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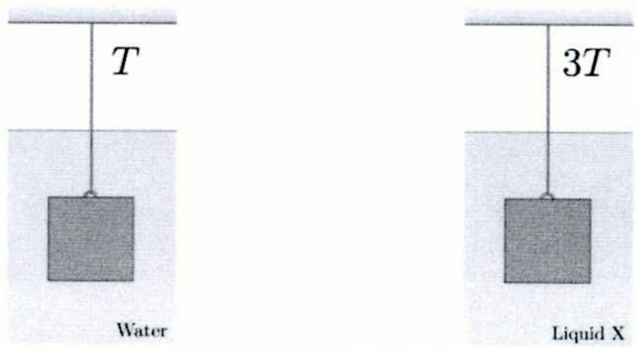
1. (15 points, 3 points each): When an object of mass M is completely submerged in water, it requires an upward force T to keep the object in equilibrium ("T" for "Tension" in the string holding it up). When the same object is completely submerged in "Liquid X," the tension required in the string is $3T$.

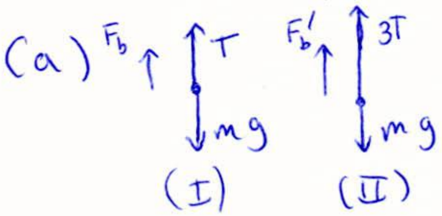


(a) Draw the free-body diagrams for both situations and write down both of the force equations of the form $\sum \vec{F} = m\vec{a}$.

(b) Does Liquid X have a density that is greater than or less than water? Explain.

(c) Given $T = 250$ N and $Mg = 1250$ N, find the density of Liquid X in SI units (Hint: compute it in terms of $\rho_{\text{water}} = 1000\ \text{kg/m}^3$).

(a)



(I) $T + F_b - Mg = 0$

(II) $3T + F_b' - Mg = 0$

$\left(\Rightarrow 2T + F_b' = F_b \quad F_b' < F_b \right)$

(b) From part (a), Liquid X provides a smaller buoyant force $F_b' = \rho_x g V_{disp}$ than water $F_b = \rho_w g V_{disp}$

$F_b' < F_b \Rightarrow \boxed{\rho_x < \rho_w}$ so density is less than water

(c) $F_b' = Mg - 3T = 500N = \rho_x g V_{disp} = \frac{1}{2} \rho_w g V_{disp}$

$F_b = Mg - T = 1000\ N = \rho_{water} g V_{disp}$

$\Rightarrow \boxed{\rho_X = \rho_w/2 = 500\ kg/m^3}$

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2. (16 points, 4 points each): A loudspeaker, broadcasting sound waves at a single frequency, emits sound isotropically.

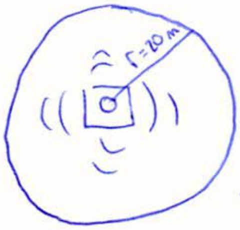
   (a) What is the speaker's power output if the sound intensity level is 90.0 dB at distance 20.0 m?

   (b) Someone runs straight toward the speaker at constant speed v_r. Write an expression for the frequency f' that the runner hears in terms of the frequency at the source f and the speed of sound in air v.

   (c) After passing the loudspeaker, the runner continues running away from the speaker at the same constant speed v_r. Write an expression for the frequency f'' that the runner hears hears in terms of the frequency at the source f and the speed of sound v.

   (d) While running away, the runner hears sound waves at a frequency 8.00 Hz less than when the runner is running towards the speaker. Given the speed of the runner $v_r = 5.00$ m/s and the speed of sound in air $v = 343.0$ m/s, calculate the original frequency f of sound waves emitted by the source.

(a)



$A = 4\pi r^2$

$I = \frac{P_{out}}{A}$

$\beta = (10\text{ dB}) \log_{10}\left(\frac{I}{I_0}\right) = 90\text{ dB}$

$\Rightarrow I = 10^9 I_0 = 10^{-3}\text{ W/m}^2$

$\Rightarrow P_{out} = IA = (10^{-3}\text{ W/m}^2)\, 4\pi (20\text{ m})^2 = \boxed{5.03\text{ W}}$

(b) $f' = \left(\frac{v \oplus v_r}{v \pm \cancel{v_s}}\right) f = \left(1 + \frac{v_r}{v}\right) f$

(c) $f'' = \left(\frac{v \ominus v_r}{v \pm \cancel{v_s}}\right) f = \left(1 - \frac{v_r}{v}\right) f$

(d) $f' = 8.00\text{ Hz} + f''$

$\left(1 + \frac{v_r}{v}\right) f = 8.00\text{ Hz} + \left(1 - \frac{v_r}{v}\right) f$

$\left(\frac{2v_r}{v}\right) f = 8.00\text{ Hz} \Rightarrow f = (8.00\text{ Hz})\frac{343\text{ m/s}}{2(5\text{ m/s})}$

$\boxed{f = 274\text{ Hz}}$

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3. (15 points, 5 points each): A transverse wave travels in the $+\hat{x}$ direction with speed 3 m/s. A particle at $x = 1$ m has displacement vs. time which follows the equation

$$D_{[x=1\text{ m}]}(t) = (1\text{ mm})\sin\left[\left(\frac{3\pi}{2}\text{rad/s}\right)t + \pi\right]$$

You may take all values as exact.

(a) What is the wavelength of this wave?

