Sangam SKM College – Nadi

Lesson Notes: Week 1

Year 13

Physics

Strand:	Waves
Sub Strand:	Wave Motion
Content Learning Outcome:	Write the equation of a travelling wave.

WAVES

- A wave is a disturbance that propagates, or moves from the place it was created.
- The two main types of waves are mechanical waves and electromagnetic waves.
- Mechanical waves – requires a medium travel eg. water waves or sound waves.
- Electromagnetic waves do not require a medium to propagate eg. visible light, radio waves and TV signals.

WAVE EQUATION

$$\boxed{y = Asin(wt \pm kx)}$$

IF f is 2f then w = 2w and K = 2K

Where: A= amplitude (m)

w = angular frequency (rad s^{-1})

$$\boxed{k = \frac{2\pi}{\lambda}} \qquad \boxed{k = \frac{w}{v}}$$

- kx means wave travelling towards right

+ kx means wave travelling towards left

Example 1

A wave travelling through a string along the x-axis has the equation:

y = 0.05sin (0.2x+ 4t).

(a) State the direction of wave.

(b) Calculate the value of:

(i) Amplitude	(ii) Frequency	(iii) Wavelength	(iv) Velocity of wave

Solution:

(a) Direction is to the left because the term kx is positive.

(b) (i) y = 0.05sin (0.2x+ 4t)

y = 0.05sin (4t+ 0.2x) compare with

$$y = Asin(wt + kx)$$

<u>A = 0.05 m</u>

(ii) $w = 4\,rads^{-1}$ $\quad w = 2\pi f;\ f = \frac{w}{2\pi} = \frac{4}{2\pi} = \frac{2}{\pi}\,Hz$

(iii) $k = \frac{2\pi}{\lambda}$ $\quad 0.2 = \frac{2\pi}{\lambda}$ $\ ;\ \lambda = \frac{2\pi}{0.2} = \underline{10\pi\ m}$

(iv) $v = f\lambda = \frac{2}{\pi} \times 10\pi = 20\ ms^{-1}$

Example 2

A transverse wave disturbance on a string, propagating along the x – axis is described by

$$y = \text{Sin } 2\pi\left(5t - \frac{x}{2}\right)$$ with x and y in metres and t in seconds.

(i) Calculate the wavelength, amplitude, frequency and speed of the wave.

(ii) A similar wave travelling in the opposite direction is sent down the wire. Calculate the distance between successive nodes in metres.

Solution:

(i) First rewrite the equation $y = \text{Sin } 2\pi\left(5t - \frac{x}{2}\right)$ in the form $y = A \sin(\omega t - kx)$

$y = \text{Sin }(10\pi t - \pi x)$

$k = \frac{2\pi}{\lambda}$ $\quad \pi = \frac{2\pi}{\lambda}$ $\ ;\ \lambda = \frac{2\pi}{\pi} = \underline{2\ m}$

$\underline{A = 1\ m}$

$w = 10\pi\,rads^{-1}$ $\quad w = 2\pi f;\ f = \frac{w}{2\pi} = \frac{10\pi}{2\pi} = \underline{5\ Hz}$

$v = f\lambda = 5 \times 12 = \underline{10\ ms^{-1}}$

(ii) Opposite direction – change the sign $y = \text{Sin } 2\pi\left(5t + \frac{x}{2}\right)$

(iii) Nodal dist $= \frac{\lambda}{2} = \frac{2}{2} = \underline{1\ m}$

Example 3

A sinusoidal wave travelling in the positive x-direction has an amplitude of 15.0 cm, wavelength of 40.0 cm and a frequency of 8.00 Hz. Find the wave number, period, angular frequency and the speed of the wave.

$k = \frac{2\pi}{\lambda} = \frac{2\pi}{0.4} = 15.71\text{rad m}^{-1}$ (Wave number)

$T = \frac{1}{f} = \frac{1}{8.00} = 0.125\,\text{s}$ (Period)

$\omega = 2\pi f = 2 \times \pi \times 8 = 50.27\ rads^{-1}$ (angular freq)

$v = f\lambda = 8.00 \times 0.4 = 3.2\ \text{ms}^{-1}$ (Speed)

Activity

Exercise 3.1 Pg 68 Q1

Pg 69 Q4

3. The forward component of a standing wave is represented by $y = 0.04\text{Sin}3\pi\left(\frac{-x}{o.5} + 50t\right)$ where all measurements are in S.I units.

i. Find its frequency.
ii. Calculate the velocity of the wave.
iii. Write the equation for the reflected component of the standing wave with twice frequency.

