Name: ______________________

Class: ______________________

Due Date: ______________________

C.1 Simple Harmonic Motion

Understandings

- Conditions that lead to simple harmonic motion.
- The defining equation of simple harmonic motion as given by $a = -\omega^2 x$.
- A particle undergoing simple harmonic motion can be described using time period *T*, frequency *f*, angular frequency ω, amplitude, equilibrium position, and displacement.
- The time period in terms of frequency of oscillation and angular frequency as given by $T = \frac{1}{f} = \frac{2\pi}{\omega}$.
- The time period of a mass-spring system as given by $T = 2\pi\sqrt{\frac{m}{k}}$.
- The time period of a simple pendulum as given by $T = 2\pi\sqrt{\frac{l}{g}}$.
- A qualitative approach to energy changes during one cycle of an oscillation.

Equations

$$a = -\omega^2 x$$

$$T = \frac{1}{f} = \frac{2\pi}{\omega}$$

$$T = 2\pi\sqrt{\frac{m}{k}}$$

$$T = 2\pi\sqrt{\frac{l}{g}}$$

Additional HL Understandings

- A particle undergoing simple harmonic motion can be described using phase angle.
- Problems can be solved using the equations for simple harmonic motion as given by
  - $x = x_0 \sin(\omega t + \phi)$
  - $v = \omega x_0 \cos(\omega t + \phi)$
  - $v = \pm\omega\sqrt{{x_0}^2 - x^2}$
  - $E_\mathrm{T} = \frac{1}{2}m\omega^2{x_0}^2$
  - $E_\mathrm{p} = \frac{1}{2}m\omega^2x^2$

Additional HL Equations

$x = x_0 \sin(\omega t + \phi)$

$v = \omega x_0 \cos(\omega t + \phi)$

$v = \pm\omega\sqrt{{x_0}^2 - x^2}$

$E_\mathrm{T} = \frac{1}{2}m\omega^2{x_0}^2$

$E_\mathrm{p} = \frac{1}{2}m\omega^2x^2$

If you are interested in learning more about waves then please read the book *Vibrations and Waves* by George C. King.

The solutions can be found on the YouTube channel Go Physics Go:

https://www.youtube.com/@gophysicsgo/playlists

Part 1: Use your favorite sources to answer the following questions

1. C: Define *oscillation.*

2. C: Give three examples of oscillations.

3. C: Define *periodic.*

4. C: Define *period.* Units?

5. C: Define *amplitude.* Units?

6. C: Define *frequency*. Units?

7. C: What is the mathematical relationship between the *frequency* and *period* of a wave?

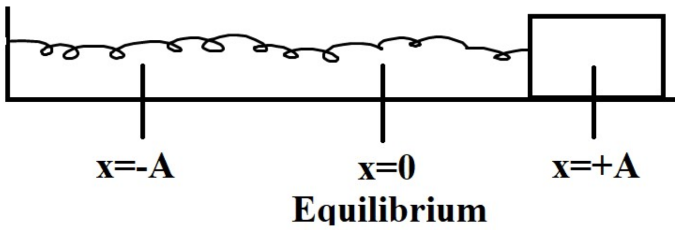
8. C: State the equation for the angular frequency for an object undergoing simple harmonic motion.

9. C: Topic A.1 Review: The slope of a displacement vs. time graph tells us the ___________ of an object while the slope of a velocity vs. time graph tells us the ___________ of an object.

10.C: Topic A.2 Review: Define *equilibrium.*

11.C: Give the name, define, and give the units of each variable from Hooke's Law $\vec{F} = -k \times \Delta\vec{x}$.

12.C: A mass lying on a smooth horizontal surface is attached to a spring and is stretched from its equilibrium position. It is then released. Label the forces on the mass.



13.C: **Use a pencil and ruler!** Draw and label an *acceleration vs. displacement* graph for simple harmonic motion.

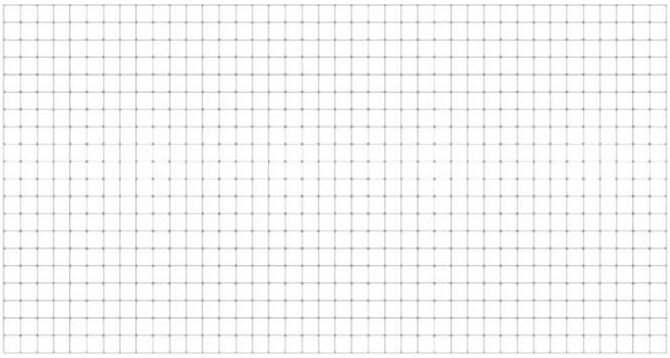
14.C: Derive the defining equation of simple harmonic motion $a = -\omega^2 x$.

15.C: What are the main characteristics of simple harmonic motion?

16.C: Derive the equation for the time period of a mass-spring system $T = 2\pi\sqrt{\frac{m}{k}}$.

17.C: State the equation for the time period of a simple pendulum.

18.C: **Use a pencil and ruler!** Draw two waves which are *in phase*.

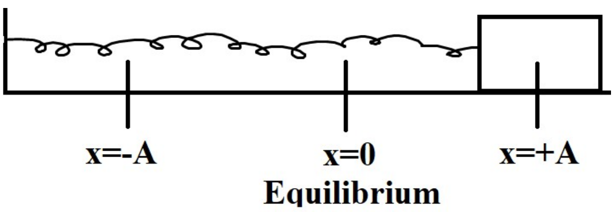


19.C: **Use a pencil and ruler!** Draw two waves which are *out of phase by 180°.*

20.C: **Use a pencil and ruler!** Draw two waves which are *out of phase by 90°*.

21.C: **Use a pencil!** The total energy of a simple harmonic oscillator is given by the equation $E_\mathrm{T} = E_\mathrm{k} + E_\mathrm{p} = \frac{1}{2}mv^2 + \frac{1}{2}k\Delta x^2 = \text{constant}$. In the figure below label the locations of

$E_{\mathrm{k,max}}$	$E_{\mathrm{k,min}} = 0\ \mathrm{J}$	$E_{\mathrm{p,max}}$	$E_{\mathrm{p,min}} = 0\ \mathrm{J}$
a_{max}	$a_{\mathrm{min}} = 0\,\frac{\mathrm{m}}{\mathrm{s}^2}$	v_{max}	$v_{\mathrm{min}} = 0\ \frac{\mathrm{m}}{\mathrm{s}}$



22.C: What is the mathematical relationship between the energy and amplitude of an object in simple harmonic motion?

23.C: **Use a pencil and ruler!** On the graph below draw an energy vs. displacement graph for a mass on a spring with three curves: a potential energy vs. displacement curve, a kinetic energy vs. displacement curve, and a total energy vs. displacement curve.

24.C: **Use a pencil and ruler!** On the graph below draw an energy vs. time graph during one oscillation for a mass on a spring with three curves: a potential energy vs. displacement curve, a kinetic energy vs. displacement curve, and a total energy vs. displacement curve.

25.E: A pendulum makes 22.0 oscillations in 42.0 seconds. Determine the period and frequency of the pendulum.

26.E: A 600. g mass is hung at the end of a vertical spring. The spring stretches 22.5 cm.

a. Determine the spring constant.

b. How much further will it stretch if a 900. g mass is hung from it?

27.E: A 497 g mass is attached to a spring with a spring constant $k = 9.87\ \frac{\mathrm{N}}{\mathrm{m}}$ and oscillates horizontally on a frictionless surface. The mass is displaced 6.54 cm from its equilibrium position and released.

a. Determine the maximum speed of the mass.

b. Determine the speed of the mass when it is 3.00 cm from its equilibrium position.

c. Determine the acceleration of the mass when it is 3.00 cm from its equilibrium position.

