harmonic ( f_2 = 2f_1 )</th>
<th>3rd Harmonic ( f_3 = 3f_1 )</th>
<th>4th Harmonic ( f_4 = 4f_1 )</th>
<th>5th Harmonic ( f_5 = 5f_1 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₁</td>
<td>2H</td>
<td>3H</td>
<td>4H</td>
<td>5H</td>
<td></td>
</tr>
<tr>
<td>H₂</td>
<td>4Hz</td>
<td>6Hz</td>
<td>8Hz</td>
<td>10Hz</td>
<td></td>
</tr>
<tr>
<td>H₃</td>
<td>10Hz</td>
<td>15Hz</td>
<td>20Hz</td>
<td>25Hz</td>
<td></td>
</tr>
<tr>
<td>H₄</td>
<td>20Hz</td>
<td>30Hz</td>
<td>40Hz</td>
<td>50Hz</td>
<td></td>
</tr>
</tbody>
</table>

Frequency of a Harmonic

Frequency of the harmonic N (in Hz) \( f_{HN} = N(H) \)

\[ f_{HN} = N(H) \]

<table>
<thead>
<tr>
<th>Harmonic</th>
<th>Frequency of the harmonic N (in Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ex. Find the frequency of the third harmonic ( H₃ ) of a 4 Hz fundamental.</td>
<td></td>
</tr>
<tr>
<td>( H = 4 \text{ Hz} )</td>
<td>( N = 3 )</td>
</tr>
<tr>
<td>( H = 4 \text{ Hz} )</td>
<td>( N = 5 )</td>
</tr>
</tbody>
</table>

Speed of a Standing Wave

To find the speed of a fixed string you would need to know the frequency of any harmonic and that harmonic’s wavelength.

\[ f = \frac{v}{\lambda} \]

<table>
<thead>
<tr>
<th>( \lambda ) (wavelength)</th>
<th>( f )</th>
<th>( v )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \lambda = 3 \text{ m} )</td>
<td>21 Hz</td>
<td>( v = 21(3) )</td>
</tr>
<tr>
<td>( \lambda = 3 \text{ m} )</td>
<td>( v = 63 \text{ m/s} )</td>
<td></td>
</tr>
</tbody>
</table>
1. Standing wave
2. Harmonic
3. Fundamental Frequency
4. Natural Frequency
5. Node
6. Anti-node

<table>
<thead>
<tr>
<th></th>
<th>A. Where wave’s amplitude is greatest.</th>
<th>B. Where the wave has no motion.</th>
<th>C. A wave that is a multiple of another wave.</th>
<th>D. A wave that is trapped within boundaries.</th>
<th>E. The first harmonic of a standing wave, equal to 1/2 its wavelength.</th>
<th>F. The frequency at which any space will vibrate when disturbed.</th>
</tr>
</thead>
</table>

Why does a violin have a wood body instead of just strings?

Sometimes when talking or singing in a room, certain notes get very loud. Why?

---

The following table shows the frequencies of the first 5 harmonics of different strings. Fill in the blank spaces.

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4 Hz</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>6 Hz</td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>4 Hz</td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>36 Hz</td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>44 Hz</td>
<td></td>
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</tr>
</tbody>
</table>

A fellow student shows you the frequencies of four harmonics of a string. Which one would you question and why?

Frequencies: 12 Hz; 24 Hz; 29 Hz; 48 Hz

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A string has a fundamental (first harmonic) of 15 Hz, find the frequency of harmonic 3 (H₃).

If 20 Hz is the fundamental, find H₆.

If 35 Hz is H₇, what is the fundamental frequency?

---

String A has a fundamental with a period of 0.25 seconds.

A) What is the fundamental’s frequency?
B) How many antinodes does it have?
C) If the fundamental is on a 6 m long string, what is its wavelength?
D) Find the speed of the wave on that string.
E) What would be the frequency of the third harmonic?
F) What is the wave speed of the fourth harmonic?

Find its period: ____________

Wavelength: ____________

Amplitude: ____________

# of Anti-nodes: ____________

Harmonic #: ____________

---

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<tr>
<td></td>
<td>4 Hz</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6 Hz</td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>4 Hz</td>
<td></td>
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<td></td>
</tr>
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<td>36 Hz</td>
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</tr>
<tr>
<td></td>
<td>44 Hz</td>
<td></td>
<td></td>
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</tbody>
</table>

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Mark the nodes and anti-nodes.

What harmonic is this? ____________

Fundamental frequency = ____________

3rd harmonic frequency = ____________

Wavelength = ____________

Speed of the wave = ____________

Speed of 5th harmonic = ____________

---

Why does a violin have a wood body instead of just strings?

Sometimes when talking or singing in a room, certain notes get very loud. Why?

---

A fellow student shows you the frequencies of four harmonics of a string. Which one would you question and why?

Frequencies: 12 Hz; 24 Hz; 29 Hz; 48 Hz

---

A string has a fundamental (first harmonic) of 15 Hz, find the frequency of harmonic 3 (H₃).

If 20 Hz is the fundamental, find H₆.

If 35 Hz is H₇, what is the fundamental frequency?

---

String A has a fundamental with a period of 0.25 seconds.

A) What is the fundamental’s frequency?
B) How many antinodes does it have?
C) If the fundamental is on a 6 m long string, what is its wavelength?
D) Find the speed of the wave on that string.
E) What would be the frequency of the third harmonic?
F) What is the wave speed of the fourth harmonic?

Find its period: ____________

Wavelength: ____________

Amplitude: ____________

# of Anti-nodes: ____________

Harmonic #: ____________

---

The following table shows the frequencies of the first 5 harmonics of different strings. Fill in the blank spaces.

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4 Hz</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6 Hz</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4 Hz</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>36 Hz</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>44 Hz</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

Mark the nodes and anti-nodes.

What harmonic is this? ____________

Fundamental frequency = ____________

3rd harmonic frequency = ____________

Wavelength = ____________

Speed of the wave = ____________

Speed of 5th harmonic = ____________
1. Standing wave
2. Harmonic
3. Fundamental
4. Natural Frequency
5. Node
6. Anti-node

Why does a violin have a wood body instead of just strings?

The wood gives resonance to amplify the strings.

Sometimes when talking or singing in a room, certain notes get very loud. Why?

If note matches size of room, then resonance occurs.

A string has a fundamental (first harmonic) of 15 Hz, find the frequency of harmonic 3 ($H_3$).

$$f_3 = 3f_1 = 3 \times 15 \text{ Hz} = 45 \text{ Hz}$$

If 20 Hz is the fundamental, find $H_6$.

$$H_6 = \frac{6}{1} = 6$$

If 35 Hz is $H_7$, what is the fundamental frequency?

$$\frac{35}{7} = 5 \text{ Hz}$$

String A has a fundamental with a period of 0.25 seconds.

A) What is the fundamental's frequency?

$$f = \frac{1}{0.25} = 4 \text{ Hz}$$

B) How many antinodes does it have?

C) If the fundamental is on a 6 m long string, what is its wave length?

$$\lambda_{fund} = 2L$$

D) Find the speed of the wave on that string.

$$v = f \lambda = 4 \times (12) = 48 \text{ m/s}$$

E) What would be the frequency of the third harmonic?

$$f_3 = 4f_1 = 4 \times 12 \text{ Hz} = 48 \text{ Hz}$$

F) What is the wave speed of the fourth harmonic? 48 m/s

Find its period:

$$T = \frac{1}{f} = \frac{1}{40} = 0.025 \text{ s} = 40 \text{ Hz}$$

Mark the nodes and anti-nodes.

What harmonic is this?

Fundamental frequency = 20 Hz

3rd harmonic frequency = 60 Hz

Wavelength = 3 m

Speed of the wave =

$$v = f \lambda = 40 \times 3$$

= 120 m/s

Speed of 5th harmonic = 120 m/s (does not change)

A fellow student shows you the frequencies of four harmonics of a string. Which one would you question and why?

Frequencies: 12 Hz; 24 Hz; 29 Hz; 48 Hz

Not a multiple of 12 (not dividing by 12)
Standing Wave Lab

Change the frequency of the oscillator until you find a harmonic. You will know because the amplitude (antinode) will be big and the oscillator will be quieter.

1 wavelength (\(\lambda\)) = 2 antinodes.

You will need to find the first 6 harmonics for your string.

<table>
<thead>
<tr>
<th>Harmonic</th>
<th>Difference between frequencies:</th>
</tr>
</thead>
</table>
|          | \(\begin{array}{c}
 f_2 - f_1 \\
 f_3 - f_2 \\
 f_4 - f_3 \\
 f_5 - f_4 \\
 f_6 - f_5 \\
\end{array}\) |
| 1        | \(\begin{array}{c}
 1 \\
 2 \\
 3 \\
 4 \\
 5 \\
\end{array}\) |
| 2        | \(\begin{array}{c}
 2 \\
 3 \\
 4 \\
 5 \\
 6 \\
\end{array}\) |

Answer the questions on the back.

Standing Wave Lab

Change the frequency of the oscillator until you find a harmonic. You will know because the amplitude (antinode) will be big and the oscillator will be quieter.

1 wavelength (\(\lambda\)) = 2 antinodes.

You will need to find the first 6 harmonics for your string.

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 f_2 - f_1 \\
 f_3 - f_2 \\
 f_4 - f_3 \\
 f_5 - f_4 \\
 f_6 - f_5 \\
\end{array}\) |
| 1        | \(\begin{array}{c}
 1 \\
 2 \\
 3 \\
 4 \\
 5 \\
\end{array}\) |
| 2        | \(\begin{array}{c}
 2 \\
 3 \\
 4 \\
 5 \\
 6 \\
\end{array}\) |

Answer the questions on the back.

