PCS125 Lecture 1 CH 15 Jan 9, 2018 Lei Yu

Wave Model: an organized disturbance propagating across space in a medium or field

Phet simulations

Wave: collective motion of particles

Simple Harmonic Motion

- The simple harmonic oscillator is a mass on a spring undergoing oscillations.
- Hooke's Law $\vec{F}_s = -k\vec{x}_{stretch}$, $\vec{x}_{stretch}$ defined from resting position

$[k] = \frac{N}{m}$

- Potential energy of the oscillator $U_{osc} = \frac{1}{2}k(\vec{x}_{stretch})^2$

$x(t) = A\cos(\omega t + \phi)$, $-A \le x(t) \le A$

Amplitude $[\omega t] = rad$ Phase constant

$\omega = \sqrt{\frac{k}{m}}$ $[\omega] = rad/sec$ $\omega = 2\pi f$

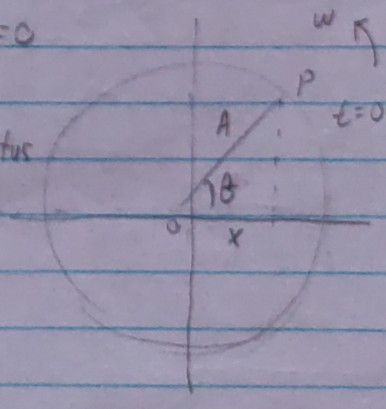
$\omega T = 2\pi \Rightarrow \boxed{T_{spring} = \frac{2\pi}{\omega} = 2\pi\sqrt{\frac{m}{k}}}$ $\boxed{f = \frac{1}{T} = \frac{\omega}{2\pi} = \frac{1}{2\pi}\sqrt{\frac{k}{m}}}$

Oscillation to uniformed circular motion

- Radius and angular velocity is related to period.
- The circle with A (oscillation amplitude) as the radius is called a reference circle.
- Line OP makes an angle ϕ with the $+x$ at $t=0$

phase $\theta = \omega t + \theta$, position needs direction,

ϕ is initial angle phase is easier way to describe status



$V_{max} = \omega A$, x component of P is velocity

$V = -\omega A\sin(\omega t + \phi)$

if $-\omega$, rotate clock wise, all other instance CCW. $x(t) = A\cos\theta = A\cos(\omega t + \phi)$

$T = 2\pi\sqrt{\frac{L}{g}}$, $x = Ae^{-bt/2m}$

$w = \sqrt{\frac{g}{L}}$

SHO require a force that pulls back

↓

equation in the form $F = -k\vec{x}$ defines a SHM

Angular frequecy, period, and frequency only depend on the spring constant and mass.

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

To pinpoint phase constant require velocity of particle.

$a(t) = -Aw^2\cos(wt + \phi)$ $a_{max} = +Aw^2 = \frac{Ak}{m}$

Energy of SHO

- In SHO mechanical energy is converted from PE to KE and back

$E_{Tot} = \frac{1}{2}kA^2 = \frac{1}{2}mv^2 + \frac{1}{2}kx^2$

$A^2 = \frac{m}{k}v^2 + x^2 = \frac{v_{max}^2}{w^2} + x^2$ $A^2 = \frac{v_{max}^2}{w^2} + x^2$

Pendulum Jan 16, 2018

Simple Pendulum

- Cosist of particle like mass m, and string length L_0. $m_{string} < m_{mass}$
- driven by gravitational force
- Very similar to SHO if $\theta < 10°$

$\theta = \theta_{max}\cos(wt + \phi)$, $w = \sqrt{\frac{g}{L}}$, $T = 2\pi\sqrt{\frac{L}{g}}$

$L\uparrow$, $T\uparrow$

$g\uparrow$, $T\downarrow$

larger driving force period will be smaller.

Physical Pendulum

- occilates about a fixed axis, not CM
- object can't be approximated as a point mass.
- Can not be treated as simple pendulum.
- F_g provides torque about pivot.
- Magnitude of torque is $mgd\sin\theta$, d is lever arm from pivot to CM.