28.E: A 40.0 g mass undergoes simple harmonic motion at the end of a spring. Its maximum displacement from equilibrium is 18.0 cm and period is 1.20 s.

a. Determine the frequency.

b. Determine the spring constant.

c. Determine the maximum speed.

d. Determine the maximum acceleration.

e. Determine the speed of the mass when its displacement is 8.00 cm.

f. Determine the acceleration of the mass when its displacement is 8.00 cm.

29.E: Six vertical springs, each with a spring constant of 2570 N/m, are individually hung on a wall. Each spring hangs a 35.5 kg mass. Determine the period of the mass when it oscillates.

30.E: On Planet X an IB student wants to determine the acceleration of gravity near its surface by using a pendulum. The time to complete 20.0 oscillations is 35.0 s on a 0.825 m long massless string. Determine the acceleration of gravity on Planet X.

31.E: A 34.5 g mass is attached to a horizontal spring. The mass performs simple harmonic motion according to the equation $y(t) = (0.975\text{ m})\cos(12t)$.

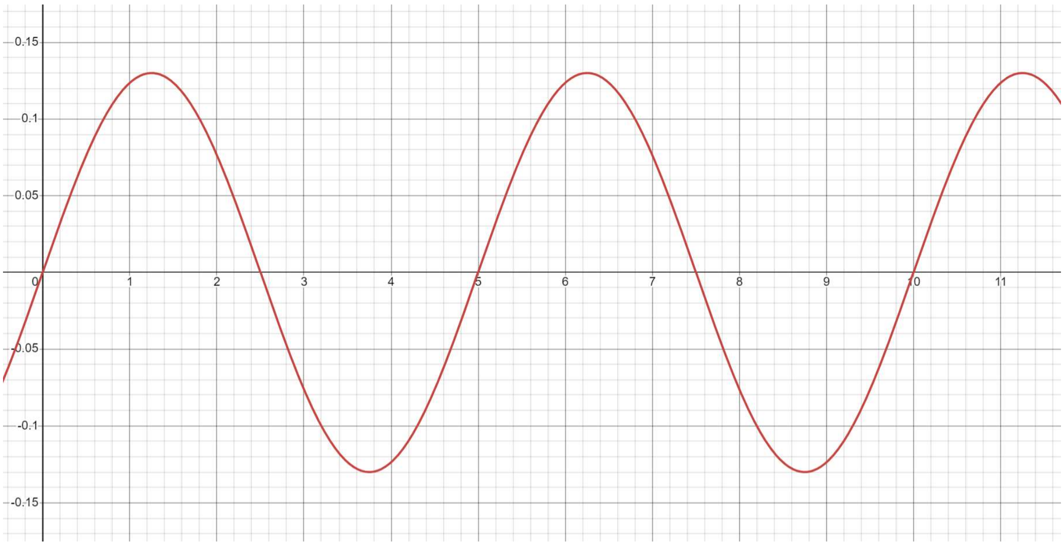
a. Determine the amplitude.

b. Determine the frequency.

c. Determine the position of the mass at $t = 0.682\text{ s}$.

d. Determine the spring constant.

32.E: The *position vs. time* graph of a pendulum is given below:



a. What is the period of this pendulum?

b. What is the maximum displacement of this pendulum from the equilibrium position?

c. What is the angular velocity of this pendulum?

d. Write the equation which describes the position of this pendulum as a function of time.

e. What will be the position of this pendulum 4.5 seconds after it is released?

f. What will be the position of this pendulum 11.5 seconds after it is released?

g. What will be the maximum speed of this pendulum?

h. Write the equation predicting the velocity of this pendulum as a function of time.

i. What will be the velocity of this pendulum 4.50 seconds after it has been released?

j. What will be the velocity of this pendulum 3.75 seconds after it has been released?

k. What will be the maximum acceleration of this pendulum?

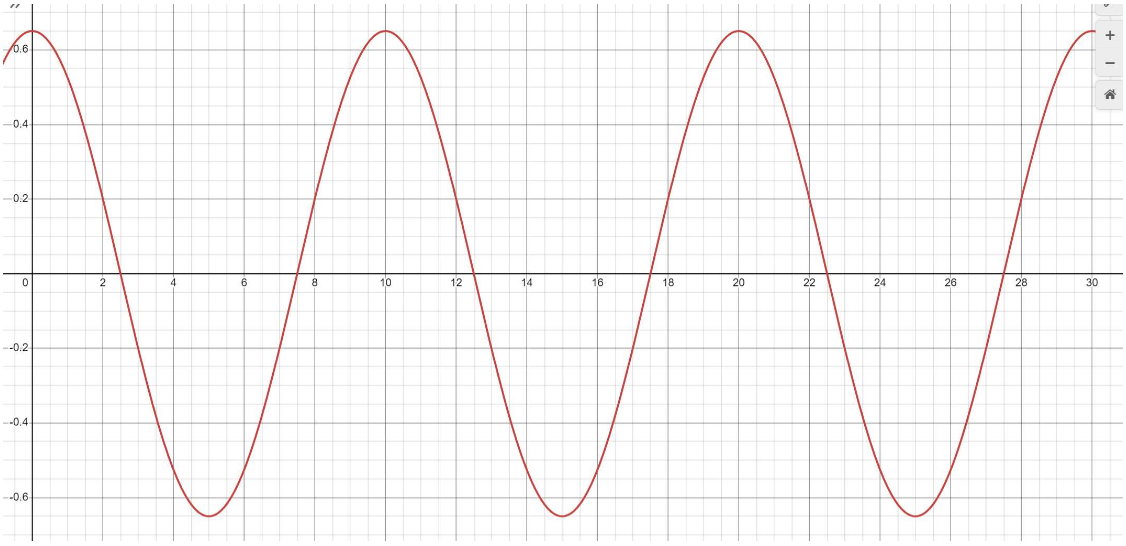
l. What will be the acceleration of this pendulum 4.50 seconds after it has been released?

m. What is the length of this pendulum?

n. Based on the graph, at which times is the velocity of this pendulum zero?

o. Based on the graph, at which times is the acceleration of this pendulum zero?

33.E: The *position vs. time* graph of a pendulum is given below:



a. What is the period of this pendulum?

b. What is the maximum displacement of this pendulum from the equilibrium position?

c. What is the angular velocity of this pendulum?

d. Write the equation which describes the position of this pendulum as a function of time.

e. What will be the position of this pendulum 18.5 seconds after it is released?

f. What will be the position of this pendulum 44.5 seconds after it is released?

g. What will be the maximum speed of this pendulum?

h. Write the equation predicting the velocity of this pendulum as a function of time.

i. What will be the velocity of this pendulum 18.5 seconds after it has been released?

j. What will be the velocity of this pendulum 25.0 seconds after it has been released?

k. What will be the maximum acceleration of this pendulum?

l. What will be the acceleration of this pendulum 18.5 seconds after it has been released?

m. What will be the acceleration of this pendulum 25.0 seconds after it has been released?

n. Based on the graph, at which times is the velocity of this pendulum zero?

o. Based on the graph, at which times is the acceleration of this pendulum zero?

Additional HL Understandings

34.C: Math review: Describe the significance of the variables *A*, *B*, *C*, and *D* in the equation $y = A\sin(Bx + C) + D$.

35.E: An object is undergoing simple harmonic motion with a period of 0.255 s, a maximum displacement of 5.28 cm, and a phase angle of $\frac{\pi}{4}$.

a. Determine the displacement of the object after 1.25 s.

b. Determine the velocity of the object after 2.50 s.

c. Determine the maximum speed of the object.