Standing Wave Lab

Change the frequency of the oscillator until you find a harmonic. You will know because the amplitude (antinode) will be big and the oscillator will be quieter.

1 wavelength (\(\lambda\)) = 2 antinodes.

You will need to find the first 6 harmonics for your string.

<table>
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</thead>
</table>
|          | \(\begin{array}{c}
 f_2 - f_1 \\
 f_3 - f_2 \\
 f_4 - f_3 \\
 f_5 - f_4 \\
 f_6 - f_5 \\
\end{array}\) |
| 1        | \(\begin{array}{c}
 1 \\
 2 \\
 3 \\
 4 \\
 5 \\
\end{array}\) |
| 2        | \(\begin{array}{c}
 2 \\
 3 \\
 4 \\
 5 \\
 6 \\
\end{array}\) |

Answer the questions on the back.
**Lab Questions:**

1. How many antinodes is one wavelength?
2. How many wavelengths is the first harmonic?
3. How do you find the wavelength of the first harmonic?
4. What did you notice about the difference between the frequencies each harmonic (left side of the table)?
5. What did you notice about the speed of the wave (v)?
6. As the frequency went up (bigger number) the wavelength went:

7. Find the fourth harmonic and fill in the following information.

<table>
<thead>
<tr>
<th>$H$ (# of AN)</th>
<th>$f$ (Hz)</th>
<th>$\lambda$ (m)</th>
<th>$V = f\lambda$ (in m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

8. Did the length of the string change?

9. What did change for the harmonic?

---

**Tighten the string by looping the string around the top twice.**
Each set shows the harmonics for a fixed string with a particular tension and length.

Example:

1. Mark the nodes (N) and antinodes (AN) for harmonic 3.
2. Show the waveform of $H_4$ at one moment in time.
3. Mark one wavelength of $H_4$. (Notice that 2 AN = 1 $\lambda$)

$$H\# = \frac{H_1}{1X} = \frac{H_2}{2X} = \frac{H_3}{3X} = \frac{H_4}{4X} = \frac{H_5}{5X} =$$

$$f = \frac{6\text{ Hz}}{12\text{ Hz}} = \frac{18\text{ Hz}}{24\text{ Hz}} = \frac{30\text{ Hz}}{20\text{ Hz}}$$

1. Mark the nodes (N) and antinodes (AN) for harmonic 2.
2. Show the waveform of $H_3$ at one moment in time.
3. Mark one wavelength of $H_3$.

$H\# = f = f_{\text{fundamental}}$  

f = ______  ______  ______  ______  ______

1. Mark the nodes (N) and antinodes (AN) for harmonic 4.
2. Which harmonic is one wavelength long? ______
3. Which harmonic is also called the fundamental? ______
Note: the fundamental frequency is also known as the natural frequency.

5. H# = ______ ______ ______ ______ ______

f = ______ ______ ______ ______ ______ 100 Hz

1. Mark the nodes (N) and antinodes (AN) for harmonic 5.
2. Which one is the natural frequency? _____ (see top)
3. Which harmonic is 2 wavelengths long? _____

The first harmonic has ______ antinodes.
The third harmonic has ______ antinodes.
The eighth harmonic has ______ antinodes.
The first harmonic has two other names:

________________________________
________________________________

If the fundamental frequency is 20 Hz, find H₃.

If the natural frequency is 8 Hz, find H₅.

If the 4th harmonic is 48 Hz, find the fundamental.

If the 3rd harmonic is 12 Hz, find the fundamental.

6. H# = ______ ______ ______ ______ ______

f = ______ ______ ______ ______ ______ 48 Hz

1. Mark one wavelength on harmonic 2.
2. Mark one wavelength on harmonic 4.
3. The wavelength of H₂ is double or half that of H₄?

If the 4th harmonic is 20 Hz, find the fundamental:
A) find the fundamental frequency:

B) find the frequency of the 5th harmonic:

If the 3rd harmonic is 21 Hz, find harmonic 4.

What harmonic is this? ________

Mark the nodes and anti-nodes.

Mark one wavelength on the wave.

Find its natural frequency:

Find the frequency of H₄.
Each set shows the harmonics for a fixed string with a particular tension and length.

**Example:**

1. Mark the nodes (N) and antinodes (AN) for harmonic 3.
2. Show the waveform of $H_4$ at one moment in time.
3. Mark one wavelength of $H_4$. *(Notice that $2 \lambda N = 1 \lambda$)*

<table>
<thead>
<tr>
<th>Harmonic</th>
<th>$f$ (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H_1$</td>
<td>6</td>
</tr>
<tr>
<td>$H_2$</td>
<td>12</td>
</tr>
<tr>
<td>$H_3$</td>
<td>18</td>
</tr>
<tr>
<td>$H_4$</td>
<td>24</td>
</tr>
<tr>
<td>$H_5$</td>
<td>30</td>
</tr>
</tbody>
</table>

4. Mark the nodes (N) and antinodes (AN) for harmonic 5.
5. Which harmonic is one wavelength long? $H_5$
6. Which harmonic is also called the fundamental? $H_1$

<table>
<thead>
<tr>
<th>Harmonic</th>
<th>$f$ (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H_1$</td>
<td>70</td>
</tr>
<tr>
<td>$H_2$</td>
<td>40</td>
</tr>
<tr>
<td>$H_3$</td>
<td>60</td>
</tr>
<tr>
<td>$H_4$</td>
<td>80 Hz</td>
</tr>
<tr>
<td>$H_5$</td>
<td>100 Hz</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Harmonic</th>
<th>$f$ (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H_1$</td>
<td>1</td>
</tr>
<tr>
<td>$H_2$</td>
<td>22</td>
</tr>
<tr>
<td>$H_3$</td>
<td>33 Hz</td>
</tr>
<tr>
<td>$H_4$</td>
<td>44 Hz</td>
</tr>
<tr>
<td>$H_5$</td>
<td>55</td>
</tr>
</tbody>
</table>
Note: the fundamental frequency is also known as the natural frequency.

5. \[ \text{H}^\# = \frac{100}{5} = 20 \text{ Hz} \]
   \[ \text{H}^\# = \frac{50}{10} = 5 \text{ Hz} \]
   \[ \text{H}^\# = \frac{40}{20} = 2 \text{ Hz} \]
   \[ \text{H}^\# = 80 \text{ Hz} \]
   \[ \text{H}^\# = 100 \text{ Hz} \]

1. Mark the nodes (N) and antinodes (AN) for harmonic 5.
2. Which one is the natural frequency? \[ \text{H}^\# \] (see top)
3. Which harmonic is 2 wavelengths long? \[ \text{H}^\# \]

<table>
<thead>
<tr>
<th>Harmonic</th>
<th>Nodes (N)</th>
<th>Antinodes (AN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H_1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H_2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H_3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H_4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H_5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H_6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H_7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H_8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The first harmonic has \[ \text{two other names:} \]
- Fundamental
- Natural freq.

If the fundamental frequency is 20 Hz, find H_3.
\[ \frac{40}{20} = 2 \text{ Hz} \]
If the natural frequency is 8 Hz, find H_5.
\[ \frac{40}{5} = 8 \text{ Hz} \]
If the 4th harmonic is 48 Hz, find the fundamental.
\[ \frac{40}{4} = 12 \text{ Hz} \]
If the 3rd harmonic is 12 Hz, find the fundamental.
\[ \frac{40}{3} = 13.33 \text{ Hz} \]

6. \[ \text{H}^\# = \frac{12}{3} = 4 \text{ Hz} \]
   \[ \text{H}^\# = \frac{24}{6} = 4 \text{ Hz} \]
   \[ \text{H}^\# = \frac{36}{9} = 4 \text{ Hz} \]
   \[ \text{H}^\# = 48 \text{ Hz} \]
   \[ \text{H}^\# = 60 \text{ Hz} \]

1. Mark one wavelength on harmonic 2.
2. Mark one wavelength on harmonic 4.
3. The wavelength of H_2 is \[ \text{double vs.} \] half that of H_4?

If the 4th harmonic is 20 Hz,
A) find the fundamental frequency:
\[ \frac{20}{4} = 5 \text{ Hz} \]

If the 3rd harmonic is 21 Hz, find harmonic 4.
\[ \frac{21}{3} = 7 \text{ Hz} \]
\[ F_q = 7(4) = 28 \text{ Hz} \]

What harmonic is this? \[ \text{3rd} \]
Mark the nodes and anti-nodes.
Mark one wavelength on the wave.
Find its natural frequency:
\[ \frac{40}{4} = 13.33 \text{ Hz} \]
Find the frequency of H_4.
\[ 13.33(4) = 53.33 \text{ Hz} \]
**Damping**

Harmonic motion eventually stops. A pendulum will stop swinging; a wave will eventually weaken and stop. Friction or the restoring force causes the motion to lose its energy and to die out. This gradual reduction of amplitude we call **damping**.

**Boundary Reactions**

There are four ways a wave can react depending on the boundary it encounters: Absorption; Reflection; Refraction; Diffraction.

**Soft Boundaries Absorb**

*Absorption*—a wave’s energy dies out in a soft material (damping). Example: Yelling into a pillow. The soft pillow absorbs (dampens) the sound.

**Hard Boundaries Reflect**

*Reflection*—a wave bounces off when it hits a hard boundary. Example: yelling against a wall, the sound wave reflects back (called an echo).