Physical Pendulum, 2 Jan 16, ~~2018~~ 2018

$F = ma$ assume θ is small

$T = I\frac{d\theta^2}{dt^2}$

$~~-mgd\sin\theta~~ = I\frac{d^2\theta}{dt^2}$

d, distance from pivot to center of mass

$\omega = \sqrt{\frac{mgd}{I}}$

$T = 2\pi\sqrt{\frac{I}{mgd}}$

Physical Pendulum, 4 if $I = md^2$

$I = mL^2$, $d = L$ Physical to Simple

$$w = \sqrt{\frac{mgd}{I}} = \sqrt{\frac{mgL}{mL^2}} = \sqrt{\frac{g}{L}}$$

Torsional Pendulum

$T = -k\theta$

K, torsion constant

Damped Example

- Retarding Force

$\vec{R} = -b\vec{v}$ -b is a constant

-b is damping coefficient

$\sum F_x = -kx - bv_x = ma_x$ $X = Ae^{-bt/2m}$

if b is small compared to maximum restoring force

- $x = Ae^{-(b/2m)t}\cos(\omega t + \phi)$ "$Ae^{-(\frac{b}{2m})t}$" is amplitude at t.

4A is amplitud at $t = 0$

- Angular frequency will be $w = \sqrt{\frac{k}{m} - \left(\frac{b}{2m}\right)^2}$ ← b have to make sure Γ not negative

if negative not an oscillation anymore

$w = \sqrt{w_0^2 - \left(\frac{b}{2m}\right)^2}$, w_0 is natural frequency $T = \frac{2\pi}{w}$

$w_0 = \sqrt{\frac{k}{m}}$

Types of Damping

· if restoring force is such that $b/2m < \omega_0$, the system is said to be underdamped.

Smaller the mass
highter damping force
come to rest faster

Critically damped
- come to rest fastest, no oscillation

Over damped
- Come to rest slowest, no oscillation.

Forced Oscillation

· external oscillating (driving) force is applied at a frequency close to the natural frequency, can get very large

Driving force → $F = F_0 \cos(\omega t)$, F_0 is amplitude of driving force
, ω is angular frequency of the driving force

$E_{driving} = E_{lose\ to\ internal}$, a steady state condition is reached.

⇓

$x = A\cos(\omega t + \phi_x)$, $$A = \frac{F_0/m}{\sqrt{(\omega^2 - \omega_0^2)^2 + \left(\frac{b\omega}{m}\right)^2}}$$

Resonance occured when $\omega_0 = \omega$.

PCS125 - CH16 From SHM to Wave   Jan 23, 2018   Lei Yu

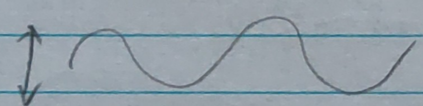
Wave: Propagated disturbance $\omega=\sqrt{\frac{k}{m}}$, is characteristic of the spring system.

Wave Characteristic:

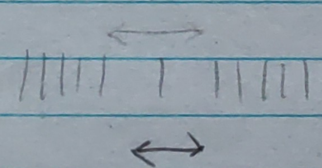
- Speed

Wave:

- A traveling disturbance, carries energy,
- travels through a medium (exception is light).
- light and sound
- Quantum mechanic says that particle also act as waves. (everything is waves)
- disturbance is the thing that moves
- particle says at same position of average.

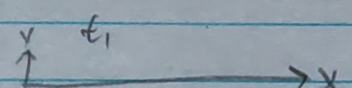


Transverse - the thing that is moving moves perpendicular to disturbance
(light)

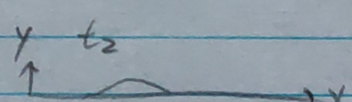


Longitudical - parallel to disturbance.
(sound)

$y(x,t)$ - displacement(y) of the string element at position x at time t.

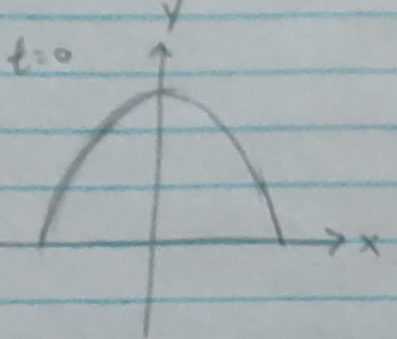


at time t_0, $y(x,t_0)$ describes shape of string at t_0



at position x_0, $y(x_0,t)$ describes what happens at x_0 as times goes one

$t=0$



$t=0$

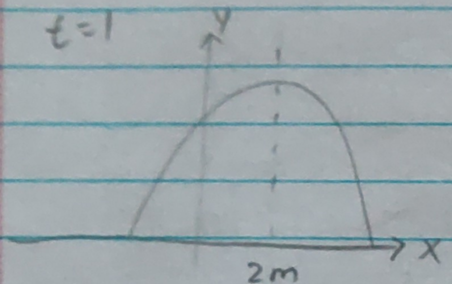
Assume

- shape doesn't change as it propagates
- speed is +2 m/sec
- what's the equation for the wave at $t=1$ sec?