36.C: Derive the equations of motion, energy, and speed for simple harmonic motion.

37.E: A mass of 0.765 kg undergoes simple harmonic motion with a maximum displacement of 0.232 m and a frequency of 0.652 Hz.

a. Determine the period of the motion.

b. Determine the total energy.

c. Determine the potential energy of the mass when it is 0.100 m from its equilibrium position.

d. Determine the kinetic energy of the mass when it is 0.100 m from its equilibrium position.

e. Determine the speed of the mass when it is 0.100 m from its equilibrium position.

f. Determine the maximum speed of the mass.

Optional for math lovers

The small angle approximation ($\theta < 10°$) for the period of a pendulum is given in the physics data booklet: $T = 2\pi\sqrt{\frac{l}{g}}$

The exact solution is given from the video below:

Exact Solution of the Nonlinear Pendulum
Flammable Maths
https://www.youtube.com/watch?v=efvT2iUSjaA

Watch and take notes from the video above.

Name: ______________________

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C.2 Wave Model

Understandings

- Transverse and longitudinal traveling waves.
- Wavelength λ, frequency *f*, time period *T*, and wave speed *v* applied to wave motion as given by $v = f\lambda = \frac{\lambda}{T}$.
- The nature of sound waves.
- The nature of electromagnetic waves.
- The differences between mechanical waves and electromagnetic waves.

Equations

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

The solutions can be found on the YouTube channel Go Physics Go:

https://www.youtube.com/@gophysicsgo/playlists

Use your favorite sources to answer the following questions

1. C: What is a *wave*? What do waves transfer? What do waves not transfer?

2. C: How are all waves created?

3. C: Define *medium.*

4. C: Define *vacuum.*

5. C: Define *mechanical wave.* Give an example.

6. C: Define *electromagnetic waves*. Give some examples.

7. C: List the seven electromagnetic waves in order of decreasing wavelength λ, increasing frequency f, and increasing energy $E = hf$.
   a.

   b.

   c.

   d.

   e.

   f.

   g.

8. C: State the meaning of ROY G BIV
   https://www.youtube.com/watch?v=wfIgC_PRTVc

9. C: Define *longitudinal wave*. Give an example.

10. C: Define *compression.*

11. C: Define *rarefaction.* Do not confuse *rarefaction* with *refraction*!

12. C: **Use a pencil and ruler!** Draw a *longitudinal wave*. Label the *compression* and *rarefaction*.

13. C: Define *transverse wave.* Give an example.

14. C: Define *crest.*

15. C: Define *trough.*

16. C: **Use a pencil and ruler!** Draw a *transverse wave*. Label the *crest* and *trough*.

17. C: Define *wavelength* λ. Units?

18.C: Define *period* T. Units?

19.C: Define *frequency* f. Units?

20.C: State the equation which relates the *speed*, *wavelength*, and *frequency* of a wave.

21.E: What will be the wavelength of a wave which has a wave speed of 0.560 m/s and a frequency of 4.40 Hz?

22.E: A wave has a period of 2.20 s. What is the frequency of this wave?

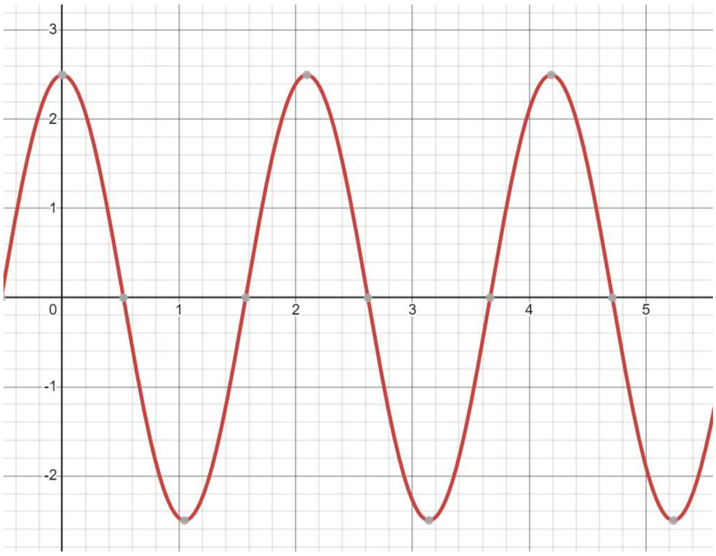
23.E: A wave has a frequency of 14.0 Hz. What is the period of this wave?

24.E: You are at the beach sitting on a pier in the water and you notice that the water level where you are sitting rises and falls once every 4.10 s. What is the frequency of these waves?

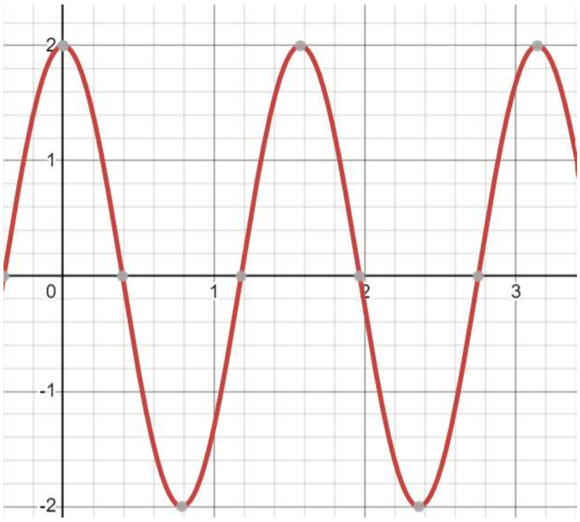
25.E: A wave has a frequency of 5.50 Hz and a wavelength of 2.50 m. What is the speed of this wave?

26.C: What information can we obtain from a *displacement vs. distance* graph?

27.E A *displacement vs. distance* graph of a sound wave traveling at 340. m/s is shown below. Both the vertical axis and the horizontal axis are in meters. Determine the amplitude, wavelength, frequency, and period of the wave.

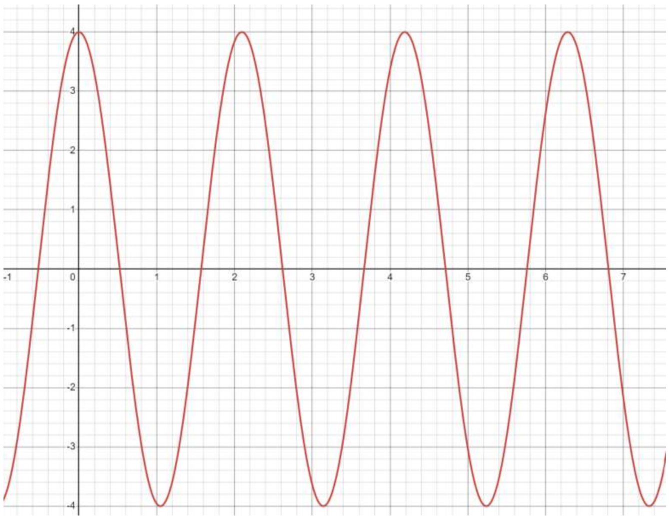


28.E A *displacement vs. distance* graph of an electromagnetic wave traveling at $3.00 \times 10^{8}\ \frac{\mathrm{m}}{\mathrm{s}}$ is shown below. The vertical axis is in meters while the horizontal axis is in 10^{-6} m. Determine the amplitude, wavelength, frequency, and period of the wave.

