UNIVERSITY OF SASKATCHEWAN

Department of Physics and Engineering Physics

Physics 117.3
<u>MIDTERM EXAM – Regular Sitting</u>

February 13, 2020 Time: 90 minutes

NAME: ________________SOLUTIONS__________________ STUDENT NO.: ____________

(Last) **Please Print** (Given)

LECTURE SECTION (please check):

- ❑ 01 Dr. G. S. Chang
- ❑ 02 Mr. B. Zulkoskey

<u>INSTRUCTIONS:</u>

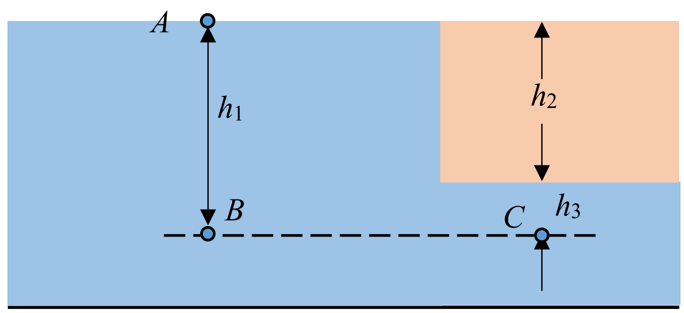
1. This is a closed book exam.
2. The test package includes a test paper (this document), an exam booklet, a formula sheet, a scratch card and an OMR (OpScan / bubble) sheet. The test paper consists of 8 pages, including this cover page. **It is the responsibility of the student to check that the test paper is complete**.
3. Only a basic scientific calculator (e.g. Texas Instruments TI-30X series, Hewlett-Packard HP 10s or 30S) may be used. Graphing or programmable calculators, or calculators with communication capability, or calculators in smart phones are **<u>not</u>** allowed.
4. Enter your name and student number on the cover of the test paper and check the appropriate box for your lecture section. Also enter your name on the exam booklet and scratch card.
5. Enter your name and NSID on the OMR (OpScan / bubble) sheet.
6. The test paper, the exam booklet, the formula sheet, the scratch card, and the OMR (OpScan / bubble) sheet must all be submitted.
7. No test materials will be returned.

QUESTION NUMBER	MAXIMUM MARKS	MARKS OBTAINED
A1-12	12	
B1-4	8	
B5-8	8	
B9-12	8	
B13-16	8	
MARK	out of 36:	

PART A

For each of the following questions in Part A, enter the most appropriate response on the OMR (OpScan / bubble) sheet. Use the exam booklet for your rough work.

A1. Consider an underwater cave that is completely filled with water, as shown in the diagram below. Point *A* is at the surface of the water, and points *B* and *C* are at the same vertical distance below point *A*. Point *C* is inside the cave. Which one of the following statements is correct for the absolute pressures at points *B* and *C*?



(A) $P_B = P_C = P_{atm} + \rho g h_1$
(B) $P_B = P_{atm} + \rho g h_1$ and $P_C = \rho g h_1$
(C) $P_B = P_{atm} + \rho g h_3$ and $P_C = \rho g h_3$
(D) $P_B = P_{atm} + \rho g h_2$ and $P_C = P_{atm} + \rho g h_3$
(E) $P_B = P_{atm} + \rho g h_1$ and $P_C = P_{atm} + \rho g h_2$

Points *B* and *C* are in the same fluid (water) at the same depth below the surface, so the pressures are the same at these points. Since the depth below the surface is h_1, $P_B = P_C = P_{atm} + \rho g h_1$. (A)

A2. When an object is suspended at rest from a spring scale, the scale reads 12 N when the object is in air and 8 N when the object is at rest and fully submerged in a liquid. The magnitude of the buoyant force exerted by the liquid on the object is…

(A) 2 N. (B) 4 N. (C) 10 N. (D) 16 N. (E) 20 N.

When the object is in air, the forces acting on the object are the weight (vertically-down) and the force of the spring scale (vertically-up). Since the object is at rest, and choosing up to be the positive direction, $-F_{grav} + F_{spring1} = 0$, so $F_{grav} = F_{spring1} = 12$ N. When the object is fully submerged in a liquid, the forces on the object are the weight (vertically-down), the force of the spring scale (vertically-up), and the buoyant force of the liquid (vertically-up). Since the object is again at rest, $-F_{grav} + F_{spring2} + B = 0$, so $B = F_{grav} - F_{spring2} = 12\text{ N} - 8\text{ N} = 4\text{N}$. (B)

A3. Two hoses, one of 20-mm diameter, the other of 15-mm diameter, are connected to a faucet, one after the other. At the open end of the hose, the volume flow rate of water is 10 litres per minute. Through which hose is the flow speed greatest?

