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PHYSICS FOR THE LIFE SCIENCES

Solution Manual

Created by WebStraw

Physics for the Life Sciences – Oscillations and Waves Solutions

Introduction:

Dear student,

Thank you for opening this solution manual for the Oscillations and Waves chapter of the Physics for the Life Sciences Question Manual. This resource has been created by members of the Education Team at WebStraw who have previously taken an introductory university physics course.

Purpose:

This resource is meant to supplement the Physics for the Life Sciences Question Manual, by providing solutions to select questions. To access the full question manual, please click here.

Instructions

We recommend first trying to complete the problems in the question manual on your own. If you get stuck, you can use this resource to view the solution provided by one of our Education Team members. Once you are confident you understand how to solve that question, we recommend solving additional related problems in order to successfully master the topic.

Disclaimer

This resource assumes that you have a basic understanding of key concepts related to the Oscillations and Waves unit in physics. If you are looking to improve your understanding of specific physics content, check out the additional resources provided at the end of the question manual.

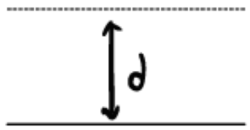
Note: There may be more than one correct method to solve some of the problems outlined in the question manual. Thus, the solutions provided may not represent the only acceptable solution.

If you have any comments or feedback regarding this resource or the solutions contained in it, please do not hesitate to contact us at team@webstraw.ca

We wish you the best of luck on your learning journey!

- The WebStraw Education Team

11)



let d be the depth of the pool

time to reach top = 0.2s

$V_{\text{sound in water}} = 1480$ m/s

Only one way = 0.1s

$v = d/t$

$d = vt = 148m$

$\therefore$ the pool is 148m deep

I3) freq = 3.1 Hz.

$\text{Period} = \frac{1}{\text{freq}} = \frac{1}{3.1}$ Hz.

Spring mass system

$\text{Period} = 2\pi\sqrt{\text{mass}/\text{spring con}}$

- mass n spring system oscillating in fix manner
- mass of spring neglegible
- no air drag

I5) $L_{tube} = 5m$ $V_{air} = 340$ m/s

a) fundamental freq of open tube $\Rightarrow n=1$

$f_n = \frac{nV_{air}}{2L}$

$f_n = 34$ Hz

b) $V_{Hel} = 2.5(V_{air}) = 600$ m/s

$f'_n = \frac{nV_{Hel}}{2L}$

$f'_n = 60.0$ Hz

I7) Pipe w/open end, first harmonic frequency

$f = \frac{V}{4L}$ — speed of sound, — length

$L = \frac{V}{4f} = 6.25m$

I9) a T

time period (T) only depend on length and gravity

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

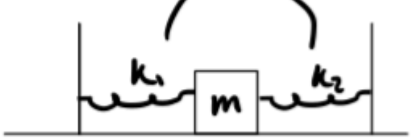
$= \frac{mg}{L} = \frac{(2m)g}{L}$

2 ppl

$$T = 2\pi\sqrt{\frac{2m}{\frac{(2m)g}{L}}} = 2\pi\sqrt{\frac{L}{g}}$$

I11)

identical spring



→ spring in parallel combination

$K_{net} = K_1 + K_2 = 2K$

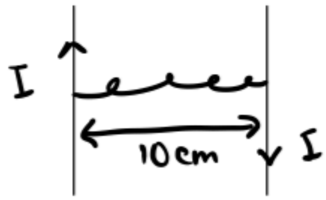
$$T = 2\pi\sqrt{\frac{m}{K_{net}}}$$

$$= 2\pi\sqrt{\frac{m}{2k}} \begin{smallmatrix}\times 2\\ \times 2\end{smallmatrix}$$

$$= 2\pi\sqrt{\frac{2m}{4k}}$$

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

I 13)



Magnetic force = Spring force

$$\frac{\mu_0 I^2 L}{2\pi \cdot R} = k(L_2 - L_1)$$

$L = 1m$ $\quad$ $L_2 = 0.15m$

$k = 0.02\ N/m$ $\quad$ $L_1 = 0.1m$

$R = 0.15m$ $\quad$ $\mu_0 = 4\pi \times 10^{-7}\ H/m$

$$I = \sqrt{\frac{k(L_2 - L_1)\,2\pi \cdot R}{\mu_0}}$$

$$I = 27.39A$$

I 15)