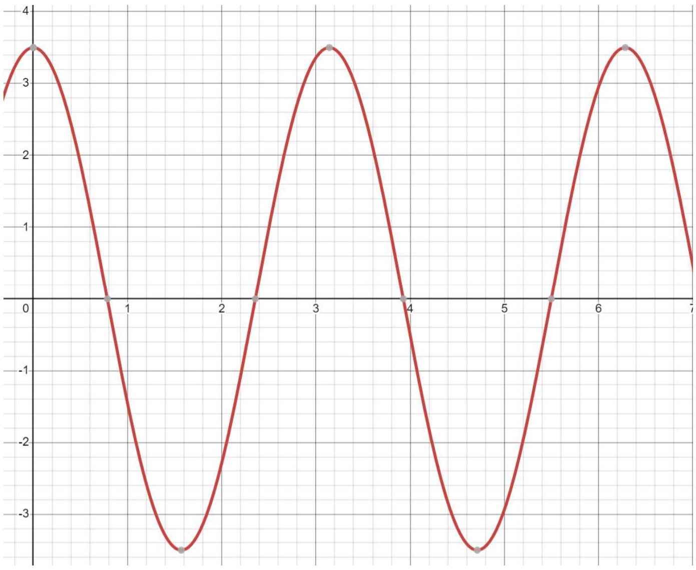


29.C: What information can we obtain from a *displacement vs. time* graph?

30.E A *displacement vs. time* graph of a sound wave traveling at 340. m/s is shown below. The vertical axis is in meters and the horizontal axis is in seconds. Determine the amplitude, period, frequency, and wavelength of the wave.



31.E: A *displacement vs. time* graph of an electromagnetic wave traveling at $3.00 \times 10^8\ \frac{\text{m}}{\text{s}}$ is shown below. The vertical axis is in meters and the horizontal axis is in 10^{-6} seconds. Determine the amplitude, period, frequency, and wavelength of the wave.



32.C: Define *intensity*. Units?

33.C: What is the mathematical relationship between the *intensity* and *amplitude* of a wave? What about the *energy* and *amplitude* of a wave?

34.E: An IB student sends a single wave pulse along a string such that the amplitude of the wave pulse is 0.440 m and the energy content of the pulse is 3.50 J.

a. Another IB student sends another single wave pulse along the same string with an amplitude of 0.880 m. What is the energy of the second wave pulse?

b. What is the energy of a third wave pulse if the amplitude of the third wave is 0.220 m?

35.E: An IB student sends a single wave pulse along a string such that the amplitude of the wave pulse is 0.555 m and the energy content of the pulse is 3.33 J.

a. Another IB student sends another single wave pulse along the same string with an amplitude of 0.111 m. What is the energy of the second wave pulse?

b. What is the energy of a third wave pulse if the amplitude of the third wave is 0.444 m?

36.C: What is the mathematical relationship between the *intensity* and *distance* from a wave source?

37.E: An IB student has a really loud and annoying physics teacher. When the student is 12.5 m from his teacher he measures a sound intensity of 145 decibels. What would be the measured intensity of the loud and annoying physics teacher if a student is 20.0 m from the source?

38.E: An IB student has a really soft and gentle physics teacher. When the student is 20.5 m from his teacher he measures a sound intensity of 12.0 decibels. At which distance does the IB student need to be from his teacher to hear the teacher with a sound intensity of 30.5 decibels?

39.C: Imagine a boat which is in the middle of the ocean. Several water waves passes under it. What happens to the boat? Does it oscillate vertically (up and down)? Does it oscillate horizontally (left and right)? Both? Neither?

40.C: What is the speed of sound in a vacuum? In air? In a metal?

41.C: What is the speed of an electromagnetic wave in a vacuum? In air? In a metal?

42.C: For sound waves pitch is directly proportional to ___________ and loudness is directly proportional to ___________.

43.E: The speed of sound waves at 25.0°C is 346 m/s. What will be the wavelength of a sound wave which has a frequency of 512 Hz under these conditions?

44.E: The speed of light waves is $3.00 \times 10^8 \ \frac{\mathrm{m}}{\mathrm{s}}$ in a vacuum. What will be the wavelength of the radio signal generated by WCBS FM, given that the frequency assigned to it by the FCC is 101 MHz?

Name: ______________________

Class: ______________________

Due Date: ______________________

C.3 Wave Phenomena

Understandings

- Waves traveling in two and three dimensions can be described through the concepts of wavefronts and rays.
- Wave behavior at boundaries in terms of reflection, refraction, and transmission.
- Wave diffraction around a body and through an aperture.
- Wavefront-ray diagrams showing refraction and diffraction.
- Snell's law, critical angle, and total internal reflection.
- Snell's law as given by $\frac{n_1}{n_2} = \frac{\sin\theta_2}{\sin\ {}_1} = \frac{v_2}{v_1}$ where *n* is the refractive index and θ is the angle between the normal and the ray.
- Superposition of waves and wave pulses.
- Double-source interference requires coherent sources.
- The condition for constructive interference as given by path difference $= n\lambda$.
- The condition for destructive interference as given by path difference $= \left(n + \frac{1}{2}\right)\lambda$.
- Young's double-slit interference as given by $s = \frac{\lambda D}{d}$ where *s* is the separation of fringes, *d* is the separation of the slits, and *D* is the distance from the slits to the screen.

Equations

$$\frac{n_1}{n_2} = \frac{\sin\ {}_2}{\sin\theta_1} = \frac{v_2}{v_1}$$

Constructive interference: path difference $= n\lambda$

Destructive interference: path difference $= \left(n + \frac{1}{2}\right)\lambda$

$s = \frac{\lambda D}{d}$

Additional HL Understandings

- Single-slit diffraction including intensity patterns as given by $\theta = \frac{\lambda}{b}$ where b is the slit width.
- The single-slit pattern modulates the double slit interference pattern.
- Interference patterns from multiple slits and diffraction gratings as given by $n\lambda = d\sin\theta$.

Additional HL Equations

$\theta = \frac{\lambda}{b}$

$n\lambda = d\sin\theta$

The solutions can be found on the YouTube channel Go Physics Go:

https://www.youtube.com/@gophysicsgo/playlists

Use your favorite sources to answer the following questions

1. C: Define *wavefront.*

2. C: Define *ray.*

3. E: **Use a pencil and ruler!** Draw 3 wavefronts and 6 rays after a small rock falls vertically and hits water.

4. E: **Use a pencil and ruler!** Draw 2 wavefronts and 8 rays after a long thin rod falls horizontally and hits water.

5. C: Define *superposition.*

6. C: **Use a pencil and ruler!** Draw a before, during, and after image of two pulses on a rope traveling in opposite directions which go through constructive interference.

7. C: **Use a pencil and ruler!** Draw a before, during, and after image of two pulses on a rope traveling in opposite directions which go through destructive interference.

8. C: **Use a pencil and ruler!** Draw a before and after image of a single pulse wave on a string striking and being reflected from a vertical pole with a fixed end.

9. C: **Use a pencil and ruler!** Draw a before and after image of a single pulse wave on a string striking and being reflected from a vertical pole with a free/loose end.

10.C: What is the equation, units, and meaning of *index of refraction n*? What is the range of values for the *refractive index* of an object? What is the *refractive index* for a vacuum?

11.E: The speed of light in a vacuum is $3.00 \times 10^8\ \frac{\mathrm{m}}{\mathrm{s}}$ while the speed of light in a diamond is measured to be $1.24 \times 10^8\ \frac{\mathrm{m}}{\mathrm{s}}$. What is the index of refraction of diamond?

12.E: The index of refraction of light in water is $n_{\mathrm{water}} = 1.33$. What is the speed of light in water?