$$y(x,0) = -ax^2 + b$$

↓ shift right 2m

$t=1$



$$y(x,1) = -a(x-2m)^2 + b$$

$$y(x,t) = -a\left[x - 2\tfrac{m}{s}(t)\right]^2 + b$$

$f(x)^2$ ↘

$y(x,t) = -a(x-vt)^2 + b$, wave at different speed

$y(x,t) = f(x-vt)$, $f(x)$ shape of wave.

<u>Sinusodial Wave</u> $\quad y(x,t) = A\sin[k(x-vt)]$

- A, amplitude
- $\frac{2\pi}{\lambda} =$ k, wave number (controls how closely the oscillations are)

<u>Wavelength and Period</u>

- Wavelength (λ), space between wave repeation
- Period (T), time for each iteration.

$$A\sin\theta = A\sin(\theta - 2\pi) \quad \text{and} \quad A\sin kx = A\sin(k(x-\lambda))$$

$$A\sin(kx) = A\sin(k(x-\lambda)) \qquad k\lambda = kx \qquad 2\pi = k\lambda$$

$$A\sin(kx - 2\pi) = A\sin(kx - k\lambda)$$

$$y(x,t) = A\sin\left[\frac{2\pi}{\lambda}(x-vt)\right] \Rightarrow y(x,t) = A\sin\left[\underbrace{\frac{2\pi}{\lambda}x}_{\phi} - \underbrace{\frac{2\pi}{\lambda}vt}_{\omega}\right]$$

$\omega = \frac{2\pi v}{\lambda}$, $T = \frac{\lambda}{v}$, a wave travels one λ in one T

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

PCS125 CH16 pg.2 Jan 23,2018

$$k = \frac{2\pi}{\lambda},\ w = \frac{2\pi}{T},\ \frac{w}{k} = V$$

Wave snapshot (x, t_0):
Graph history (x_0, t):

Oscillation speed of the element is

$$V_y = \left.\frac{dy}{dt}\right|_{x=constant} \qquad y(x,t) = A\sin[kx - wt + \phi]$$

or $V_y = -wA\cos(kx - wt + \phi) \Rightarrow V_{max} = wA$

Acceleration of element

$$a_y = \left.\frac{dV_y}{dt}\right|_{x=constant} \quad \text{or} \quad a_y = -w^2 A\sin(kx - wt + \phi) \quad a_{max} = Aw^2$$

Ex. $y(x,t) = 0.350\,m\ \sin\left[\left(\frac{10\pi\,rad}{sec}\right)t - \left(\frac{3\pi\,rad}{m}\right)x + \frac{\pi}{4}rad\right]$

$$\sin\theta = \sin(\pi - \theta) \Rightarrow y(x,t) = 0.35\sin\left(\pi - \left(wt - kx + \frac{\pi}{4}rad\right)\right)$$
$$= 0.35\sin\left(kx - wt + \frac{3}{4}\pi\right)$$

$$w = \frac{10\pi\,rad}{sec} = \frac{2\pi}{T} \Rightarrow T = \frac{1}{5}\,second \Rightarrow f = \frac{1}{T} = 5Hz$$