$m_{ball} = 1.50kg$

$T_1 = 1.40s$ $\rightarrow$ increase by 0.6s

$T_2 = 2.0s$

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

① $1.4 = 2\pi\sqrt{\frac{1.5}{k}}$ $\qquad$ ② $2.0 = 2\pi\sqrt{\frac{1.5+\Delta m}{k}}$

$$\frac{①}{②} \qquad \frac{1.4}{2.0} = \sqrt{\frac{1.5}{1.5+\Delta m}}$$

$$\Delta m = 1.56\ kg$$

$\therefore$ additional 1.56kg added

I 17)

$m = 0.450\ kg$

$L_1 = 0.300m$

① $k\Delta x_1 = mg = 4.41 \Rightarrow k = \frac{4.41}{\Delta x_1}$

② $k\Delta x_2 = 18.13 \Rightarrow k = \frac{18.13}{\Delta x_2}$

$$\frac{4.41}{\Delta x_1} = \frac{18.13}{\Delta x_2} \Rightarrow \frac{18.13}{4.41} = \frac{\Delta x_2}{\Delta x_1}$$

$$\frac{18.13}{4.41} = \frac{x - 0.84}{x - 0.30}$$

∴ w/o mass, spring

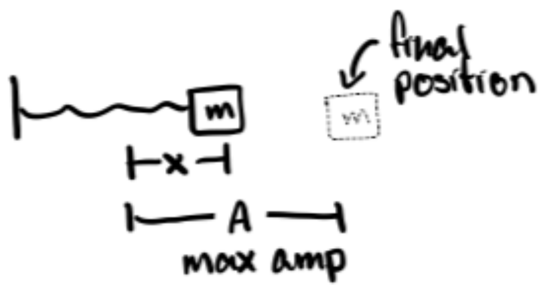
$x = 0.126\text{m}$

I A) $k = 180\ \text{N/m}$

$m = 0.4\ \text{kg}$

$x = 8\text{cm} = 0.08\text{m}$

$v_i = 2.8\text{m/s} \quad v_f = 0\ \text{m/s}$



Conservation of energy

$$\Sigma E_i = \Sigma E_f$$

$$K_i + P_i = K_f + P_f$$

$$\tfrac{1}{2}mv_i^2 + \tfrac{1}{2}kx^2 = \tfrac{1}{2}mv_f^2 + \tfrac{1}{2}kA^2$$

$$A = \sqrt{\frac{2\left(\frac{1}{2}mv_i^2 + \frac{1}{2}kx^2 - \frac{1}{2}mv_f^2\right)}{k}}$$

$A = 0.24\text{m}$

I21) $k = 1000\ N/m$ $m = 500kg$

a) n = displacement of rhino in SHM

$F = -kx \Rightarrow \frac{d^2x}{dt^2} + \omega^2 x = 0$

$\quad \llcorner \sqrt{\frac{k}{m}} = \sqrt{2}$

$\Downarrow$

general eqn $x = A\cos(\omega t + \theta)$

knowing @ $t=0$, $n = 10m$, $v_i = 0\ m/s \Rightarrow \therefore \theta = 0$

$x = 10\cos(\sqrt{2}t)$

b) @ 4s

$x = 10\cos(\sqrt{2}\cdot 4) = 9.95m$

$\therefore$ 9.95m frm equilibrium point

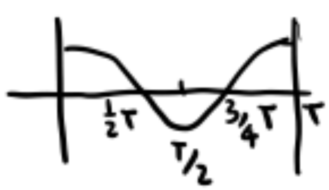
c) differenciate general eqn

$v = \frac{dx}{dt} = -10\cdot\sqrt{2}\sin(\sqrt{2}\cdot t)$

$t = 4s$

$v = -1.39m/s$ $\therefore$ rhino traveling 1.39 m/s

d) Period $(T) = \frac{2\pi}{\omega} = \frac{2\pi}{\sqrt{2}} = 4.4s$



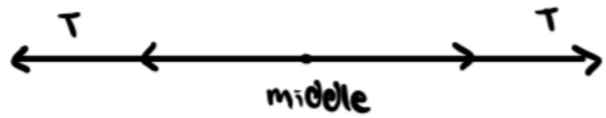
est $3/4\,T = 4.4 \cdot \frac{3}{4} = 3.3s$

$\therefore$ @ 4s the rhino +ve on graph so opposite of equilibrum position

I23)

- can be traverse or longitudil
- disturbance confine btwn start n reflecting point

I25)



if tension act in opposite direction

the middle would be $\frac{T+T}{2} = \frac{\cancel{2}T}{\cancel{2}} = T$

$\therefore$ tension in middle is avg Tension

I27)