13.E: Light, which has a wavelength of $\lambda = 450\ \mathrm{nm}$, is moving through Carbon Tetrachloride with a speed of $2.056 \times 10^8\ \frac{\mathrm{m}}{\mathrm{s}}$.

a. What is the index of refraction of Carbon Tetrachloride?

b. What is the frequency of this light wave as it passes through the Carbon Tetrachloride?

c. What will be the corresponding wavelength of this light wave in air?

14.E: Light, which has a wavelength of 625 nm in air, enters flint glass. The index of refraction of flint glass is approximately 1.63.

a. What is the speed of light in flint glass?

b. What will be the wavelength of this light within the glass?

c. What is the frequency of this light within the glass?

d. What is the frequency of this light in air?

15.C: **Use a pencil and ruler!** Define *reflection* and draw a labeled figure.

16.C: State the equation for the *law of reflection*.

17.C: **Use a pencil and ruler!** Define *refraction* and draw a labeled figure. (Do not confuse *refraction* with *rarefaction*!)
https://physics.bu.edu/~duffy/HTML5/refraction_block.html
https://physics.bu.edu/~duffy/HTML5/refraction.html

18.C: State the equation for refraction: *Snell's law*. **Use a pencil and ruler!** Draw an image describing *Snell's law*.

19.C: **Use a pencil and ruler!** Draw a detailed image of a ray traveling from a fast medium to a slow medium.

20.C: **Use a pencil and ruler!** Draw a detailed image of a ray traveling from a slow medium to a fast medium.

21.C: **Use a pencil and ruler!** Define *dispersion* and draw a labeled figure.

22.E: A wave, which has a wavelength of 1.40 m and a wave speed of 4.80 m/s, enters a second medium where the wavelength is reduced to 0.900 m. What will be the wave speed in the second medium?

23. A wave moving with a speed of 38.0 cm/s and having a wavelength of 4.50 cm strikes an interface at an angle of 57.0° relative to the normal. In the second medium the speed of the wave is reduced to 24.0 cm/s.

a. What will be the angle of the wave in the second medium?

b. What will be the wavelength in the second medium?

c. What will be the frequency of this wave in the first medium?

d. What will be the frequency of this wave in the second medium?

e. Which medium has a higher index of refraction?

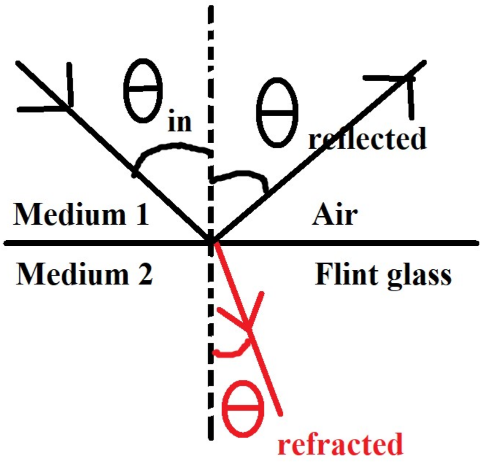
24.E: A wave moving with a speed of 1.25 m/s strikes an interface at an incident angle of 82.0°. After passing through the interface the angle shifts to 55.0° and the wavelength becomes 5.60 cm.

a. What will be the speed of this wave in the second medium?

b. What will be the wavelength in the first medium?

c. What will be the frequency in the second medium?

25.E: A light ray, which has a wavelength of 580 nm, strikes a horizontal interface going from air into flint glass. Given that the angle between the incident light ray and the normal to the interface is 47.0°. The index of refraction of flint glass is approximately 1.63.



a. What will be the corresponding angle in the flint glass?

b. What will be the wavelength of this light within the flint glass?

c. What will be the frequency of this light within the flint glass?

d. Some of the light reflects at the interface. What will be the angle between the reflected light ray and the normal to the interface?

26.E: A light beam traveling through glycerol, which has an index of refraction of 1.48, encounters an interface at an angle of 67.0° relative to the normal to the surface. The corresponding angle in the second medium is measured to be 50.5°. What is the index of refraction of the second medium?

27.E: A light wave moving through an unknown medium encounters an interface at an angle of 52.0° and then refracts to an angle of 45.2° into Lucite, which has an index of refraction of 1.50. What is the index of refraction of the first medium?

28.C: **Use a pencil and ruler!** Define *total internal reflection* and *critical angle*. Draw a labeled figure.

29.E: A light beam is moving from flint glass into water. What is the critical angle between these two mediums? The index of refraction of flint glass is 1.63 while the index of refraction of water is 1.33.

30.E: Determine the critical angle between the following two media:

a. diamond ($n = 2.42$) and water ($n = 1.33$)

b. alcohol ($n = 1.36$) and Lucite ($n = 1.50$)

c. Hot air ($n = 1.02$) and room temperature ($n = 1.00$)

31.C: Define *diffraction*. Give two examples.

32.C: What is the relationship between the slit width and wavelength of the wave which gives maximum diffraction?

33.C: What is the relationship between the slit width and wavelength of the wave which gives minimum diffraction?

34.C: Light passes through a slit which is equal to the lights wavelength. What happens to the intensity of the central maximum as the slit width decreases?

35.C: **Use a pencil and ruler!** Draw an intensity vs. displacement graph for *single source interference*.

36.C: For double source interference state the equations for

a. constructive interference:

b. for destructive interference:

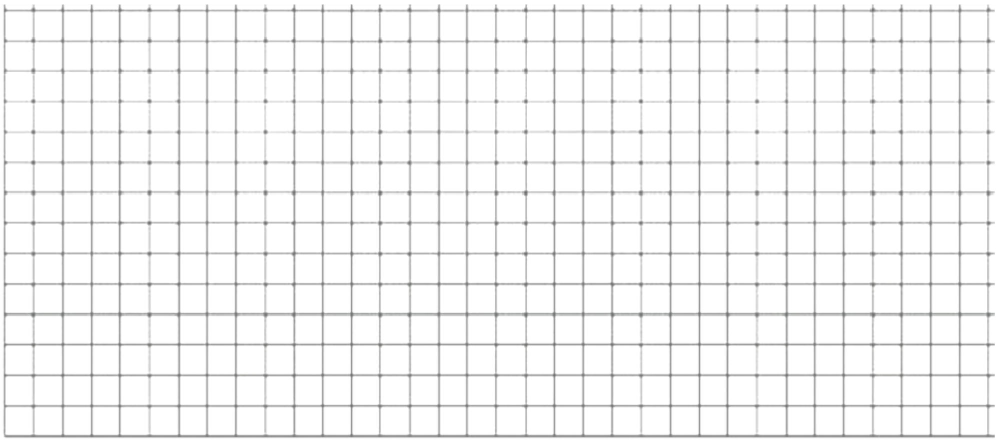
37.C: The equation for double slit wave interference is $s = \frac{\lambda D}{d}$. Define the following variables and draw a neat and detailed intensity vs. displacement graph for double slit interference:

s:

λ:

D:

d:



38.E: You are looking at a sodium discharge tube with $\lambda = 5{,}890$ Angstroms through a double slit which has a distance of 0.170 millimeters between the centers of the two slits. The light source is placed 1.20 m from the double slit. What will be the distance between the interference fringes visible on the screen?
https://www.physicsclassroom.com/Physics-Interactives/Light-and-Color/Youngs-Experiment/Youngs-Experiment-InteractiveV1

Additional HL Content

39.C: **Use a pencil!** Draw the lab setup and the intensity vs. distance graph for single slit diffraction.

40.C: Derive the equation $\theta = \frac{\lambda}{b}$. Define each variable.