Sangam SKM College – Nadi

Lesson Notes: Week 2

Year 13

Physics

Strand:	Waves
Sub Strand:	String Waves
Content Learning Outcome:	Calculate mass per unit length, speed, energy and power for waves generated on string.

Speed and Energy Transfer for String Waves

- The wave speed is dependent on the tension of the string.
- The acceleration and wave speed increase with increase in tension of the string.
- Wave speed is inversely dependent on the mass per unit length of the string.

The speed v is given by:

$$\boxed{v = \sqrt{\frac{T}{\mu}}}$$

$$\boxed{\mu = \frac{m}{l}}$$

Where

v = wave speed (ms^{-1})

T = tension in the string (N)

μ = mass per unit length (kgm^{-1})

Energy transfer for string waves

Energy is carried along by the wave with velocity. As a piece of string moves up and down executing SHM, it has kinetic energy as well as potential energy because the string is stretched like a spring.

Energy per unit length = $\boxed{E = \frac{1}{2}\mu\omega^2 A^2}$ *Unit: **J/m***

The power transmitted by the wave is:

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

*Unit: **W***

Where: v = wave speed (ms^{-1})

ω = angular frequency (rad s^{-1})

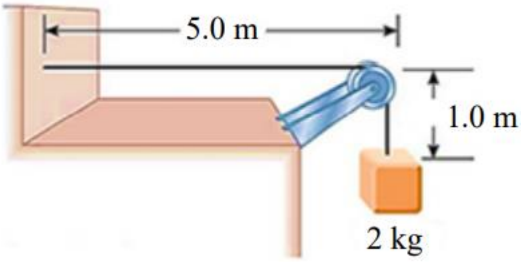
A = amplitude (m)

μ = mass per unit length (kgm^{-1})

The rate of energy (power) transfer in any sinusoidal wave is proportional to the square of the angular frequency and to the square of the amplitude.

Example

1. A uniform cord has a mass of 0.30 kg and a length of 5.00 m as shown. The chord passes over a pulley and supports a 2.00 kg object. Find the speed of a pulse travelling along this cord. The tension in the cord is equal to the weight of the suspended 2.00 kg object.



$T = mg = 2.00 \times 9.8 = 19.6 \text{ N}$

The mass per unit length of the cord is;

$$\mu = \frac{m}{l} = \frac{0.300 \text{ kg}}{6.00 \text{ m}} = 0.05 \text{ kgm}^{-1}$$

Therefore, the wave speed is;

$$v = \sqrt{\frac{T}{\mu}} = \sqrt{\frac{19.6 \text{ N}}{0.05 \text{ kgm}^{-1}}} = 19.80 \text{ ms}^{-1}$$

Example

A string for which $\mu = 5.00 \times 10^{-2} \text{ kgm}^{-1}$ is under a tension of 80.0 N. How much power must be supplied to the string to generate sinusoidal waves at a frequency of 60.0 Hz and an amplitude of 6.00 cm.

Solution

The wave speed on string is $v = \sqrt{\frac{T}{\mu}} = \sqrt{\frac{80.0\text{N}}{5.00 \times 10^{-2} \text{kgm}^{-1}}} = 40.0 \text{ ms}^{-1}$

The angular frequency of the waves on the string has the value

$\omega = 2\pi f = 2\pi \times 600 = 377 \text{ s}^{-1}$ and the amplitude of the wave is 0.06 m.

$$\therefore P = \frac{1}{2}\mu v \omega^2 A^2 = \frac{1}{2} \times 5.00 \times 10^{-2} \times 40.0 \times 377^2 \times 0.06^2 = 511.6 \text{ W}$$

Activity

1. Transverse waves with a speed of 50.0 ms^{-1} are to be produced on a stretched string. A 5.00 m length of string with a total mass of 0.060 kg is used.
   a) What is the required tension in the string?
   b) Calculate the wave speed in the string if the tension is 8.00 N.