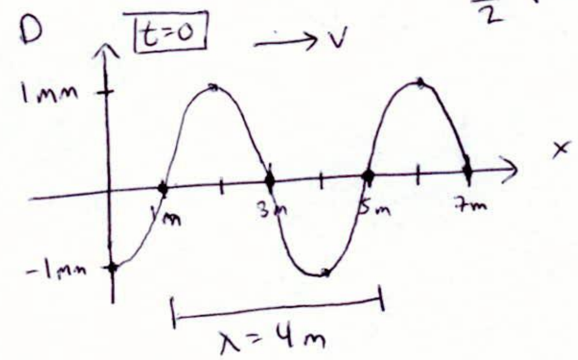
(b) Draw a snapshot of the wave at $t = 0$ s (i.e., a plot of $D(x)$).

(c) Write down an equation for the wave valid for all x and t. Your equation should be of the form:

$$D(x,t) = (1\text{ mm})\sin[\ldots]$$

(a) $\lambda = \frac{v}{f} = \frac{2\pi v}{\omega} = \frac{2\pi\,(3\text{ m/s})}{\frac{3\pi}{2}\text{ rad/s}} = \boxed{4\text{ m}}$

(b)



@ x = 1 m, particle is in equilibrium D = 0 but is about to become negative after t = 0 s

(c) $D(x,t) = A\sin[kx - \omega t + \phi_0]$, $k = \frac{2\pi}{\lambda} = \frac{\pi}{2}\frac{\text{rad}}{\text{m}}$ and $\omega = \frac{3\pi}{2}\frac{\text{rad}}{\text{s}}$, $A = 1\text{ mm}$

To find ϕ_0, note that snapshot @ t = 0 has form

$A\sin\left(kx - \frac{\pi}{2}\right) = A\sin\left(kx + \frac{3\pi}{2}\right)$ Thus $\phi_0 = \frac{3\pi}{2}$ (or $-\frac{\pi}{2}$)

$D(x,t) = (1\text{ mm})\sin\left[\left(\frac{\pi}{2}\frac{\text{rad}}{\text{m}}\right)x - \left(\frac{3\pi}{2}\frac{\text{rad}}{\text{s}}\right)t + \frac{3\pi}{2}\right]$

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(12 points, 4 points each): 4 Multiple-choice questions / fill-in-the-blanks on various topics.

Directions for multiple-choice questions: COMPLETELY FILL IN THE SQUARE for the answer. Directions for fill-in-the-blank questions: Your answer should be entirely in the boxed region. Include the number of significant figures ("sig. figs.") requested in the problem.

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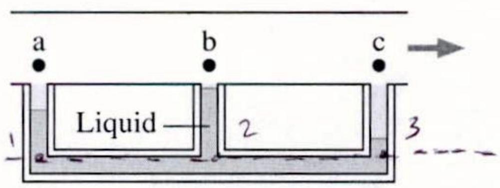
4. Gas flows through the pipe of the following figure (the liquid is in equilibrium). You can't see into the pipe to know how the inner diameter changes. Where is the gas moving the fastest?



$P_1 = P_2 = P_3$

- ☐ Point a
- ■ Point b
- ☐ Point c

= lowest pressure
= needs greater column of water underneath so that pressure here is the same

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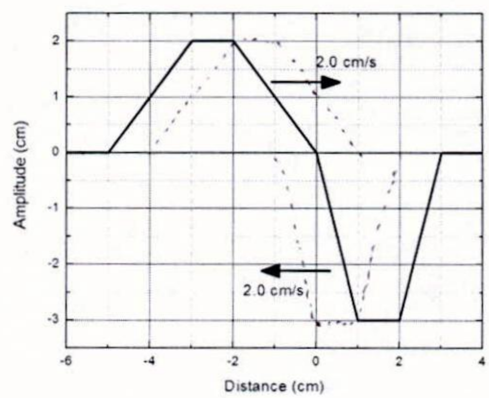
5. The graph on the right shows two waves at time $t = 0$ s, one moving toward the right at 2.0 cm/s and the other moving to the left at 2.0 cm/s. What ~~will~~ is the amplitude of the combined waves at $x = 0$ at time $t = 0.50$ s?

- ☐ +1.0 cm
- ☐ 0 cm
- ☐ −1.0 cm
- ■ −2.0 cm
- ☐ +2.0 cm



@ $x = 0$

$A = A_1 + A_2$
$= +1\text{cm} - 3\text{cm}$
$= -2\text{ cm}$

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6. In class, the quietest we got was 39 dB and the loudest was 103 dB. Calculate to 2 sig. figs. the change in absolute intensity.

$\Delta\beta = (10\text{ dB})\log_{10}\left(\frac{I_f}{I_i}\right)$

$$\boxed{2.5\times10^{6}}$$

$10^{\left(\frac{64\text{ dB}}{10\text{ dB}}\right)} = \frac{I_f}{I_i} = 2.5\times10^{6}$

but we will accept If - Ii

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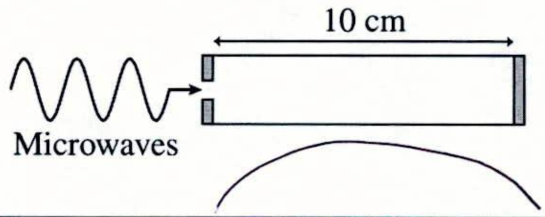
7. Microwaves pass through a small hole into the “microwave cavity.” Ignoring the small hole, you can consider the walls of the cavity fully reflective. What is the fundamental frequency for standing waves in the cavity?

- ☐ 6.0 ~~M~~GHz
- ☐ 3.0 ~~M~~GHz
- ☒ 1.5 ~~M~~GHz
- ☐ 0.75 ~~M~~GHz



$f = \frac{c}{\lambda}$

$= \frac{3\times10^{8}\,m/s}{0.2\,m}$

$= 1.5\ GHz$

$\lambda = 2L$
$= 20\ cm$