41.C: What will happen to the thickness of the central maximum $2\theta = \frac{2\lambda}{b}$ if

a. the wavelength λ of a wave passing through a single slit is increased?

b. the wavelength λ of a wave passing through a single slit is decreased?

c. the opening of a single slit b is increased?

d. the opening of a single slit b is decreased?

42.C: What happens when white light passes through a single slit?

43.E: A monochromatic light source with a wavelength of 5,500 Angstroms is shined through a single slit onto a screen placed 75.0 cm from the slit. The distance between the center of the central antinode and the first node is measured to be 1.10 mm.

a. What is the width of the single slit?
https://sciencesims.com/sims/single-slit/

b. How far from the center of the central antinode will the fourth order node be found?

c. How far from the center of the central antinode will the second order antinode be found?

44.C: **Use a pencil!** Draw an intensity vs. displacement graph for Young's double slit experiment.
https://sciencesims.com/sims/double-slit/

https://www.physicsclassroom.com/Physics-Interactives/Light-and-Color/Youngs-Experiment/Youngs-Experiment-InteractiveV1

45.C: State the equation for double slit **constructive interference** and define each variable.

46.C: State the equation for double slit **destructive interference** and define each variable.

47.C: **Use a pencil and ruler!** Go to the following websites and carefully draw an *intensity vs. distance* graph for the following number of slits:

For one slit: https://sciencesims.com/sims/single-slit/
For 2-10 slits: https://www.geogebra.org/m/g6fsxcyn

One slit
Two slits
Three slits
Four slits

Five slits
Six slits
Seven slits
Eight slits
Nine slits

Ten slits

48.C: Describe the meaning of the single slit *envelope*.

49.C: What happens to the intensity pattern as the number of slits increases?
https://www.geogebra.org/m/g6fsxcyn

50.C: What is a *diffraction grating*? What is its purpose?

51.C: Describe the equation $n\lambda = d \sin\theta$ for multiple slit diffraction.

52.E: While observing a gas discharge tube through a diffraction grating, which has 600 slits/mm, you note that the first bright yellow emission line is visible at an angle of 20.6° from the center antinode. What is the wavelength of this yellow light?

53.E: A diffraction grating which contains 600 slits/mm is used to observe a gas discharge tube containing mercury gas and the first bright violet light is visible at an angle of 15.1° from the central antinode.

a. What is the wavelength of this light?

b. At what angle will the second order antinode appear?

54.E: While looking through a diffraction grating at a nitrogen discharge tube you note that light with a known wavelength of 5679 angstroms is visible at an angle of 37.0° from the central antinode. How many slits are there in this diffraction grating for each millimeter of width?

55.E: You are looking through a diffraction grating, which contains 520. slits for each millimeter of width, at a light source emitting light with a wavelength of 5890 angstroms. At which angles will the first and second order antinodes be visible?

Name: ______________________

Class: ______________________

Due Date: ______________________

C.4 Standing Waves and Resonance

Understandings
- The nature and formation of standing waves in terms of superposition of two identical waves traveling in opposite directions.
- Nodes and antinodes, relative amplitude, and phase difference of points along a standing wave.
- Standing waves patterns in strings and pipes.
- The nature of resonance including natural frequency and amplitude of oscillation based on driving frequency.
- The effect of damping on the maximum amplitude and resonant frequency of oscillation.
- The effects of light, critical, and heavy damping on the system.

You need to watch animations on ***standing waves*** to perfectly understand it!:

https://www.acs.psu.edu/drussell/Demos/StandingWaves/StandingWaves.html

Topics C.1-C.3 dealt with **traveling waves**.
Topic C.4 deals with **standing waves**.
Please treat **standing waves** and **traveling waves** differently!

Something to think about: Imagine plucking a string from a musical instrument. What is happening in terms of physics and waves?

There are three popular examples of standing waves:
- Waves on a string (guitar) (closed closed)
- Sound waves in a pipe (flute) (open closed or open open)
- A vertical pipe with the top end open and the bottom end in water. The vertical pipe can be raised and lowered to change its length. A tuning fork is placed on top of the vertical pipe. (open closed)

The solutions can be found on the YouTube channel Go Physics Go:

https://www.youtube.com/@gophysicsgo/playlists

1. C: List some observations which can be made from standing waves but not traveling waves.

2. C: Define the following terms:

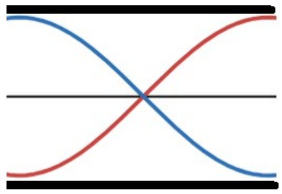
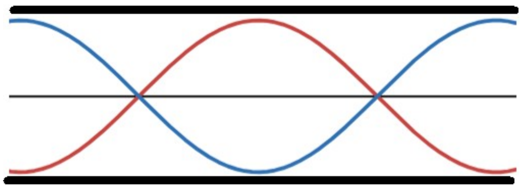
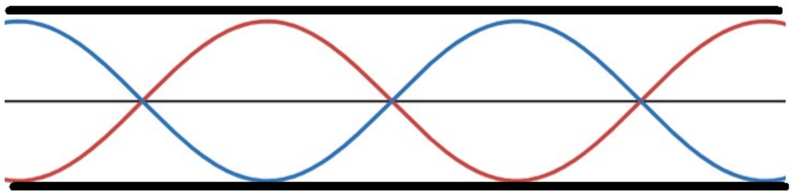
    a. Node:

    b. Anti-node:

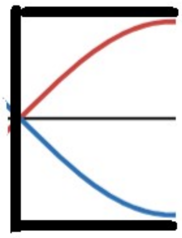
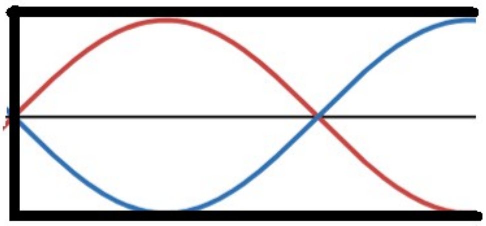
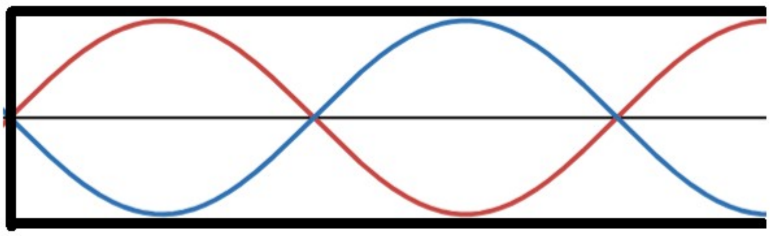
    c. First harmonic:

    d. Fundamental frequency:

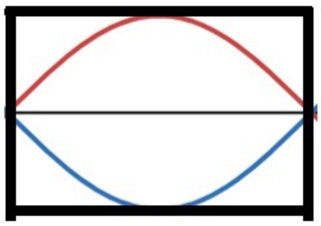
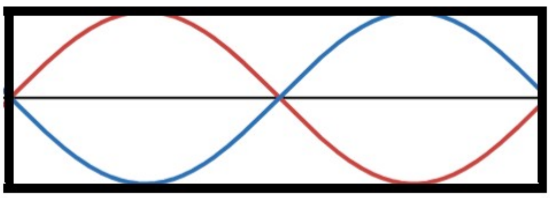
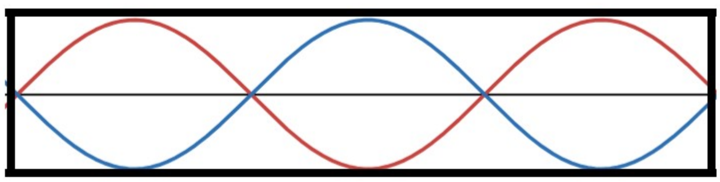
3. C: **Use a pencil and ruler!** Below are the first three harmonics of a tube with both ends open. The frequencies of the first three harmonics are derived for you. Draw and solve for the next three frequencies on the next page.