**Corners Diffract**

*Diffraction*—a wave drags against a corner, causing that part of the wave to turn. This is how we can hear around corners and how light can be seen around corners. Example: talking to someone around a corner.

**Transparent Boundaries Refract**

*Refraction*—a wave bends when it crosses a boundary into a different medium and changes speed. Example: light bends as it passes from air into the lenses of eyeglasses.

**Phase**

Phase—a particular part of a cycle. One cycle = 360°; 1/2 of a cycle = 180°; 1/4 of a cycle = 90°.

- **In-phase** means they are at the same point in their cycles.
- **180° out-of-phase** means they are at different points in their cycles.

**Interference**

*Constructive Interference*—when the energy of two waves add together. This is like pushing on a person on a swing when they are moving away from you: you give them more energy and more amplitude.

Two waves of small amplitude that are in-phase constructively interfere, combining into a wave of greater amplitude.

Two singers on the same note cause a louder sound—constructive interference.

*Destructive Interference*—when the energy of two waves subtract from each other, causing cancellation. Pushing on a person on a swing as they are coming toward you (at the wrong time) causes the amplitude to be smaller.

Two waves that are out-of-phase destructively interfere, combining into a wave of smaller amplitude. Waves that completely cancel each other it is known as complete destructive interference.

Modern headphones (and cars) use noise-canceling technology that transmits out-of-phase waves toward noise, canceling it out.
1. Phase
   A. When two waves increase amplitude.
   B. A single part of a cycle.
   C. When two waves decrease amplitude.
   D. When two waves are at different parts of their cycles.
   E. When two waves are at the same part of their cycles.

2. In-phase
   A. When a wave bends at a corner.

3. Out-of-phase
   A. The process of harmonic motion losing amplitude over time.

4. Constructive interference
   A. When two waves increase amplitude.

5. Destructive interference
   A. When two waves decrease amplitude.

6. Absorption
   A. When a wave bends at a corner.

7. Refraction
   A. The process of harmonic motion losing amplitude over time.

8. Diffraction
   A. When two waves increase amplitude.

9. Reflection
   A. When a wave bends at a corner.

10. Damping
    A. When a wave bends at a corner.

Absorption, Reflection, Refraction, or Diffraction?

If a wave hits a hard wall, it bounces off by: _______
If a wave hits a soft boundary, it dies by: _______
Waves bending due to different speed mediums: _______
A wave bends around a corner by: _______
A wave bends as it passes thru a boundary by: _______
Tile or marble makes for a loud room by: _______
Eyeglasses magnify objects by: _______
How bats see at night with sound (echolocation): _______
Carpet can keep a room quiet by: _______
Light comes back from a mirror by: _______

What is this bending called?

The light ray bends because the lens has a different w ______ s ______ than air.

Draw what will happen to the waves as they pass the two corners.
Combining the above, draw what will happen to the wave as it goes through a hole.

What do we call this?

The following show pendulums in different phases of a cycle.

Which letter is in-phase with G? ____  With D? ____
Which letter is 180° out-of-phase of E? ____  With H? ____
Which letter is 90° out-of-phase of F? ____ with G? ____

What is this bending called?

The light ray bends because the lens has a different w ______ s ______ than air.

The above is the same spring, but at different times.

Amplitude of the left spring = _______.  Right spring = _______
Which picture is the before picture?
Why?

What is the amplitude of wave 1?  Wave 2?
Are they in-phase?
What will happen if the waves combine?
What will be the amplitude of the combined wave?
Unit 10:

1. Phase \( \bigcirc \) \( \bigcirc \)  
   A. When two waves increase amplitude.
   B. A single part of a cycle.
   C. When two waves decrease amplitude.
   D. When two waves are at different parts of their cycles.
   E. When two waves are at the same part of their cycles.

2. In-phase \( \bigcirc \) \( \bigcirc \)  

3. Out-of-phase \( \bigcirc \) \( \bigcirc \)  

4. Constructive interference \( \bigcirc \) \( \bigcirc \)  

5. Destructive interference \( \bigcirc \) \( \bigcirc \)  

6. Absorption \( \bigcirc \) \( \bigcirc \)  
   A. When a wave bends at a corner.
   B. The process of harmonic motion losing amplitude over time.
   C. When a wave is dampened inside a soft boundary.
   D. A wave bouncing off of a hard boundary.
   E. A wave bending inside transparent objects.

What is this bending called?  
\textbf{refraction}  

The light ray bends because the lens has a different \textit{wave speed} than air.  

Draw what will happen to the waves as they pass the two corners.  

Combining the above, draw what will happen to the wave as it goes through a hole.  

What do we call this?  
\textbf{Diffraction}  

The following show pendulums in different phases of a cycle.  

- A.  
- B.  
- C.  
- D.  
- E.  
- F.  
- G.  
- H.  

Which letter is in-phase with G? \( \text{A} \)  
With D? \( \text{F} \)  

Which letter is 180° out-of-phase of E? \( \text{B} \)  
With H? \( \text{G} \)  

Which letter is 90° out-of-phase of F? \( \text{E} \)  
With G? \( \text{D} \)  

- The above is the same spring, but at different times.  
- Amplitude of the left spring = 10 cm. Right spring = 14 cm  
- Which picture is the before picture? \( \text{Right picture} \)  
Why? \( \text{It will dampen over time, so amplitude is smaller afterwards.} \)  

- What is the amplitude of wave 1? 2 m  
Wave 2? 2 cm  

Are they in-phase? No  

What will happen if the waves combine? They will cancel each other - destructive interference.  

What will be the amplitude of the combined wave? 0 m
What is Sound?

**Sound** is the movement of compression waves (longitudinal waves) hitting our ears. These compression waves are alternating high and low pressure areas. The air molecules vibrate back and forth, but don’t travel.

![Sound source diagram](image)

**Speakers imitate sounds by pushing air and causing vibrations.**

Sound Wave are Pressure Waves

As a wave sound needs a medium to travel through. Sound cannot travel through the vacuum of space. **Space is silent** (no matter what you hear in the movies).

Tiny hairs inside the **cochlea** (inner ear) translate air pressure into electrical impulses that can be read by the brain. Very loud sounds bend these hairs, causing deafness.

**Humans can hear frequencies that are between 20 Hz and 20,000 Hz!**

Frequency = Pitch

We hear the frequency of sound as pitch. A higher frequency we hear as a higher pitch. A lower frequency we hear as a lower pitch.

<table>
<thead>
<tr>
<th>Frequency (f)</th>
<th>Wavelength (λ)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 Hz</td>
<td>17 m</td>
<td>rumble of thunder</td>
</tr>
<tr>
<td>100 Hz</td>
<td>3.4 m</td>
<td>bass guitar</td>
</tr>
<tr>
<td>2,000 Hz</td>
<td>17 cm</td>
<td>fire truck siren</td>
</tr>
<tr>
<td>4,000 Hz</td>
<td>7 cm</td>
<td>highest note of piano</td>
</tr>
<tr>
<td>10,000 Hz</td>
<td>3.4 cm</td>
<td>whine of a jet turbine</td>
</tr>
</tbody>
</table>

**Higher Frequency = Higher Pitch**

Elephants and submarines use infrasonic sound (too low to hear) to communicate over long distances. Very low frequencies (very bass) travel very long distances and can penetrate through water (just like thru cars).

Dog whistles use ultrasonic frequencies (above human hearing [+20,000 Hz]), but perfect for dog ears!

Amplitude = Loudness

We hear pressure (the amplitude) of sound as loudness. It takes more energy to create a louder sound. Too loud of a sound can cause deafness.

**Loudness is measured in decibels (dB)**

<table>
<thead>
<tr>
<th>Loudness (dB)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 dB</td>
<td>Total silence.</td>
</tr>
<tr>
<td>30 dB</td>
<td>Total quiet in the woods at night.</td>
</tr>
<tr>
<td>60 dB</td>
<td>Normal conversation.</td>
</tr>
<tr>
<td>70 dB</td>
<td>Busy traffic in the city.</td>
</tr>
<tr>
<td>90 dB</td>
<td>A jackhammer (hearing damage if not protected)</td>
</tr>
<tr>
<td>110 dB</td>
<td>Threshold of pain from sound.</td>
</tr>
<tr>
<td>200 dB</td>
<td>Human will die from the sound pressure.</td>
</tr>
</tbody>
</table>

A +10 dB change we hear as twice as loud.

A 30 dB sound is twice as loud as a 20 dB sound.

A -10 dB change we hear as half as loud.

A 30 dB sound is half as loud as a 40 dB sound.

**Speed of Sound (v_s)**

The speed of sound changes. In gases, hotter (faster) gases conduct sound faster. In solids and liquids, generally denser (tighter) materials are faster.

<table>
<thead>
<tr>
<th>Material</th>
<th>V_s (m/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>340</td>
</tr>
<tr>
<td>Helium</td>
<td>965</td>
</tr>
<tr>
<td>Water</td>
<td>1530</td>
</tr>
<tr>
<td>Wood</td>
<td>2000</td>
</tr>
<tr>
<td>Gold</td>
<td>3240</td>
</tr>
<tr>
<td>Steel</td>
<td>5940</td>
</tr>
</tbody>
</table>

The speed of sound in air is about 340 m/sec.

You can use \( v_s = f \lambda \) to find frequency or wavelength. AND use \( S = D/T \) to find distance or time. In both cases, \( V_s (S) \) is a constant for sound: 340 m/sec.