$l_A = 2m \qquad \mu_A = 0.001\ kg/m$

$l_B = 2m \qquad \mu_B = 0.02\ kg/m$

$T_A = T \qquad T_B = T$

$V_{transverse\ wave} = \sqrt{\frac{T}{\mu}}$

$V_A = \sqrt{\frac{T}{0.001}} = \sqrt{1000T}\ m/s$

$V_B = \sqrt{\frac{T}{0.02}} = \sqrt{50T}\ m/s$

$V_A > V_B \qquad l_A = l_B$

$\therefore$ wave$_A$ will be destructive w/ wave$_B$ neutralizing it bc $V_A > V_B$ and in opp direction → destructive interphase

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I29:

Given: Poles are 3m apart $T = 800N$ each $LD_1 = 0.004 \frac{kg}{m}$ $LD_2 = 0.0002 \frac{kg}{m}$

Required: Time for 2 simultaneously generated transverse waves to pulse past each other

Solve: When "passing" each other wave 1 will have travelled a distance of x and wave 2 will have travelled a distance of $3m - x$

↳ They do <u>not</u> meet exactly at middle because LD values are different

We can use formula for speed of wave on string under tension where $v = \sqrt{\frac{T}{LD}}$

LD also often designated with μ

$v_1 = \sqrt{\frac{800}{0.004}} = 447.2 \frac{m}{s}$ $v_2 = \sqrt{\frac{800}{0.0002}} = 2000 \frac{m}{s}$

$t = \frac{d}{v} \longrightarrow t_1 = t_2$ (because they are "meeting" at given point)

$\frac{d_1}{v_1} = \frac{d_2}{v_2} \longrightarrow \frac{x}{v_1} = \frac{3-x}{v_2} \longrightarrow \frac{x}{447.2} = \frac{3-x}{2000}$

$2000x = 447.2(3-x) \longrightarrow 2000x = 1341.6 - 447.2x$

$2447.2x = 1341.6 \longrightarrow x = 0.548m$

x is the distance wave 1 travels, so to find time we just use $t = \frac{d}{V} = \frac{0.548m}{447.2 \frac{m}{s}} = \boxed{0.0012 \text{ s}}$

I 31:

Given: $l = 3m$ $T = 200N$ $LD = \mu = 0.006 \frac{kg}{m}$

Required: time for wave to travel from one end to other

Solve: velocity of wave on string under tension $= v = \sqrt{\frac{T}{\mu}}$

$$v = \sqrt{\frac{200}{0.006}} = 182.6 \frac{m}{s}$$

$$t = \frac{d}{v} = \frac{3m}{182.6 \frac{m}{s}} = \boxed{0.016 s}$$

I 33:

A string with a lower density will have a higher speed of waves

↳ Mathematic reasoning: speed is given by $v = \sqrt{\frac{T}{\mu}}$; a smaller linear density (μ) gives a smaller denominator and larger value for v

↳ Logical reasoning: linear density is a measure of mass per unit length. The reason a wave "moves" in the horizontal direction (even transverse waves) is because of the tension force. A given tension force causes greater acceleration (and resultant velocity) when acting on a smaller mass

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I 35:

Given: $l = 10m$ $m = 50g = 0.05 kg$ $T = 12\,000 N$

Required: time for pulse to travel length of rope

Solve: $\mu = \frac{m}{l} = \frac{0.05 kg}{10m} = 0.005 \frac{kg}{m}$

$$v = \sqrt{\frac{T}{\mu}} = \sqrt{\frac{12000}{0.005}} = 1549.2 \ \frac{m}{s}$$

$$t = \frac{d}{v} = \frac{10 \, m}{1549.2 \frac{m}{s}} = \boxed{0.0065 \ s}$$

I37:

Given: When $T = 120 N$, $v = 44 \frac{m}{s}$

Required: T to reduce wave speed by $20 \frac{m}{s}$

Solve: $v = \sqrt{\frac{T}{\mu}} \longrightarrow \mu = \frac{T}{v^2} = \frac{120 N}{(44 \frac{m}{s})^2} = 0.062 \frac{kg}{m}$

Desired $v = 44 \frac{m}{s} - 20 \frac{m}{s} = 24 \frac{m}{s}$

$$24 = \sqrt{\frac{T}{0.062 \frac{kg}{m}}} \longrightarrow T = 24^2(0.062) = \boxed{35.7 \ N}$$

* Double check for v when $T = 35.7 N \longrightarrow v = \sqrt{\frac{35.7}{0.062}} = 24 \frac{m}{s}$ ✓ *