2. A string of linear mass density (mass per unit length) 480 gm^{-1} is under a tension of 48 N. A wave of frequency 200 Hz and amplitude 4.00 mm travels down the string. At what rate does the wave transport energy?

3. Write the equation for a wave moving along positive x direction with amplitude 0.4 m, speed 6 ms^{-1} and frequency 17 Hz. If these are waves on a string with mass per unit length μ = 0.02 kgm^{-1}, what is the energy per unit length? What is the power being fed into the vibrating string?

Sangam SKM College – Nadi

Lesson Notes: Week 3

Year 13

Physics

Strand:	Waves
Sub Strand:	Doppler Effect
Content Learning Outcome:	Calculate apparent frequency and apparent wavelength of moving source or observer.

Sound Waves

Sound waves are the most common example of longitudinal waves.

Doppler Effect

The Doppler Effect is the change in the observed frequency of a source due to the relative motion between the source and the receiver.

When the source approaches at a speed, v, a higher frequency (high-pitch sound) is heard and the apparent wavelength decreases. When the source moves away (receding), a lower frequency (the pitch drops) is heard the apparent wavelength increases.

Source approaching;

Apparent Frequency; $f' = f\left(\frac{v}{v - v_S}\right)$

Apparent wavelength; $\lambda' = \lambda - \frac{v_S}{f}$

Source receding;

Apparent Frequency; $f' = f\left(\frac{v}{v + v_S}\right)$

Apparent wavelength; $\lambda' = \lambda + \frac{v_S}{f}$

Similarly if the observer moves away from stationary source, a lower frequency is heard and vice versa. The apparent wavelength will be same as the wavelength of the source.

Observer approaching;

Apparent Frequency; $f' = f\left(\frac{v + v_O}{v}\right)$

Observer receding;

Apparent Frequency; $f' = f\left(\frac{v - v_O}{v}\right)$

General equation for Doppler Effect

$$\boxed{f' = \left(\frac{v \pm v_o}{v \mp v_s}\right) f}$$

Where:

v = speed of sound in air (ms^{-1})

v_o = speed of observer (ms^{-1})

v_s = speed of source (ms^{-1})

f' = apparent frequency (Hz)

f = frequency of source (Hz)

Example 1

A fire station sounded a siren at a frequency of 300 Hz to call for a volunteer fireman on duty. If the fire man is running towards the station at 20 ms^{-1}, what will be the frequency and apparent wavelength of the siren. Assume the speed of sound is 340 m s^{-1}.

<u>Solution</u>

Fire station – source fire man – observer

Source is stationary; observer running towards the source, apparent frequency will increase.

$$f = f\left(\frac{v + v_o}{v}\right) = 300\left(\frac{340 + 20}{340}\right) = 317.65\,\text{Hz}$$

$$\lambda' = \lambda = \frac{v}{f} = \frac{340}{300} = 1.1\,\text{m}$$

Example 2

A car travelling at 15 ms^{-1} sounds its horn of frequency 950 Hz. A stationary listener, in front of the car hears the horn of the approaching car. Assume the speed of sound in air is 343 ms^{-1}.

(i) What is the apparent frequency of the sound heard by the listener?

<u>Solution</u>

Car – source, listener – observer

Source moving towards the observer, apparent frequency will increase.

$$f' = f\left(\frac{v}{v - v_s}\right) = 950\left(\frac{343}{343 - 15}\right) = 993.45\,\text{Hz}$$

(ii) Calculate the apparent wavelength?

$$\lambda = \frac{v}{f} = \frac{343}{950} = 0.361\,\text{m}$$

$$\lambda' = \lambda - \frac{v_s}{f}$$

$$\lambda' = 0.361 - \frac{v_s}{f} = 0.361 - \frac{15}{950} = 0.345\,\text{m}$$

Activity

Exercise 3.3 Page 74

Q1 a, b, c, d

Q2 a, b, c