**Ex. Find the wavelength of a 200 Hz sound.**

\[
\begin{align*}
V_s &= 340 \text{ m/sec} \\
F &= 200 \text{ Hz} \\
\lambda &= ?
\end{align*}
\]

\[
\lambda = \frac{V_s}{F} = \frac{340 \text{ m/sec}}{200 \text{ Hz}} = 1.7 \text{ m}
\]

**Ex. If you hear a sound 3 seconds after you see the motion. How far away is it?**

\[
\begin{align*}
V_s &= 340 \text{ m/sec} \\
T &= 3 \text{ sec} \\
D &= ?
\end{align*}
\]

\[
\begin{align*}
D &= V_s T = (340 \text{ m/sec}) \times (3 \text{ sec}) \\
D &= 1020 \text{ m}
\end{align*}
\]

**Motion faster than sound is called supersonic.** Supersonic planes give their speed in multiples of Mach (1 × the speed of sound).

\[
\begin{align*}
\text{Mach 1} &= 340 \text{ m/sec} \\
\text{Mach 2} &= 680 \text{ m/sec}
\end{align*}
\]

A sonic boom is caused by an object breaking through the sound barrier. Supersonic planes, bullets, and bullwhips all make sonic booms.
1. Sound  
   A. Faster than the speed of sound.
2. Sonic boom  
   B. A wave caused by alternating high and low pressure.
3. Supersonic  
   C. The organ that detects sound waves.
4. Ultrasonic  
   D. A pressure wave caused by an object going faster than sound.
5. Cochlea  
   E. A sound higher than humans can hear.

### Unit 10: 5

**Displacement vs. Position**

**Use the graph to answer these questions:**

1. What is the wavelength?  

2. What is the period?  

3. What is the frequency?  

4. Is this frequency audible to humans (can we hear it)?

---

**A wave’s velocity is 90 m/sec with a frequency of 6 Hz. What is it’s wavelength?**

**A sound wave has a wavelength of 20 m. Find its frequency.**

**If a sound wave’s frequency is 100 Hz. What is its period?**

**What is the above wave’s wavelength?**

**A railroad crew is repairing a rail. You hear the hammer 0.5 seconds after it is swung. How far away is the crew?**

**You hear a plane 4 seconds after you see it. Find the distance to the plane.**

**If a sound is 40 dB loud. Answer how many dB these would be:**

1. A sound twice as loud:
2. A sound half as loud:

**Compared to a 50 dB sound, you would hear a 60 dB as:**

---

**Why is space silent?**

If I increase the energy I give a sound wave what changes:

**If a wave’s fourth harmonic has a frequency of 40 Hz, what is its natural frequency and what is the frequency of \( H_6 \)?**

**If a wave’s fundamental is 6 Hz, what harmonic has a frequency of 48 Hz?**

**Find its period:**

**What harmonic is this?**

**Could a human hear this frequency?**

**Mark the nodes and anti-nodes.**

**How many wavelengths is it?**

**What is its wavelength?**

**Find the fundamental frequency:**

**5th harmonic frequency:**

**Speed of the wave on this string:**
A wave's velocity is 90 m/sec with a frequency of 6 Hz. What is its wavelength?

\[ v = f \lambda \]
\[ 90 = f (\lambda) \]
\[ 90 = f (15) \]
\[ f = 6 \text{ Hz} \]

A sound wave has a wavelength of 20 m. Find its frequency.

\[ v = \lambda f \]
\[ 340 = \lambda f (20) \]
\[ f = 17 \text{ Hz} \]

If a sound wave's frequency is 100 Hz. What is its period?

\[ f = \frac{1}{T} \]
\[ T = \frac{1}{f} = \frac{1}{100} = 0.01 \text{ sec} \]

What is the above wave's wavelength?

\[ v = f \lambda \]
\[ 340 = 100 \lambda \]
\[ \lambda = 3.4 \text{ m} \]

A railroad crew is repairing a railroad. You hear the hammer 0.5 seconds after it is swung. How far away is the crew?

\[ v = \frac{D}{T} \]
\[ D = vT = 340(0.5) \]
\[ v = 170 \text{ m} \]

You hear a plane 4 seconds after you see it. Find the distance to the plane.

\[ 340 = \frac{D}{4} \]
\[ 1360 = D \]

If a sound is 40 dB loud. Answer how many dB these would be:
1) A sound twice as loud: 50 dB
2) A sound half as loud: 30 dB

Compared to a 50 dB sound, you would hear a 60 dB as:

\[ \text{twice as loud} \]

Use the graph to answer these questions: \( \lambda = 2 \text{ m} \)

1 cycle is from 1 m to 3 m; 1/2 cycle is from 0 m to 1 m.

Amplitude (A) = \( \frac{3}{m} \)  Total cycles: 2.5

It is a sound wave; find frequency:

\[ v = 340 \text{ m/s} = f \lambda \]
\[ 340 = f (2) \]
\[ f = 170 \text{ Hz} \]

Is this frequency audible to humans (can we hear it)?

\[ \text{yes between 20 - 20,000 Hz} \]

Why is space silent?

\[ \text{No medium} \]
\[ \left( \frac{\text{v=c}}{\text{a=c}} \right) \]

If I increase the energy I give a sound wave what changes:

\[ \text{amplitude} \]
\[ \text{loud ness} \]

If a wave's fourth harmonic has a frequency of 40 Hz, what is its natural frequency and what is the frequency of Hz?

\[ \frac{40}{4} = 10 \text{ Hz} \]
\[ H_4 = 6(10) = 60 \text{ Hz} \]

If a wave's fundamental is 6 Hz, what harmonic has a frequency of 48 Hz?

\[ \frac{48}{6} = 8 \text{ th harmonic} \]

Find its period:

\[ T = \frac{1}{80} = \text{0.125 sec} \]

What harmonic is this?

\[ 4 \]

Could a human hear this frequency? \[ \text{yes} \]

Mark the nodes and anti-nodes.

How many wavelengths is it?

\[ 2 \lambda = 6 \text{ m} \]

What is its wavelength?

\[ \lambda = 3 \text{ m} \]

Find the fundamental frequency:

\[ \frac{40}{4} = 20 \text{ Hz} \]

5th harmonic frequency:

\[ 20(5) = 100 \text{ Hz} \]

Speed of the wave on this string:

\[ v = \frac{f \lambda}{80(3)} = \frac{240}{7} \text{ m/s} \]
**Light is a Wave**

Light is refracted in lenses and reflected by mirror. Also, two fingers close together causes lines of darkness in between: destructive interference. 

*So, light must be a wave!*

**Light is a Particle**

Light can travel thru the vacuum of space, but a wave can’t travel in a vacuum. *So light must be a particle!*

**Light is Both**

This contradiction perplexed scientists for many, many years, but the evidence must be believed: light is both a wave and a particle.

*A light packet is called a photon.*

---

**Speed of Light**

Speed Limit: **C**

**Where Does Light Come From?**

*Photons (light) come from electrons falling from high electron orbits to low orbits.*

These orbits are also called **energy levels**.

![Diagram of electron orbit transition](image)

- **Energy can raise an electron to a higher energy level.**
- **When the electron falls back, a photon is given off: light!**

Because each element has a different number of protons, **each element** has slightly different electron energy levels and gives off different colors.

This fact allows us to tell the chemical makeup of stars. Just by looking at the light it gives off (its spectrum) scientist know the elements in the star.

---

**Visible Light**

White light is actually made up of many different colors, each with a different wavelength and frequency.

- **A prism separates light by dispersion.**
- **Rainbow out**
- **Different wavelengths (colors) refract (bend) differently when passing into glass. A prism’s double refraction makes this more obvious.**
- **The first letters spell: ROY – G – BIV**

**Colors have Different Energies**

You know that different color flames give off different amounts of heat. Red flames are the coolest and blue flames are the hottest. *As you move from Red to Blue, light GAINS energy.*

White light is made up of all colors. That is why a white flame is the hottest!

---

**Electromagnetic (EM) Spectrum**

“Light” waves are electromagnetic radiation and includes ALL light: visible and invisible.

- **High Energy**
- **High Frequency**
- **Short Wavelength**

**Gamma rays** ($\lambda = \text{less than .01 nm}$ [a billionth of a meter]) – the most powerful and dangerous form of radiation. Emitted by nuclear reactions, they can break chemical and nuclear bonds and cause mutations.

**X-rays** ($\lambda = .01 \text{ nm to } 10 \text{ nm}$) – Used in medicine and industry because they can penetrate materials and tissues. Too much can cause mutations or tissue damage.

**Ultraviolet light** ($\lambda = 10 \text{ to } 400 \text{ nm}$) – just above visible light; causes sunburns and skin cancer. The ozone layer protects us from most of the sun’s ultraviolet light.

**Visible light** ($\lambda = 400 \text{ to } 700 \text{ nm}$) – The smallest part of the EM spectrum.

**Infrared** ($\lambda = 1 \text{ mm to } 700 \text{ nm}$) – invisible red light radiation: what most people think of as heat. Can be seen by infrared cameras and goggles.

**Microwaves** ($\lambda = 1 \text{ mm to } 30 \text{ cm}$) – used to cook food and for cell phones.

**Radio waves** ($\lambda = \text{less than a cm to hundreds of meters}$) – very long, low energy waves used to transmit radio and television signals. Radio towers have to be so tall so they can long radio waves.

---

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### Put these from shortest to longest wavelengths

1. Radio waves
2. Infrared
3. Ultraviolet
4. X-rays
5. Gamma rays
6. Microwaves

A. Electromagnetic waves we feel as heat.
B. Dangerous EM waves that have very high energy and come from nuclear reactions.
C. EM waves that have very low energy and long wavelengths.
D. EM waves that can pass through skin and have short wavelengths.
E. EM waves with more energy than visible light and can cause sunburns.
F. Long wavelengths; used in cell phones.