$$k = \frac{3\pi}{m} = \frac{2\pi}{\lambda} \Rightarrow \lambda = \frac{2}{3}m$$

$$V = \frac{\lambda}{T} \quad \text{or} \quad V = \frac{w}{k}$$

$V_{y\,max} = wA$
$A = 0.35m$

Ex 16.2

$A = 15.0m$

$\lambda = 40cm$

$f = 5Hz$

$\uparrow + $

Goal: A, k, w, ϕ

$$k = \frac{2\pi}{\lambda} = \frac{2\pi}{40cm} = \frac{\pi}{20}cm$$

$$w = 2\pi f = 10\pi$$

$y(t=0, x=0) = 7.5cm$

$v_y(t=0, v=0) < 0$

$$y(0,0) = 7.5 = A\sin(wt + kx + \phi)$$

$$= 15\sin(-2\pi(5)t + \cancel{\tfrac{2\pi}{40}x} + \phi)$$

$$\frac{1}{2} = \sin(-10\pi + \theta$$

$$10\pi + \frac{\pi}{6} = \theta$$

$$\frac{\pi}{6} \text{ or } \pi - \frac{\pi}{6} = \phi$$

$\downarrow$

$v_y < 0$

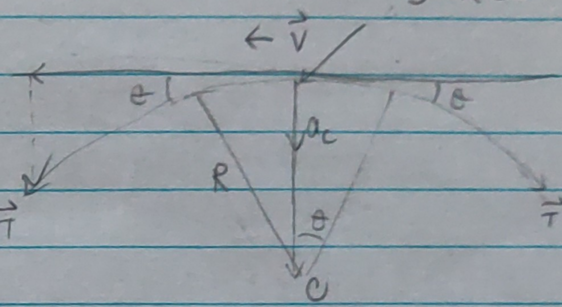
PCS125 CH16 Lecture 2 Jan 25 2018 Lei Yu

Oscillation / particle speed: speed of particle
Wave speed: how fast energy's being transfered away.

Wave speed

- Wave speed's controled by the medium
- type of wave does not affect wave speed

$\Delta S = R \cdot 2\theta$



Pulse's POV

16.6 • The rope undergoes circular motion

$\cdot \sum F_y = ma_y = \frac{mv^2}{R}$

Small angle approx. →

$2T\sin\theta = \frac{mv^2}{R}$ $m = \mu\Delta S = \mu R(2\theta)$

$2T\theta \approx mv^2/R$ μ = Mass per length

$\cancel{2}T\cancel{\theta} \approx \mu \cancel{R}(\cancel{2\theta})v^2/\cancel{R}$

$T \approx \mu v^2$

$v = \sqrt{\frac{T}{\mu}}$ T, tension of string

v,

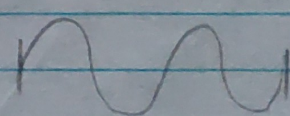
Wave Energy on a String

$dE = \frac{1}{2}(dm)v_{y\,max}^2$ $v_{y\,max} = A\omega$ $dm = \mu \cdot dx$

$dE = \frac{1}{2}(\mu \cdot dx)A^2\omega^2 \Rightarrow \frac{dE}{dx} = \frac{1}{2}(\mu A^2\omega^2)$

Power Transmission: the energy going through a cross section per second.

- Wave travels $v \times (1\,sec)$ per second
- Energy density per unit length: $\frac{dE}{dx} = \frac{1}{2}(\mu A^2\omega^2)$