	$L = \frac{\lambda}{2}$ $\lambda = 2L$ $v = \lambda f$ $v = 2Lf$ $f = \frac{v}{2L}$
	$L = \lambda$ $\lambda = L$ $v = \lambda f$ $v = Lf$ $f = \frac{v}{L}$
	$L = \frac{3\lambda}{2}$ $\lambda = \frac{2L}{3}$ $v = \lambda f$ $v = \frac{2Lf}{3}$ $f = \frac{3v}{2L}$

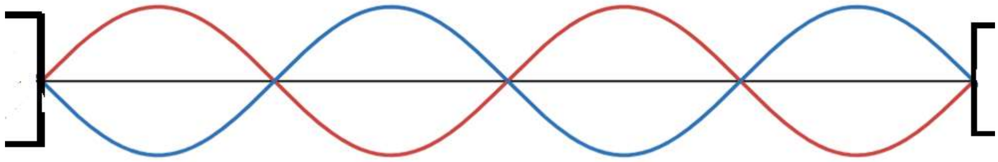
4. C: **Use a pencil and ruler!** Below are the first three harmonics of a tube with one end open and one end closed. The frequencies of the first three harmonics are derived for you. Draw and solve for the next three frequencies on the next page.

	$L = \frac{\lambda}{4}$ $\lambda = 4L$ $v = \lambda f$ $v = 4Lf$ $f = \frac{v}{4L}$
	$L = \frac{3\lambda}{4}$ $\lambda = \frac{4L}{3}$ $v = \lambda f$ $v = \frac{4Lf}{3}$ $f = \frac{3v}{4L}$
	$L = \frac{5\lambda}{4}$ $\lambda = \frac{4L}{5}$ $v = \lambda f$ $v = \frac{4Lf}{5}$ $f = \frac{5v}{4L}$

5. C: **Use a pencil and ruler!** Below are the first three harmonics of a tube with both ends closed. The frequencies of the first three harmonics are derived for you. Draw and solve for the next three frequencies on the next page.

	$L = \frac{\lambda}{2}$ $\lambda = 2L$ $v = \lambda f$ $v = 2Lf$ $f = \frac{v}{2L}$
	$L = \lambda$ $\lambda = L$ $v = \lambda f$ $v = Lf$ $f = \frac{v}{L}$
	$L = \frac{3\lambda}{2}$ $\lambda = \frac{2L}{3}$ $v = \lambda f$ $v = \frac{2Lf}{3}$ $f = \frac{3v}{2L}$

6. E: A string is stretched between two rigid supports which are 1.20 m apart. The string is plucked and it is noted that a standing wave is formed on the string which consists of five nodes, including the endpoints, and four antinodes.

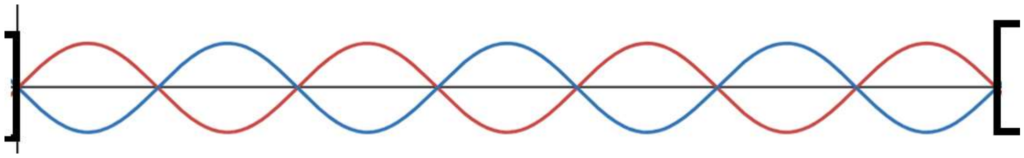


a. What is the wavelength of this standing wave?

b. If the frequency of this vibration is 220. Hz then what is the frequency of the fundamental frequency which will vibrate in this string?

c. What will be the frequency of the fifth harmonic which will vibrate in this string?

7. E: Transverse waves are being generated in a string between two fixed points which are 3.50 m apart by a wave oscillator which is generating a frequency of 28.0 Hz.



a. What is the wavelength of the wave?

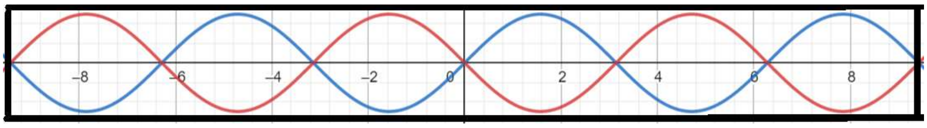
b. What is the speed of the wave?

c. What is the lowest frequency which could be used to generate a standing wave in this string?

d. What is the wavelength of the lowest frequency wave which could form a standing wave in the string?

e. What other frequencies could form standing waves in the string?

8. E: Consider the string vibrating below and forming a standing wave with a frequency of 180. Hz. The length of this string is 1.50 m.



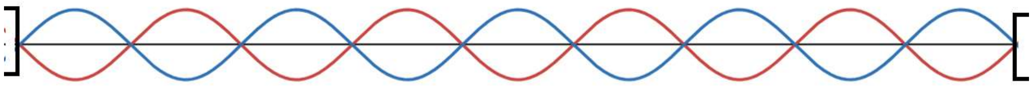
a. What is the wavelength of the wave?

b. What is the speed of the wave?

c. What is the fundamental frequency which will resonate in the string?

d. What will be the frequency of the third harmonic which will resonate in the string?

e. What will be the frequency of the ninth harmonic which will resonate in the string?

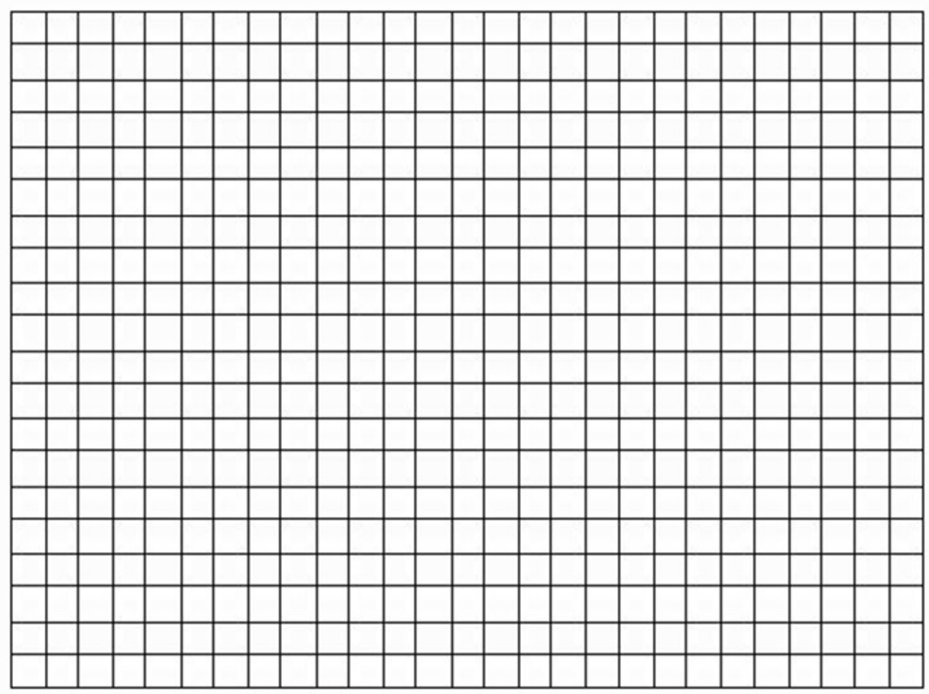


9. C: What is a *restoring force*?

10. C: What are some characteristics for *simple harmonic motion?*

11. C: Define *free oscillation.*

12. C: **Use a pencil!** Label and draw a *displacement vs. time* graph for a *free oscillation.*



13.C: Define *damping*.