### Where does light come from?

Find its period: _______________________

What harmonic is this? _________________

Mark the nodes and anti-nodes.

Mark one wavelength on the harmonic.

Can humans hear this frequency?__________

Find the fundamental frequency:

3rd harmonic frequency: _______________ 40 Hz

---

### Put these three in order from slowest to fastest:

Light waves; sound waves; water waves.

---

### Put these from shortest to longest wavelengths

Radio waves Ultraviolet X-rays Visible Microwaves

---

### Put these from least energy to most energy.

Radio waves Ultraviolet X-rays Visible Microwaves

---

### Why do we see lightening and hear the thunder a few seconds later?

Find its period: _______________________

What harmonic is this? _________________

Mark the nodes and anti-nodes.

Mark one wavelength on the harmonic.

Can humans hear this frequency?__________

Find the fundamental frequency:

3rd harmonic frequency: _______________ 40 Hz
Unit 10:

1. Photon E
   - the speed of light and the fastest speed in the universe.
2. $3 \times 10^5$ m/sec
   - Also known as an electron orbit. To move from low to high requires energy.
3. Prism D
   - All light: visible and invisible.
4. Light F
   - Used to separate white light into its colors.
5. EM Spectrum C
   - A single particle or packet of light.
6. Energy Level E
   - A wave that can travel through a vacuum.

Is light a wave or a particle? Prove your answer:
Both waves can interfere
Particle: can go thru vacuum

Where does light come from?
electrons falling from high orbits to low orbits

Find the period of a 10 Hz wave.

$f = 10 \text{ Hz}$

$T = \frac{1}{f} = \frac{1}{10} \text{ s} = 0.1 \text{ s}$

A wave has these characteristics: 25 Hz and 8 m. Find speed.

$f = 25 \text{ Hz}$
$v = f \lambda$

$\lambda = 8 \text{ m}$

$v = 25(8) = 200 \text{ m/s}$

A sound changes from 25 dB to 5 dB. How much louder does the 25 dB seem to us?

Four times as loud.

You hear a thunder 3 seconds after you see the lightening. How far away is the storm?

$t = 3 \text{ sec}$

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

$v = 340 \text{ m/s}$

$D = \frac{v t}{2} = \frac{340(3)}{2} = 1020 \text{ m}$

You are in a concert hall and yell up to the ceiling. It takes 1 second for the echo to come back to you.

A) 1 second— is that the time for the sound to go to the ceiling or for the sound to go to the ceiling and back?
B) If you want to know how high the ceiling is, how long does it take for the sound to get to the ceiling? 5 sec.
C) Find the how high the ceiling is.

$D = v t = 340(0.5) = 170 \text{ m}$

1. Radio waves C
   - Electromagnetic waves we feel as heat.
2. Infrared A
   - Dangerous EM waves that have very high energy and come from nuclear reactions.
3. Ultraviolet E
   - EM waves that have very low energy and long wavelengths.
4. X-rays D
   - EM waves that can pass through skin and have short wavelengths.
5. Gamma rays F
   - EM waves with more energy than visible light and can cause sunburns.
6. Microwaves F
   - Long wavelengths; used in cell phones.

Put these three in order from slowest to fastest:

Light waves; sound waves; water waves.

water / sound / light

Put these from shortest to longest wavelengths

Radio waves Ultraviolet X-rays Visible Microwaves

5 2 shortest 3 1 longest

Put these from least energy to most energy

Radio waves Ultraviolet X-rays Visible Microwaves

1 5 3 2 least most E

Why do we see lightening and hear the thunder a few seconds later?
Light travels faster than sound.

Find its period:

$I = \frac{1}{f} = \frac{1}{40} = 0.25 \text{ sec}$

What harmonic is this?

5th

Mark the nodes and anti-nodes.

Mark one wavelength on the harmonic.

Can humans hear this frequency?

Yes

(about 20 Hz to below 20,000 Hz)

Find the fundamental frequency:

$5x = 40 \text{ Hz}$

$x = 8 \text{ Hz}$

3rd harmonic frequency:

$x = 8 \text{ Hz}$

$3x = 24 \text{ Hz}$

40 Hz
Light Comes from the Atom

Photons (light) come from electrons falling from high electron orbits to low orbits.

When the electron falls back, a photon is given off: light!

Different Colors

Different colors come from white (sun) light. Each of these colors has its own frequency, wavelength, and energy.

Addition of Light Colors:
- Red and Blue lights make Magenta (purple).
- Red and Green lights make Yellow.
- Green and Blue lights make Cyan (sea green).

Using the Color Chart:

Lights (RGB): Follow the arrows from the lights to the color you are making. Red and Blue make Magenta.

Pigments (CMYK): Follow the arrows from the pigments to the color you are making. Yellow and Cyan make Green.

Pigments—Subtractive Color

CMYK Model

Pigments are dyes that color paints, inks, and even food. Pigments produce color by reflection. What you see is what is reflected.

You can tell that printers use CMYK, because the paper is white.

CMYK—As you know from your color printer at home, color pigments are very expensive. To make black by mixing three pigments (CMY) doesn’t make sense. So printers add black (K) to make four colors: CMYK. (K stands for black because B stands for blue.)

When you buy paint, pigments (dyes) are mixed into white paint. Yet because the store has more room than your printer, they can use more than just three dyes.

Lights—Additive Color

RGB Model

Before you turn on any lights, a room is black. By turning on lights you add colors. The three primary light colors are red, green, and blue. By adding different amounts of each color we can make any color. This method of additive color is known as RGB.

Computers and TVs are black when off, so they use lights: RGB. Red, green, and blue lights make all the millions of colors on your screen.

Lights add color to a black background. The three primary lights colors are Red, Green, and Blue (RGB).

Adding Light Colors:
- Red and Blue lights make Magenta (purple).
- Red and Green lights make Yellow.
- Green and Blue lights make Cyan (sea green).

Pigments reflect color and have a white background. The three primary colors of pigments are Cyan, Magenta, and Yellow. Each one absorbs a different color.

BLACK
- Pigments that absorb all light look black.

WHITE
- Pigments that reflect all light look white.

Yellow reflects red and green light, so blue was absorbed.

Green light is reflected off a leaf, so the leaf absorbs red and blue. To make green with CMYK you would use yellow (absorbs blue) and cyan (absorbs red). (Or remember that both yellow and cyan have green in them.)
1. Period: _____________________

5. RGB

Find the frequency of a wave with a period of 0.5 seconds.

E. A color model that uses lights on a black background.

7. White reflects what two colors? __________

Make the following additive colors using RGB.

Red _______  White _______  Yellow _______

What color is a stop sign?

3. Cyan

B. A color made from red and green.

C. Dyes and paints are a type of this.

2. Magenta

D. A color made from blue and red.

Yellow reflects what two colors? __________

So what color does Yellow absorb?

6. CMYK

F. A color made from green and blue.

Magenta reflects what two colors?

So what color does Magenta absorb?

What harmonic is this?

Find its period:

You hear a thunder 4 seconds after you see the lightening.

A) What is the speed of sound?

B) How far away is the storm?

You are in a canyon and yell across. It takes 4 seconds for the echo to come back to you. How wide is the canyon?

Find the frequency of a wave with a period of 0.5 seconds.

A 40 Hz wave is 3 m from crest to crest. Find the speed of the wave.

Decide if the following use RGB or CMYK and why.

Television: _______  Why?  ________________

Paint on a wall:_______  Why?  ________________

Movie Theater:_______  Why?  ________________

Color Printer:_______  Why?  ________________

Light shines on a cyan table.

What color light is shining on the table?

To be Cyan what colors of light are reflecting off of the table?

What color is being absorbed by the table?

What color is a stop sign?

Is this additive or subtractive color?

What two colors would a printer use to make this color?

Find its period: 300 Hz

How many nodes?

How many antinodes?

What harmonic is this?

How many wavelengths is it?

Can humans hear this frequency?

Find the fundamental (natural) frequency:

Fifth harmonic frequency:

How would it change if it had less amplitude?
Unit 10:

1. Pigment C  
   A. A color model that uses pigments on a white background.  
   B. A color made from red and green.  
   C. Dyes and paints are a type of this.  
   D. A color made from blue and red.  
   E. A color model that uses lights on a black background.  
   F. A color made from green and blue.

2. Magenta D  
   A. A color made from red and green.  
   B. A color made from red and blue.  
   C. Dyes and paints are a type of this.  
   D. A color made from blue and red.  
   E. A color model that uses lights on a black background.  
   F. A color made from green and blue.

3. Cyan F  
   A. A color made from blue and green.  
   B. A color made from red and blue.  
   C. Dyes and paints are a type of this.  
   D. A color made from blue and red.  
   E. A color model that uses lights on a black background.  
   F. A color made from green and blue.

4. Yellow B  
   A. A color made from red and yellow.  
   B. A color made from red and green.  
   C. Dyes and paints are a type of this.  
   D. A color made from blue and red.  
   E. A color model that uses lights on a black background.  
   F. A color made from green and blue.

5. RGB E  
   A. A color model that uses pigments on a white background.  
   B. A color made from red and green.  
   C. Dyes and paints are a type of this.  
   D. A color made from blue and red.  
   E. A color model that uses lights on a black background.  
   F. A color made from green and blue.

6. CMYK A  
   A. A color model that uses pigments on a white background.  
   B. A color made from red and green.  
   C. Dyes and paints are a type of this.  
   D. A color made from blue and red.  
   E. A color model that uses lights on a black background.  
   F. A color made from green and blue.