$P = \frac{1}{2}\mu A^2\omega^2 v$

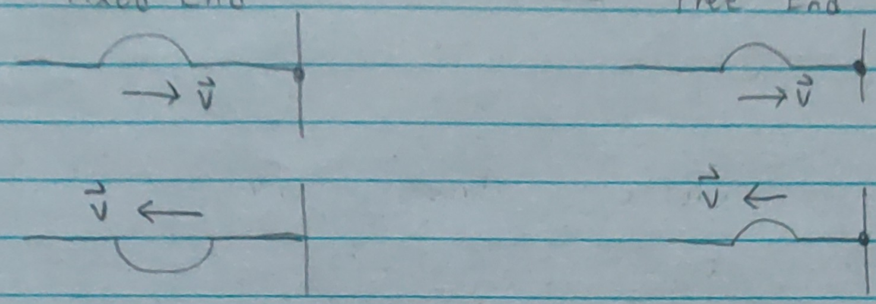
$v \times (1sec)$

$P = \frac{dE}{dt} = \frac{dE}{dx} \times v \times (1)$

$E \propto \omega^2 A^2$

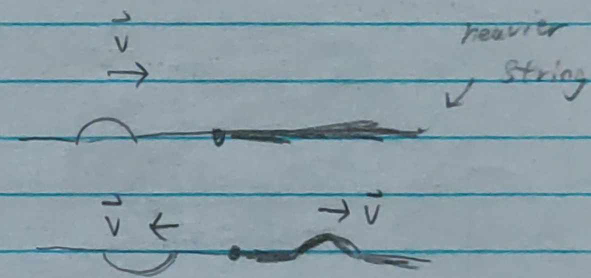
Reflection / Transmission

Fixed End — Free End



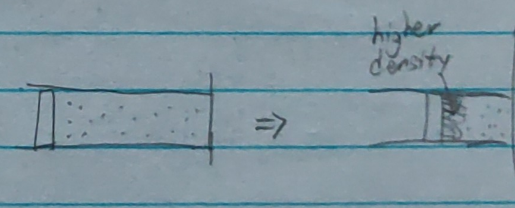
- When a wave hits a new medium some are reflective some are transmitted.
- If wave travels slower in second medium the reflected pulse will be reflected.

$$A_{inc} + A_x = A_T$$



CH 17. Introduction to Sound Waves | Jan 30, 2018 Lei Yu

Sound waves are longitudinal wave.
They travel through any material medium
- changes in density and pressure of the air



- lower the frequency, bigger the vibration

Compressed region : Compression
low pressure region : rarefraction

Periodic Sound Wave: Displacement

$S(x,t) = S_{max} \cos(Kx - wt)$, S is in the same direction as the wave.
positive x propagation

Pe

17

Periodic Sound Waves: Pressure   Jan 30, 2018   Lei Yu

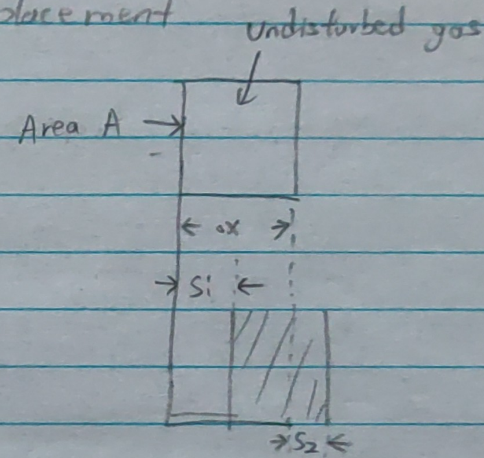
☆ $\Delta P = \Delta P_{max} \sin(kx - \omega t)$

ΔP = maximum pressure change from equilibrium

- Pressure and displacement are out of phase (difference of $\frac{\pi}{2}$)

Bulk Modulus to relate Pressure to Displacement

B: resistance to compression



$$\Delta P = -B \frac{\Delta V}{V_i} \Rightarrow \Delta P = -B \frac{\partial s}{\partial x}$$

- Pressure ↑, Volume ↓

$$V_i = A \cdot \Delta x \qquad \Delta V = V_f - V_i$$
$$V_f = A \cdot (\Delta x + s_2 - s_1) \qquad = A(s_2 - s_1)$$

$$\Delta P = -B \frac{[\cancel{A}(s_2 - s_1)]}{\cancel{A}\,\Delta x} = -B \frac{\Delta s}{\Delta x} = -B \frac{ds}{dx}\Big|_t \text{ is constant}$$

- when displacement is 0, pressure is max.

Speed of Sound in a gas

$[B]$ = Pascal

$B_{water} = 10^9$ Pascal

$$V = \sqrt{\frac{B}{\rho}} = \sqrt{\frac{\text{Bulk}}{\text{density}}}$$

General $\Rightarrow V = \sqrt{\frac{\text{elastic property}}{\text{Inertial property}}}$, string $\Rightarrow V = \sqrt{\frac{T}{\mu}}$

Amplitude of Pressure and Displacement

$$\Delta P = -B \frac{\partial s}{\partial x} \Leftarrow \begin{array}{l} \Delta P = \Delta P_{max} \sin(kx - \omega t) \\ s = s_{max} \cos(kx - \omega t) \end{array}$$

$\Downarrow$

$\Delta P_{max} = B\, s_{max}\, k \Leftarrow \omega = kv$

$= \rho v \omega s_{max} \qquad v = \sqrt{\frac{B}{\rho}} \Rightarrow B = \rho v^2$