14.C: Define *underdamping* (or *light damping*).

15.C: **Use a pencil!** Label and draw a *displacement vs. time* graph for an *underdamped system.*

16.C: Define *overdamped motion*.

17.C: **Use a pencil!** Label and draw a *displacement vs. time* graph for *overdamped* motion.

18.C: Define *critically damped motion*.

19.C: **Use a pencil!** Label and draw a *displacement vs. time* graph for a *critically damped system.*

20.C: What is a *driving force?*

21.C: Define *natural frequency.*

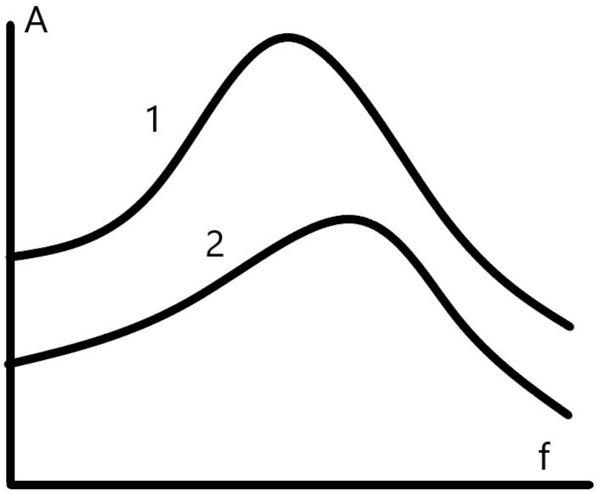
22.C: Define *resonance*. When does *resonance* occur?

23.C: What happens to the amplitude of an object when the *natural frequency* of the object is much lower or much higher than the *driving frequency*?

24.C: What happens to the amplitude of an object when the *natural frequency* of the object is approximately equal to the *driving frequency*?

25.C: Draw an *amplitude vs. frequency* graph of an object oscillating with a driving force and a damping force.

26.E: Two oscillators are experiencing forced oscillations at a frequency near to the natural frequency of each oscillator. The graph below shows the amplitude with forcing frequency for each oscillator:



a. Which system, 1 or 2, has a greater amount of damping?

b. Which system, 1 or 2, has a greater natural frequency of oscillation?

27.C: List some effects of resonance in the real world.

Name: ______________________

Class: ______________________

Due Date: ______________________

C.5 Doppler Effect

Understandings

- The nature of the Doppler effect for sound waves and electromagnetic waves.
- The representation of the Doppler effect in terms of wavefront diagrams when either the source or the observer is moving.
- The relative change in frequency or wavelength observed for a light wave due to the Doppler effect where the speed of light is much larger than the relative speed between the source and the observer as given by $\frac{\Delta f}{f} = \frac{\Delta \lambda}{\lambda} \approx \frac{v}{c}$.
- Shifts in spectral lines provide information about the motion of bodies like stars and galaxies in space.

Equations

$$\frac{\Delta f}{f} = \frac{\Delta \lambda}{\lambda} \approx \frac{v}{c}$$

Additional HL Understandings

- The observed frequency for sound waves and mechanical waves due to the Doppler effect as given by:
  moving source $f' = f\left(\frac{v}{v \pm u_s}\right)$ where u_s is the velocity of the source
  moving observer $f' = f\left(\frac{v \pm u_o}{v}\right)$ where u_o is the velocity of the observer.

Additional HL Equations

Moving source: $f' = f\left(\frac{v}{v \pm u_s}\right)$

Moving observer: $f' = f\left(\frac{v \pm u_0}{v}\right)$

The solutions can be found on the YouTube channel Go Physics Go:

https://www.youtube.com/@gophysicsgo/playlists

1. C: Define the *Doppler effect*.

2. C: **Use a pencil!** Draw a wavefront diagram for a moving source and stationary observer in front of the source and behind the source.

3. C: **Use a pencil!** Draw a wavefront diagram for a stationary source and moving observer in front of the source and behind the source.

4. C: Describe the equation $\frac{\Delta f}{f} = \frac{\Delta \lambda}{\lambda} \approx \frac{v}{c}$ and define each variable.

5. C: Describe the term *red shift*.

6. C: Describe the term *blue shift*.

7. C: Describe the term *expanding universe*.

8. C: A train approaches and then passes a train station with a constant speed. During the whole time the train is emitting a sound. Draw a *frequency vs. time* graph of the observed frequency measured by the people at the train station.

9. C: An accelerating train approaches and then passes a train station. During the whole time the train is emitting a sound. Draw a *frequency vs. time* graph of the observed frequency measured by an observer at the train station.

10. E: An element on Earth has one emission wavelength of 8.67×10^{-7} m. This same element, when detected from a moving distant galaxy, has the same emission wavelength of 3.09×10^{-7} m.

    a. Is this galaxy moving towards or away from Earth?

    b. What is the speed of this moving galaxy?

11. E: This is the classic "the emitter becomes the detector" problem! A stationary police car emits a microwave with a frequency of 3.00×10^{10} Hz to an approaching car. The microwave is reflected off the moving car and is received by the stationary police car. The police car detects that the frequency is altered by 6.00×10^{3} Hz.

    a. What is the wavelength of the microwave being emitted by the police car?

    b. What is the speed of the approaching car?

    c. How much has the wavelength altered?

Additional HL Content

12.C: Describe the equations for the Doppler effect given in the IB physics data booklet.

13. E: Late to class! Usain Bolt runs towards his physics class with a constant speed of 10.44 m/s while blasting music from his boom box which emits a frequency of 440. Hz. What is the observed frequency and wavelength detected by the students in his physics classroom? The speed of sound in air at sea level is approximately 340.29 m/s.

14. E: Class ends! Usain Bolt runs away from his physics class towards the cafeteria with a constant speed of 10.44 m/s while blasting music from his boom box which emits a frequency of 440. Hz. What is the observed frequency and wavelength detected by the students in his physics classroom? The speed of sound in air at sea level is approximately 340.29 m/s.

15. E: Late to class! Usain Bolt runs towards his physics class with a constant speed of 10.44 m/s. He can hear his physics teacher lecturing with frequency of 440. Hz. What is the observed frequency and wavelength detected by Usain Bolt as he is running towards his physics class? The speed of sound in air at sea level is approximately 340.29 m/s.

16.E: Class ends! Usain Bolt runs away from his physics class to the cafeteria with a constant speed of 10.44 m/s. He can hear his teacher continue to lecture with frequency of 440. Hz. What is the observed frequency and wavelength detected by Usain Bolt as he is running towards the cafeteria? The speed of sound in air at sea level is approximately 340.29 m/s.

17.E: This is the classic "the emitter becomes the detector" problem! An emitter at rest emits a sound wave of frequency 3.00×10^4 Hz towards a car. The wave is reflected back to the emitter. The emitter now becomes the receiver. The receiver receives the sound wave with a frequency of 2.90×10^4 Hz. The speed of sound is $3.30 \times 10^2 \ \frac{\mathrm{m}}{\mathrm{s}}$. Determine the speed of the car.

18.E: This is another classic "the emitter becomes the detector" problem! An emitter at rest emits a sound wave of frequency 3.00×10^4 Hz towards a car. The wave is reflected back to the emitter. The emitter now becomes the receiver. The receiver receives the sound wave with a frequency of 3.10×10^4 Hz. The speed of sound is $3.30 \times 10^2\ \frac{\mathrm{m}}{\mathrm{s}}$. Determine the speed of the car.