Magenta reflects what two colors? R and B
What color does Magenta absorb? G

Yellow reflects what two colors? R and G
What color does Yellow absorb? B

Make the following additive colors using RGB.

Cyan R G B  
White R G B  
Yellow R G B

Red R  
Magenta B  
Black B

Make the following subtractive colors using CMYK.

Blue C M Y  
White C M Y  
Green C M Y

Red C M Y  
Magenta C M Y  
Black C M Y

What color is a stop sign? Red
Is this additive or subtractive color? Subtractive
What two colors would a printer use to make this color? Yellow and Magenta

Find the frequency of a wave with a period of 0.5 seconds.

\[ T = \frac{1}{f} \]
\[ f = \frac{1}{0.5} = 2 \text{ Hz} \]

A 40 Hz wave is 3 m from crest to crest. Find the speed of the wave.

\[ f = \frac{40}{\lambda} \]
\[ v = \frac{C}{\lambda} = 40 \text{ m/s} \]

You hear a thunder 4 seconds after you see the lightning.

A. What is the speed of sound? \[ 340 \text{ m/s} \]
B. How far away is the storm?

\[ v = \frac{340 \text{ m}}{4} \]
\[ t = \frac{9}{4} \text{ sec} \]

Distance = \[ D = vt = \frac{340(4)}{4} = 340 \text{ m} \]

You are in a canyon and yell across. It takes 4 seconds for the echo to come back to you. How wide is the canyon?

\[ v = \frac{340 \text{ m}}{4} \]
\[ t = \frac{2}{4} \text{ sec} \]

Distance = \[ D = \frac{340(2)}{2} = 340 \text{ m} \]

Decide if the following use RGB or CMYK and why.

Television: RGB Why? Black when off
Paint on a wall: CMYK Why? Paints (white wall)
Movie Theater: RGB Why? Black background
Color Printer: CMYK Why? White paper

Light shines on a cyan table.

What color light is shining on the table? White
What colors of light are reflecting off of the table? G, B
What color is being absorbed by the table? R

If the above wave has a frequency of 10 Hz, find its speed. \[ 10(1.5) = 15 \text{ m/s} \]

Find its period:

\[ T = \frac{1}{300} = 0.0033 \text{ sec} \]

How many nodes? 4
How many antinodes? 3
What harmonic is this? 3rd
How many wavelengths is it? 1.5

Can humans hear this frequency? yes

Find the fundamental (natural) frequency:

\[ 300/3 = 100 \text{ Hz} \]

Fifth harmonic frequency: \[ 100(5) = 500 \text{ Hz} \]

How would it change if it had less amplitude? skinner (not as wide)
Harmonic Motion and Waves Review

<table>
<thead>
<tr>
<th>λ, v, f, T, D, A, or dB?</th>
<th>Harmonic Motion: Yes or No?</th>
</tr>
</thead>
<tbody>
<tr>
<td>A) ___ Amplitude</td>
<td>A stick pulled to one side and then released?</td>
</tr>
<tr>
<td>B) ___ Distance</td>
<td>Why or why not?</td>
</tr>
<tr>
<td>C) ___ Decibels</td>
<td>A ball that bounces on the floor?</td>
</tr>
<tr>
<td>D) ___ Velocity</td>
<td>Why or why not?</td>
</tr>
<tr>
<td>E) ___ Frequency</td>
<td>Where is the equilibrium position for this pendulum?</td>
</tr>
<tr>
<td>F) ___ Period</td>
<td>If the pendulum starts at C going to the right, where does 1 cycle end?</td>
</tr>
<tr>
<td>G) ___ Tells you how loud a sound is.</td>
<td>From letter ____ to letter ____ would be the amplitude.</td>
</tr>
<tr>
<td>H) ___ Measures distance from one wave crest to another.</td>
<td>If the pendulum starts at A, how many times does it pass point C in 1 cycle?</td>
</tr>
<tr>
<td>I) ___ How many times a wave repeats each second.</td>
<td>If it is 80° from A to E, what is the amplitude of the pendulum?</td>
</tr>
<tr>
<td>J) ___ How much energy harmonic motion has.</td>
<td></td>
</tr>
<tr>
<td>K) ___ Increases as a pendulum swings back-and-forth farther.</td>
<td></td>
</tr>
<tr>
<td>L) ___ How fast a wave moves.</td>
<td></td>
</tr>
<tr>
<td>M) ___ How far a wave travels in a certain amount of time.</td>
<td></td>
</tr>
<tr>
<td>N) ___ How long it takes for one cycle to repeat.</td>
<td></td>
</tr>
<tr>
<td>O) ___ How far a wave swings from the center to one side.</td>
<td></td>
</tr>
</tbody>
</table>

Where is the equilibrium position for this pendulum?

Position vs. Time

1 cycle after B is ____; 2 cycles after C is ____.
1/2 cycle before H is ____; 1/4 cycle before K is ____.
# of complete cycles shown is ____.
# of troughs: ____; # of crests: ____.
Period (T) = ___; Frequency (f) = ___
Equilibrium position = ___; Amplitude (A) = ___

A. ___ A transverse wave.
   ___ A longitudinal wave.
B. ___ Like sound.
   ___ Like light.
A wave is moving 20 m/s. If it vibrates at 5 Hz, find its wavelength.

Find the above wave’s period.