$Z = \rho v$, acoustic impedance

$V_{max} = s_{max}\,\omega$

$P_{max} = Z \cdot V_{max}$

17.3 Power of a Periodic Sound Wave

Power of Wave: energy going through a cross-section/area A per unit time.

$$(Energy/Vol)_{Avg} = \frac{1}{2}\rho V_{max}^2 = \frac{1}{2}\rho \omega^2 S_{max}^2$$

$(Power)_{Avg} = (Energy/vol)_{Avg} \cdot A \cdot v = \frac{1}{2}\rho A v \omega^2 S_{max}^2$ A is area of cross section

in Δt, the waves travels $Av\Delta t$, thus transmitted energy is

$$P = \frac{\Delta E}{\Delta t} = \frac{(Energy/vol)_{Avg} \cdot Av\cancel{\Delta t}}{\cancel{\Delta t}} = \frac{1}{2}\rho A v \omega^2 S_{max}^2$$ A (area)

Intensity of a Periodic Sound Wave

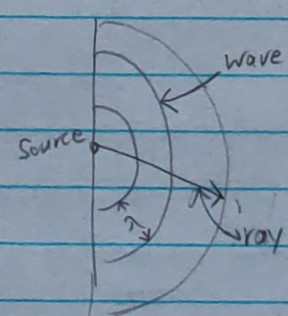
$$I = \frac{(Power)_{Avg}}{A}$$

Intensity: $\frac{Power}{area}$, (I)

- the rate at which energy is being transported by wave

A point Source

- spherical wave
- emit sound wave in all directions.



$A = 4\pi r^2$

- Intensity decreases as radius increases

Intensity of point source

$$\boxed{I = \frac{(Power)_{Avg}}{4\pi r^2}}$$

Intensity of Pressure Amplitude

$$I = \frac{(\Delta P_{max})^2}{2\rho v}$$

Sound Level

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

I_0 is reference intensity

$I_0 = 1.00 \times 10^{-12} \frac{W}{m^2}$

β Thresh hold of pain is $I = 1.0\ W/m^2$; $\beta = 120\ dB$

Thresh hold of hearing is I_0, $\beta = 0\ dB$

PCS125 Doppler Effect

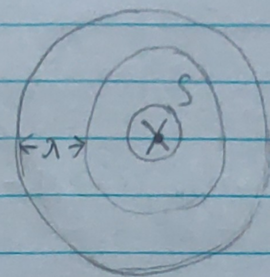
Feb 1, 2018 Lei Yu

Observer Moving

O

$\longrightarrow$

forward source $\vec{v}_o$ is positive $\rightarrow \vec{V}_o$



Sphere

V is speed of Sound

$$T = \frac{\lambda}{V}, \quad T' = \frac{\lambda}{V+V_o}$$

$$f = \frac{V}{\lambda}, \quad f' = \frac{V+V_o}{V} \cdot f$$

$$f' = \frac{1}{T'} = \frac{V+V_o}{\lambda} = \frac{V+V_o}{V} \cdot \frac{V}{\lambda} = \frac{V+V_o}{V} \cdot f$$

Source Moving

Sound barrier: the pressure caused by the compression of wave fronts.

When $V = V_s$, sonic boom

$$f' = \left(\frac{V}{V-V_s}\right) f$$

Combining both observer and Source

☆ $$f' = \left(\frac{V+V_o}{V-V_s}\right) f$$

$\rightarrow$

$$f' = \left(\frac{V+V_s}{V-V_s}\right) f$$

$$408.0 = \left(\frac{340+V_s}{340-V_s}\right) 400$$

$$1.02 = \frac{340+V_s}{340-V_s}$$

$$346.8 - 1.02V_s = 340 + V_s$$

$$6.8 = 2.02V_s$$

$$3.37\,m/s = V_s$$

CH18 Wave Interference Feb 6, 2018 Lei Yu

Super position Principle / Interference

• displacement and pressure (not amplitude) is the algebraic sum of the individual waves

$y = A\sin(kx - \omega t)$ $y_1 + y_2 = y_f$

can sum y not A

$6\sin(\pi(2(3) + 3(5))) + 6\cos[\pi(6 - 15)]$

• shape of pulse remain unchanged

$= 6\sin[\pi(21)] + 6\cos[\pi(-9)]$

$=$

Constructive Interference (building) $A > A_1, A_2$

Deconstructive Interference (canceling)

particle moving faster

• Energy does not desappear

Superposition of Sinusoidal Functions

• Same A and f $a = kx - \omega t$ different phase

• differ only in phase $b = kx - \omega t + \phi$ ✓

$y_1 = A\sin a$ $y = y_1 + y_2 = A(\sin a + \sin b) = 2A\cos\frac{a-b}{2}\sin\frac{a+b}{2}$ will become independant of time