I41

The formula for period T of a pendulum is $T = 2\pi\sqrt{\frac{L}{g}}$ where g is acceleration due to gravity. However, in free fall, the object no longer experiences acceleration (downward force from gravity exactly countered by upward force from air resistance). Thus, it will have an infinite period & zero frequency while a regular pendulum has a finite period & non-zero frequency

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I43a

Speed of a wave in a string under tension is given by $v = \sqrt{\frac{T}{\mu}}$.
If tension is doubled $(T \to 2T)$, v increases by $\sqrt{2}$ so
$v = 15 \cdot \sqrt{2} = 21.2 \frac{m}{s}$

I43b:

Following the formula $v = \sqrt{\frac{T}{\mu}}$, when T is halved, v decreases by $\frac{1}{\sqrt{2}}$ so $v = \frac{15}{\sqrt{2}} = 10.6 \frac{m}{s}$

I45a:

Given: $\ell = 10m$ weight $= 20N$ $m = 1\,kg$

Required: Speed of wave at top of rope

Solve: At the top of the rope, we must consider the tension due to the weight of the rope & the mass

$T = mg = m_r g + m_w g = 20\,N + 1\,kg(9.8 \frac{m}{s^2}) = 29.8\,N$

$v = \sqrt{T/\mu} = \sqrt{\frac{29.8}{\mu}}$

Remember that $\mu = \frac{m_r}{\ell} = \frac{(\text{weight}/g)}{\ell} = \frac{(20/9.8)}{10} = \frac{2.04}{10} = 0.204 \frac{kg}{m}$

$v = \sqrt{\frac{29.8}{0.204}} = \boxed{12.08 \frac{m}{s}}$

I45b:

Required: Speed at middle of rope ⟶ only consider half of the total rope for T

Solve: $T = mg = \frac{1}{2}(m_r g) + m_w g = \frac{1}{2}(20N) + 1\,kg(9.8 \frac{m}{s^2}) = 19.8\,N$

$v = \sqrt{\frac{T}{\mu}} = \sqrt{\frac{19.8}{0.204}} = \boxed{9.85 \frac{m}{s}}$

I45c:

Required: Speed at bottom of rope → only consider the 1kg mass for T

Solve: $T = m_w g = 1\,kg\,(9.8\,\frac{m}{s^2}) = 9.8N$

$$v = \sqrt{\frac{T}{\mu}} = \sqrt{\frac{9.8}{0.204}} = \boxed{6.93\,\frac{m}{s}}$$

I47a:

Given: $f_s = 400\,Hz$ $\quad v = 340\,\frac{m}{s}$

Required: Frequency you hear when you & the train are at rest

Solve: Using Doppler formula, $f_o = \frac{v + v_o}{v + v_s} f_s = \frac{\cancel{(340+0)}}{\cancel{(340+0)}}(400Hz)$

$$= \boxed{400\,Hz}$$

This is expected; Doppler effect requires movement towards/away from a sound source

I47b:

Given: $v_o = 20\,\frac{m}{s}$ (moving towards train so positive)

Solve: $f_o = \frac{(340+20)}{(340+0)} f_s = \boxed{423.53\,Hz}$

I47c:

Given: $v_s = -20\,\frac{m}{s}$ (subtract when source is moving closer)

Solve: $f_o = \frac{(340+0)}{(340-20)} f_s = \boxed{425\,Hz}$

I47d:

Given: $v_s = 20\,\frac{m}{s}$ (add when source is moving away)

Solve: $f_o = \frac{(340+0)}{(340+20)} f_s = \boxed{377.8\,Hz}$

I47e:

Given: $v_o = -20\,\frac{m}{s}$ (subtract when you are moving further)

Solve: $f_o = \frac{(340-20)}{(340+0)} f_s = \boxed{376.47\,Hz}$

I47f:

Given: $v_o = -20\ \frac{m}{s}$, $v_s = 20\frac{m}{s}$

Solve: $f_o = \frac{(340-20)}{(340+20)} f_s = \boxed{355.56\ Hz}$

I47g:

Given: $v_o = 20\ \frac{m}{s}$, $v_s = -20\ \frac{m}{s}$

Solve: $f_o = \frac{(340+20)}{(340-20)} f_s = \boxed{450\ Hz}$

I49:

The observer that the source is moving towards will experience a higher frequency than the observer that the source is moving away from.

Doppler formula: $f_o = \frac{(v \pm v_o)}{(v \mp v_s)} f_s$

The top sign of the $\pm$ \$ $\mp$ is used if the source and/or observer are getting closer together, increasing the numerator and/or decreasing the denominator, making the observed frequency f_o larger

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