Reflection, Refraction, Absorption, Diffraction, Interference

A. _______When a wave dies out in a soft boundary.
B. _______When two waves interact with each other.
C. _______When a wave hits a hard boundary.
D. _______When a wave bends around a corner.
E. _______When a wave bends as it goes from one material to another of a different speed.
F. _______Can make two waves cancel from one material to another of a different speed.
G. _______Allows you to hear someone around a corner.
H. _______When light hits a mirror.
I. _______When light hits a black piece of paper.
<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Can we hear 50 Hz?</td>
<td>No</td>
</tr>
<tr>
<td>Can we hear 10 Hz?</td>
<td>Yes</td>
</tr>
<tr>
<td>Can we hear 21,000 Hz?</td>
<td>No</td>
</tr>
<tr>
<td>Can we hear 19,000 Hz?</td>
<td>Yes</td>
</tr>
<tr>
<td>Which speaks at higher pitch: a bird or an elephant?</td>
<td>Bird</td>
</tr>
<tr>
<td>Is light a particle or a wave?</td>
<td>Particle</td>
</tr>
<tr>
<td>What do scientists call all light?</td>
<td>Electromagnetic Radiation</td>
</tr>
<tr>
<td>Which has more energy: radio waves or x-rays?</td>
<td>Radio Waves</td>
</tr>
<tr>
<td>Which is faster: infrared radiation or gamma rays?</td>
<td>Infrared Radiation</td>
</tr>
<tr>
<td>Which has a longer wavelength: x-rays or microwaves?</td>
<td>X-Rays</td>
</tr>
<tr>
<td>Which has a higher frequency: ultraviolet light or red light?</td>
<td>Ultraviolet Light</td>
</tr>
<tr>
<td>What is the speed of sound?</td>
<td>343 m/s</td>
</tr>
<tr>
<td>What is the speed of light?</td>
<td>299,792,458 m/s</td>
</tr>
<tr>
<td>How did we make the wave move faster on the slinky?</td>
<td>Pulling the slinky faster</td>
</tr>
<tr>
<td>Is the speed of sound faster in dense or loose materials?</td>
<td>Loose</td>
</tr>
<tr>
<td>Is the speed of sound faster when its hot or cold outside?</td>
<td>Hot</td>
</tr>
<tr>
<td>Is the speed of sound faster at sea level or high in the mountains?</td>
<td>Sea Level</td>
</tr>
<tr>
<td>Where does light come from?</td>
<td>Sun</td>
</tr>
<tr>
<td>Is the speed of sound faster in dense or loose materials?</td>
<td>Loose</td>
</tr>
<tr>
<td>Is the speed of sound faster when its hot or cold outside?</td>
<td>Hot</td>
</tr>
<tr>
<td>Is the speed of sound faster at sea level or high in the mountains?</td>
<td>Sea Level</td>
</tr>
<tr>
<td>Twice as loud as 30 dB is _____ dB.</td>
<td>60 dB</td>
</tr>
<tr>
<td>Why can waves go thru things?</td>
<td>Waves can pass through materials</td>
</tr>
<tr>
<td>A spaceship explodes in space. If you are in a ship nearby will the sound of the explosion be higher or lower pitch than if it occurred on the earth?</td>
<td>Lower Pitch</td>
</tr>
<tr>
<td>Which has more energy: radio waves or x-rays?</td>
<td>Radio Waves</td>
</tr>
<tr>
<td>Which is faster: infrared radiation or gamma rays?</td>
<td>Infrared Radiation</td>
</tr>
<tr>
<td>Which has a longer wavelength: x-rays or microwaves?</td>
<td>X-Rays</td>
</tr>
<tr>
<td>Which has a higher frequency: ultraviolet light or red light?</td>
<td>Ultraviolet Light</td>
</tr>
<tr>
<td>What color is the background?</td>
<td>RGB Background Color</td>
</tr>
<tr>
<td>Using RGB:</td>
<td></td>
</tr>
<tr>
<td>What color is the background?</td>
<td>RGB Background Color</td>
</tr>
<tr>
<td>Make the following colors:</td>
<td></td>
</tr>
<tr>
<td>Using CMYK:</td>
<td></td>
</tr>
<tr>
<td>What color is the background?</td>
<td>CMYK Background Color</td>
</tr>
<tr>
<td>Make the following colors:</td>
<td></td>
</tr>
<tr>
<td>What color does Yellow absorb?</td>
<td>Blue, Cyan</td>
</tr>
<tr>
<td>How can you separate out the different colors that are in white light?</td>
<td>Spectral Analysis</td>
</tr>
<tr>
<td>This process is called d_________.</td>
<td>Dispersion</td>
</tr>
<tr>
<td>What type of color does a computer monitor use:</td>
<td>RGB or CMYK</td>
</tr>
<tr>
<td>RGB or CMYK?</td>
<td>RGB or CMYK</td>
</tr>
<tr>
<td>How do you know?</td>
<td></td>
</tr>
<tr>
<td>Using RGB:</td>
<td></td>
</tr>
<tr>
<td>What color is the background?</td>
<td>RGB Background Color</td>
</tr>
<tr>
<td>Make the following colors:</td>
<td></td>
</tr>
<tr>
<td>Using CMYK:</td>
<td></td>
</tr>
<tr>
<td>What color is the background?</td>
<td>CMYK Background Color</td>
</tr>
<tr>
<td>Make the following colors:</td>
<td></td>
</tr>
<tr>
<td>What color does Yellow absorb?</td>
<td>Blue, Cyan</td>
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<tr>
<td>RGB or CMYK?</td>
<td>RGB or CMYK</td>
</tr>
<tr>
<td>How do you know?</td>
<td></td>
</tr>
<tr>
<td>Using RGB:</td>
<td></td>
</tr>
<tr>
<td>What color is the background?</td>
<td>RGB Background Color</td>
</tr>
<tr>
<td>Make the following colors:</td>
<td></td>
</tr>
<tr>
<td>Using CMYK:</td>
<td></td>
</tr>
<tr>
<td>What color is the background?</td>
<td>CMYK Background Color</td>
</tr>
<tr>
<td>Make the following colors:</td>
<td></td>
</tr>
<tr>
<td>What color does Yellow absorb?</td>
<td>Blue, Cyan</td>
</tr>
<tr>
<td>How can you separate out the different colors that are in white light?</td>
<td>Spectral Analysis</td>
</tr>
<tr>
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<td>Dispersion</td>
</tr>
<tr>
<td>What type of color does a computer monitor use:</td>
<td>RGB or CMYK</td>
</tr>
<tr>
<td>RGB or CMYK?</td>
<td>RGB or CMYK</td>
</tr>
<tr>
<td>How do you know?</td>
<td></td>
</tr>
<tr>
<td>Using RGB:</td>
<td></td>
</tr>
<tr>
<td>What color is the background?</td>
<td>RGB Background Color</td>
</tr>
<tr>
<td>Make the following colors:</td>
<td></td>
</tr>
<tr>
<td>Using CMYK:</td>
<td></td>
</tr>
<tr>
<td>What color is the background?</td>
<td>CMYK Background Color</td>
</tr>
<tr>
<td>Make the following colors:</td>
<td></td>
</tr>
<tr>
<td>What color does Yellow absorb?</td>
<td>Blue, Cyan</td>
</tr>
<tr>
<td>How can you separate out the different colors that are in white light?</td>
<td>Spectral Analysis</td>
</tr>
<tr>
<td>This process is called d_________.</td>
<td>Dispersion</td>
</tr>
<tr>
<td>What type of color does a computer monitor use:</td>
<td>RGB or CMYK</td>
</tr>
<tr>
<td>RGB or CMYK?</td>
<td>RGB or CMYK</td>
</tr>
<tr>
<td>How do you know?</td>
<td></td>
</tr>
<tr>
<td>Using RGB:</td>
<td></td>
</tr>
<tr>
<td>What color is the background?</td>
<td>RGB Background Color</td>
</tr>
<tr>
<td>Make the following colors:</td>
<td></td>
</tr>
<tr>
<td>Using CMYK:</td>
<td></td>
</tr>
<tr>
<td>What color is the background?</td>
<td>CMYK Background Color</td>
</tr>
<tr>
<td>Make the following colors:</td>
<td></td>
</tr>
<tr>
<td>What color does Yellow absorb?</td>
<td>Blue, Cyan</td>
</tr>
</tbody>
</table>
Harmonic Motion and Waves Review

<table>
<thead>
<tr>
<th>λ, v, f, T, D, A, or dB?</th>
<th>Harmonic Motion: Yes or No?</th>
</tr>
</thead>
<tbody>
<tr>
<td>A) Amplitude</td>
<td>A stick pulled to one side and then released? Yes</td>
</tr>
<tr>
<td>B) Distance</td>
<td>Why or why not? It stops in the middle</td>
</tr>
<tr>
<td>C) Decibels</td>
<td>A ball that bounces on the floor? No</td>
</tr>
<tr>
<td>D) Velocity</td>
<td>Why or why not? Steps at the bottom</td>
</tr>
<tr>
<td>E) Frequency</td>
<td></td>
</tr>
<tr>
<td>F) Period</td>
<td></td>
</tr>
<tr>
<td>G) Wavelength</td>
<td>Where is the equilibrium position for this pendulum? C (where stops)</td>
</tr>
<tr>
<td>H) Measured in m/s</td>
<td>If the pendulum starts at C going to the right, where does 1 cycle end? C going right</td>
</tr>
<tr>
<td>I) Measured in Hz</td>
<td>From letter C to letter E would be the amplitude, or A to C</td>
</tr>
<tr>
<td>J) Measured in m</td>
<td></td>
</tr>
<tr>
<td>K) Measured in sec</td>
<td></td>
</tr>
<tr>
<td>L) Measure in cm or m</td>
<td></td>
</tr>
</tbody>
</table>

M) Tells you how loud a sound is. |
N) Measures distance from one wave crest to another. |
O) How many times a wave repeats each second. |
P) How much energy harmonic motion has. |
Q) Increases as a pendulum swings back-and-forth farther. |
R) How fast a wave moves. |
S) How far a wave travels in a certain amount of time. |
T) How long it takes for one cycle to repeat. |
U) How far a wave swings from the center to one side. |

Position vs. Time

1 cycle after B is E. 2 cycles after C is K. 1/4 cycle before K is J. 

# of complete cycles shown is 3. 

# of troughs: 3; # of crests: 4. 

Period (T) = 1 sec 

Frequency (f) = 1 Hz 

Equilibrium position = 0 cm 

Amplitude (A) = 6 cm 

A. A transverse wave. 
B. A longitudinal wave. 

A. Like sound. 
B. Like light. 

A. Like a water wave. 
B. Like earthquakes. 

Amplitude affects speed. 

A wave is moving 20 m/s. If it vibrates at 5 Hz, find its wavelength. 

\[ v = f \lambda \] 

\[ v = 20 \text{ m/s} \] 

\[ 20 = 5 \lambda \] 

\[ \lambda = \frac{20}{5} = 4 \text{ meters} \] 

Find the above wave's period. 

\[ T = \frac{1}{f} = \frac{1}{5} = 0.2 \text{ sec} \] 