$y_2 = A\sin b$

$\sin a = \sin\left(\frac{a+b}{2} + \frac{a-b}{2}\right) \Rightarrow \sin(x+y) = \sin x\cos y + \sin y\cos x$

$\Downarrow$

$\sin\left(\frac{a+b}{2}\right)\cos\left(\frac{a-b}{2}\right) + \sin\left(\frac{a-b}{2}\right)\cos\left(\frac{a+b}{2}\right)$

$\sin b = \sin\left(\frac{a+b}{2} - \frac{a-b}{2}\right) \Rightarrow$

Review of sinusoidal

$y = A\sin(kx - \omega t + \phi_0)$ $\Delta\phi = 2\pi\left(\frac{r_2 - r_1}{\lambda}\right)$

$\lambda = 1.25$

phase, $\phi = kx - \omega t + \phi_0$,

$\Delta\phi = 1.6\pi(a5)$

$\Delta\phi = k(x_2 - x_1)$, phase difference at time t

$=$

$\Delta\phi = k(r_2 - r_1)$, from point source, r is radius from source

Wave interference   Feb 6, 2018   Lei Yu

$y = y_1 + y_2 = \underbrace{2A\cos\left(\frac{\Delta\phi}{2}\right)}_{\cancel{\text{max}}\ \text{amplitude}} \sin\left(kx - \omega t + \frac{\Delta\phi}{2}\right)$

Constructive interference

- when $\Delta\phi = 0$, or any even multiple of π then $\cos\left(\frac{\Delta\phi}{2}\right) = 1$
- Amplitude of resultant wave is $2A$.

Deconstructive Interference

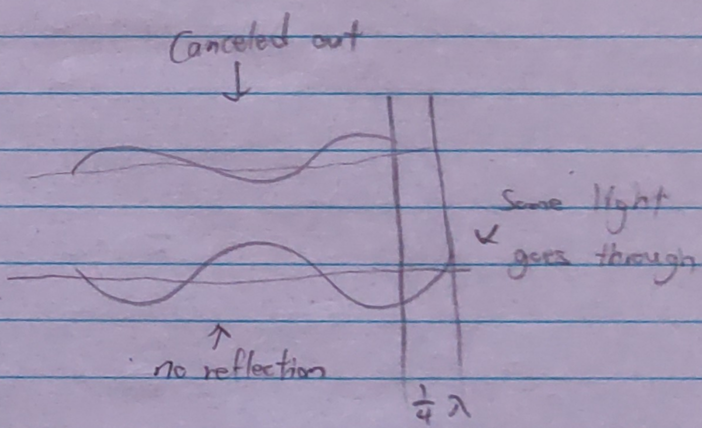
- $\Delta\phi = \pi$ or any odd multiple of π then $\cos\left(\frac{\Delta\phi}{2}\right) = 0$.
- Amplitude of wave is 0

$I \propto \left[2A\cos\left(\frac{\Delta\phi}{2}\right)\right]^2$

Anti-reflective Coatings

Coating thickness $= \frac{1}{4}\lambda$ of light

- energy in conserved
  more transmission
  less reflection

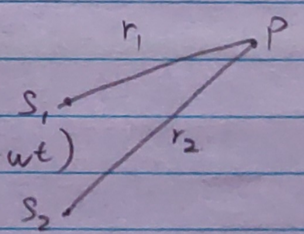


Interference Pattern

$y_1 = A\sin(kr_1 - \omega t)$

$y_2 = A\sin(kr_2 - \omega t)$

$y_r = y_1 + y_2 = 2A\cos\left(\frac{k(r_2 - r_1)}{2}\right)\sin\left(\frac{k(r_2 - r_1)}{2} - \omega t\right)$