Reflection, Refraction, Absorption, Diffraction, Interference 

A. abs When a wave dies out in a soft boundary. 
B. inter When two waves interact with each other. 
C. reflec When a wave hits a hard boundary. 
D. diff When a wave bends around a corner. 
E. refr When a wave bends as it goes from one material to another of a different speed. 
F. inter Can make two waves cancel each other out. 
G. diff Allows you to hear someone around a corner. 
H. refl When light hits a mirror. 
I. abs When light hits a black piece of paper.
<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Can we hear 50 Hz?</td>
<td>Yes</td>
</tr>
<tr>
<td>Can we hear 10 Hz?</td>
<td>No</td>
</tr>
<tr>
<td>Can we hear 21,000 Hz?</td>
<td>No</td>
</tr>
<tr>
<td>Can we hear 19,000 Hz?</td>
<td>Yes</td>
</tr>
<tr>
<td>Which speaks at higher pitch: a bird or an elephant?</td>
<td>Bird</td>
</tr>
<tr>
<td>Twice as loud as 30 dB is</td>
<td>40 dB</td>
</tr>
<tr>
<td>A spaceship explodes in space. If you are in a ship nearby will the sound of the explosion be higher or lower pitch than if it occurred on the earth?</td>
<td>Doesn't matter - no sound in space</td>
</tr>
<tr>
<td>What is the speed of sound?</td>
<td>340 m/s</td>
</tr>
<tr>
<td>What is the speed of light?</td>
<td>3 x 10^8 m/s</td>
</tr>
<tr>
<td>A person is hammering a spike from across a field.</td>
<td></td>
</tr>
<tr>
<td>A) Will you hear the sound at the same time the spike is struck or will there be a delay?</td>
<td>Delay</td>
</tr>
<tr>
<td>B) Why?</td>
<td>Light goes faster than sound</td>
</tr>
<tr>
<td>A sound's frequency is 170 Hz. Find its wavelength.</td>
<td></td>
</tr>
<tr>
<td>V = 340 m/s</td>
<td></td>
</tr>
<tr>
<td>While standing at the top of a canyon you wonder how deep it is.</td>
<td></td>
</tr>
<tr>
<td>You drop a large rock and after it hits the bottom of the canyon you time 2 seconds until the sound of the rock's impact gets back to you. How deep is the canyon?</td>
<td></td>
</tr>
<tr>
<td>V = 340 m/s</td>
<td></td>
</tr>
<tr>
<td>t = 2 sec</td>
<td></td>
</tr>
<tr>
<td>D = Vt</td>
<td></td>
</tr>
<tr>
<td>You also want to know how wide the canyon is. You clap your hands as loud as you can and it takes 6 seconds for the echo to get back to you. How wide is the canyon?</td>
<td></td>
</tr>
<tr>
<td>V = 340 m/s</td>
<td></td>
</tr>
<tr>
<td>t = 3 sec (half)</td>
<td></td>
</tr>
<tr>
<td>D = Vt (see above)</td>
<td></td>
</tr>
<tr>
<td>How did we make the wave move faster on the slinky?</td>
<td>Pull it tighter</td>
</tr>
<tr>
<td>Is the speed of sound faster in dense or loose materials?</td>
<td>Denser is tighter</td>
</tr>
<tr>
<td>Is the speed of sound faster when it's hot or cold outside?</td>
<td>Cold air is denser</td>
</tr>
<tr>
<td>Is the speed of sound faster at sea level or high in the mountains?</td>
<td>More air = denser</td>
</tr>
<tr>
<td>Where does light come from?</td>
<td>Earth falling from high to low orbits</td>
</tr>
<tr>
<td>Is light a particle or a wave?</td>
<td>Both</td>
</tr>
<tr>
<td>What do scientists call all light?</td>
<td>Electromagnetic spectrum (EM)</td>
</tr>
<tr>
<td>Which has more energy: radio waves or x-rays?</td>
<td>Radio waves</td>
</tr>
<tr>
<td>Which is faster: infrared radiation or gamma rays?</td>
<td>Gamma rays</td>
</tr>
<tr>
<td>Which has a longer wavelength: x-rays or microwaves?</td>
<td>X-rays</td>
</tr>
<tr>
<td>Which has a higher frequency: ultraviolet light or red light?</td>
<td>Ultraviolet light</td>
</tr>
<tr>
<td>Why can waves go thru things?</td>
<td>Waves are just energy</td>
</tr>
<tr>
<td>A red ball is sitting in a pool of water. A blue ball is pushed into the water, making waves. After the waves get to the red ball both balls are bobbing at the same speed. A) The two balls have the same: frequency</td>
<td></td>
</tr>
<tr>
<td>B) What transferred between the two balls to allow them to be moving up and down together?</td>
<td>Energy</td>
</tr>
<tr>
<td>How can you separate out the different colors that are in white light?</td>
<td>Prism</td>
</tr>
<tr>
<td>This process is called dispersion</td>
<td></td>
</tr>
<tr>
<td>White type of color does a computer monitor use: RGB or CMYK?</td>
<td>RGB</td>
</tr>
<tr>
<td>How do you know? black when off</td>
<td></td>
</tr>
<tr>
<td>Using RGB:</td>
<td></td>
</tr>
<tr>
<td>What color is the background?</td>
<td>Black</td>
</tr>
<tr>
<td>Make the following colors:</td>
<td></td>
</tr>
<tr>
<td>Red: R; Blue: B; Cyan: G; White: W; Magenta: M; Black: K</td>
<td></td>
</tr>
<tr>
<td>Using CMYK:</td>
<td></td>
</tr>
<tr>
<td>What color is the background?</td>
<td>White</td>
</tr>
<tr>
<td>Make the following colors:</td>
<td></td>
</tr>
<tr>
<td>Red: Y; Blue: C; Cyan: M; White: W; Magenta: M; Black: K</td>
<td></td>
</tr>
<tr>
<td>What color does Yellow absorb?</td>
<td>Blue</td>
</tr>
<tr>
<td>(Because it reflects R + G)</td>
<td></td>
</tr>
</tbody>
</table>
Lab: Period of a Pendulum

Purpose –
To be able to demonstrate how various factors influence the period of a pendulum including amplitude, mass, and length.

Background –
Students should already understand the concepts of cycle, amplitude, period, and frequency as they pertain to harmonic motion and a pendulum.

Preparation and Materials –
Pendulum – could be made of string hung from the ceiling.
Timers to record period.
Hooked Masses to vary the mass of the pendulum bob: 100 g, 100g; 500 g.

Data Tables

How does Mass Affect Period?

<table>
<thead>
<tr>
<th>Length of Pendulum</th>
<th>Mass of Pendulum Bob</th>
<th>Amplitude</th>
<th>Time for 20 cycles</th>
<th>Period (for 1 cycle)</th>
</tr>
</thead>
<tbody>
<tr>
<td>medium</td>
<td>100 g</td>
<td>medium</td>
<td></td>
<td></td>
</tr>
<tr>
<td>medium</td>
<td>200 g</td>
<td>medium</td>
<td></td>
<td></td>
</tr>
<tr>
<td>medium</td>
<td>500 g</td>
<td>medium</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

How does Amplitude Affect Period?

<table>
<thead>
<tr>
<th>Length of Pendulum</th>
<th>Mass of Pendulum Bob</th>
<th>Amplitude</th>
<th>Time for 20 cycles</th>
<th>Period (for 1 cycle)</th>
</tr>
</thead>
<tbody>
<tr>
<td>medium</td>
<td>200 g</td>
<td>small</td>
<td></td>
<td></td>
</tr>
<tr>
<td>medium</td>
<td>200 g</td>
<td>medium</td>
<td></td>
<td></td>
</tr>
<tr>
<td>medium</td>
<td>200 g</td>
<td>wide</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

How does Length Affect Period?

<table>
<thead>
<tr>
<th>Length of Pendulum</th>
<th>Mass of Pendulum Bob</th>
<th>Amplitude</th>
<th>Time for 20 cycles</th>
<th>Period (for 1 cycle)</th>
</tr>
</thead>
<tbody>
<tr>
<td>short</td>
<td>200 g</td>
<td>medium</td>
<td></td>
<td></td>
</tr>
<tr>
<td>medium</td>
<td>200 g</td>
<td>medium</td>
<td></td>
<td></td>
</tr>
<tr>
<td>long</td>
<td>200 g</td>
<td>medium</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Student Outcome –
Write a scientific explanation of what factors affect the period of a pendulum.
### What affects the period of a pendulum?

Remember: Period (T) is the time for 1 cycle.

<table>
<thead>
<tr>
<th>Different Amplitudes (same mass and length)</th>
<th>Different Masses (same length and amplitude)</th>
<th>Different Length (same amplitude and mass)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Big amplitude</td>
<td>Heavy mass</td>
<td>Short length</td>
</tr>
<tr>
<td>Small amplitude</td>
<td>Light mass</td>
<td>Long length</td>
</tr>
</tbody>
</table>

**Hint:** Take 10 periods and divide by 10 to reduce error.

<table>
<thead>
<tr>
<th>Period (T): (in sec)</th>
<th>10 T =</th>
<th>1 T =</th>
<th>10 T =</th>
<th>1 T =</th>
<th>10 T =</th>
<th>1 T =</th>
<th>10 T =</th>
<th>1 T =</th>
<th>10 T =</th>
<th>1 T =</th>
</tr>
</thead>
</table>

1. What affects the period of a pendulum?
2. To increase the period, you would:
3. To decrease the period (make it faster) you would:
4. To increase the frequency you would:

---

**cstephenmurray.com**

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Curriculum Notes—

Disclaimer: On the “Waves” notes I say that “water waves are transverse waves”. This is not perfectly true, since water waves are really circular waves. Any object sitting on water will follow a circular path, back to where it starts. I use this example because it is close to a transverse wave and certainly one example most familiar to students. Light is actually a transverse, but unfamiliar.

Beginning with the “Waves” worksheet, I emphasize that wave speed only changes if the medium changes. (See demo below.) I reemphasize this on standing waves (see standing wave lab note below). Before, I only emphasized this during sound, when it becomes essential to solve word problems. By emphasizing this for most of the chapter, not only does it teach students an important concept, but it also makes the teaching of sound easier.

Standing Waves Lab: We have the CPO wave generators. I let the students do this lab twice (yes, twice). The first day they figured out the sequence of the harmonics, how to find wavelength, and that the wave speed stayed the same. The second day, they did it much faster and locked down the information. Sound was pretty easy this year (2010).

Slinky Demo – For use with “Waves”. If you don’t have super long slinky, a normal one will suffice, as long as it is metal. A super slinky costs about $30.00 from any science supply company.

Show transverse (move slinky left and right) and longitudinal waves (move hand forward and backward).

Show amplitude, reflection (see how the pulse will invert at the end), and dampening (dying out due to friction with the floor).

Show that two waves can move thru each other. Have the student holding the other side produce a transverse wave as you produce a longitudinal wave. The two pulses will pass thru each other proving that waves are a movement of energy. Remind students that this is should seem logical, since two pairs of students can have conversations at the same time. The sound waves go thru each other.

Show the wave speed does not change unless the medium changes. Using a timer, show that a greater amplitude will not cause the speed to change. If the time is slightly different it is due to the person timing. Show this by making to close pulses (second one larger). The larger pulse will not catch the first pulse, thus proving the speed is constant. Also, a longitudinal wave has the same speed. Then pull the slinky tighter and the pulse will move obviously faster.

Students as a Wave Demo—Have 5 or 6 students standing side by side as particles in a medium

Density Affects Wave Speed—The closeness of the students represents the density of a substance. If you push on one of the students, they will bump into the next students and the next, etc, which is the wave propagating in the medium. The closer the students stand, the faster the wave moves.

Transverse Waves only Move Thru Solids—Have the students lock arms to represent a solid. Then you can push on the first student to show a longitudinal wave or move them side to side as a transverse wave.

Only Longitudinal Waves Move Thru Fluids—If their arms are not locked they represent a fluid (gas or liquid). You cannot produce a transverse wave, only a longitudinal wave.