$\Delta\phi = k(r_2 - r_1)$

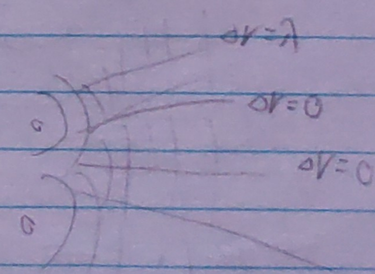
$= 2A\cos\left(\frac{\Delta\phi}{2}\right)\sin\left(\frac{\Delta\phi}{2} - \omega t\right)$

Destructive Interference: $\cos\left(\frac{\Delta\phi}{2}\right) = 0$, $\frac{\Delta\phi}{2} = \frac{\pi}{2} + n\pi \Rightarrow \frac{2\pi}{\lambda}\frac{(r_2 - r_1)}{2} = \frac{\pi(r_2 - r_1)}{\lambda}$

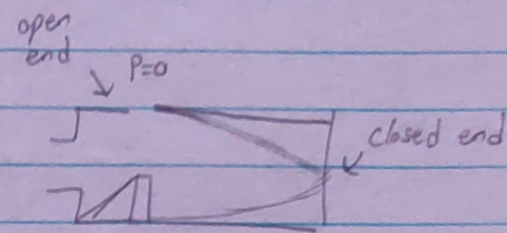
$r_2 - r_1 = (2n+1)\frac{\lambda}{2}$

Constructive Interference: $\cos\left(\frac{\Delta\phi}{2}\right) = 1$ or -1

$\Delta r = |r_2 - r_1| = n\lambda$



Standing Wave with Air Column Feb 13, 2018

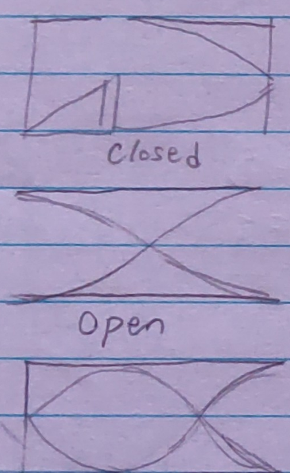


Closed End

·the closed end of a pipe is a displacement node.
↳ pressure antinode
* Pressure wave is 90° out of phase with displacement wave

Open End

·Open end, antinode of displacement wave, node of pressure wave.



one end open

fundamental

$$L = \frac{\lambda}{4} + n^*\left(\frac{\lambda}{2}\right), \quad n = 0, 1, 2 \ldots$$

both open, both closed

fundamental

$$L = n^*\left(\frac{\lambda}{2}\right) \qquad n = 1, 2 \qquad f = \frac{nv}{2L}$$

$$L = (2n+1)\frac{\lambda}{4}$$

$n=4$, we have 9th harmonic

$$f = \frac{v}{\lambda} \Rightarrow f = \frac{(2n+1)v}{4L} \quad \text{or} \quad f = \frac{(\text{harmonic}\#)v}{4L}$$

$$f = \frac{3(340)}{4(0.9)} =$$

Harmonics:

$$\text{Harmonic}\# = \frac{f}{f_0}, \quad \frac{\text{frequency}}{\text{fundamental frequency}}$$

overtones: higher than the fundamental frequency

Overton# = Harmonic# − 1

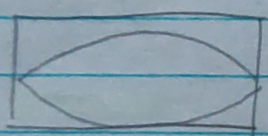
Mass on a spring: $w=\sqrt{\frac{k}{m}}=2\pi f$

Simple Pendulum: $w=\sqrt{\frac{g}{L}}$

Physical Pendulum: $w=\sqrt{\frac{gmd}{I}}$

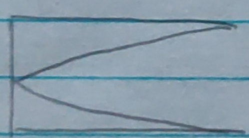
$k=\frac{2\pi}{\lambda}$, $w=\frac{2\pi}{T}$, $v=f\lambda=\frac{w}{k}$

String: $v=\sqrt{\frac{T}{\mu}}$ ← Tension   Sound $v=\sqrt{}$



1 $\frac{1}{2}\lambda=L$ $\frac{n}{2}\lambda=L$

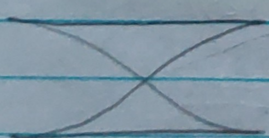
2 $\lambda=L$



1 $\frac{1}{4}\lambda=L$ $\frac{2n-1}{2}\lambda=L$

2 $\frac{3}{4}\lambda=L$

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



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

$\lambda=L$