(A) The 15-mm hose
(B) The 20-mm hose
(C) The flow speed is the same in both hoses.
(D) The answer depends on which of the hoses comes first in the flow.
(E) The answer depends on the lengths of the hoses.

According to the Continuity Equation, Q = volume flow rate = $A\upsilon$ = constant. Therefore, the flow speed will be greatest where the cross-sectional area is smallest. (A)

A4. A force F is applied to the end of a 2-m length of copper and the bar stretches x m. The bar is now cut in half and a force $2F$ is applied to the end of one of the 1 m pieces. The 1-m piece stretches a distance of …

(A) ¼ x m. (B) ½ x m. (C) x m. (D) $2x$ m. (E) $4x$ m.

Recall the stress-strain relationship for a tensile stress: $\frac{F}{A} = Y\frac{\Delta L}{L}$. Initially, $F_1 = F$, $\Delta L_1 = x$, and $L_1 = 2$ m. $F_2 = 2F = 2F_1$, $\Delta L_2 = ?$, and $L_2 = 1\text{ m} = \frac{1}{2}L_1$. Y and A do not change.

$$\frac{F_2}{A} = Y\frac{\Delta L_2}{L_2} \;\Rightarrow\; \Delta L_2 = \frac{F_2 L_2}{AY} = \frac{(2F_1)(\frac{1}{2}L_1)}{AY} = \frac{F_1 L_1}{AY} = \Delta L_1 = x \quad \text{(C)}$$

A5. An object of mass m is attached to an ideal spring of spring constant k. The mass is undergoing Simple Harmonic Motion of amplitude A as it oscillates on a horizontal, frictionless, surface. The motion of the mass is stopped, and it is now made to undergo Simple Harmonic Motion with an amplitude of $2A$. How does the new maximum speed of the object, υ_2, compare to the original maximum speed of the object, υ_1?

(A) $\upsilon_2 = 4\upsilon_1$ (B) $\upsilon_2 = 2\upsilon_1$ (C) $\upsilon_2 = \upsilon_1$ (D) $\upsilon_2 = \frac{1}{2}\upsilon_1$ (E) $\upsilon_2 = \frac{1}{4}\upsilon_1$

Mechanical energy is conserved in this situation. In general, the mechanical energy is the sum of the potential energy of the spring and the kinetic energy of the mass. All of the energy is kinetic when the mass passes through the equilibrium position ($x = 0$), and all of the energy is potential at maximum displacement, where the mass is momentarily at rest before changing its direction of motion.

$$E = \tfrac{1}{2}kx^2 + \tfrac{1}{2}m\upsilon^2 = 0 + \tfrac{1}{2}m\upsilon_{\max}{}^2 = \tfrac{1}{2}kA^2 + 0 \;\Rightarrow\; \upsilon_{\max} = A\sqrt{\frac{k}{m}} \;\Rightarrow\; \upsilon_{\max} \propto A$$

Therefore, doubling the amplitude will double the maximum speed of the object. (B)

A6. Viscous liquid flows through two pipes with the same pressure difference between their ends. The radius of pipe 2 is twice the radius of pipe 1. The length of pipe 2 is three times the length of pipe 1. If the volume flow rate through pipe 1 is Q_1, then the flow rate, Q_2, through pipe 2 is

(A) $\frac{4}{3}Q_1$ (B) $\frac{16}{3}Q_1$ (C) $8Q_1$ (D) $\frac{2}{9}Q_1$ (E) $16Q_1$

Poiseuille's Law applies to viscous flow. $Q = \frac{\Delta V}{\Delta t} = \frac{\pi R^4 (P_1 - P_2)}{8\eta L}$

Given that $(P_1 - P_2)_2 = (P_1 - P_2)_1$, $R_2 = 2R_1$, and $L_2 = 3L_1$,

$$Q_2 = \frac{\pi R_2^{\,4}(P_1 - P_2)}{8\eta L_2} = \frac{\pi (2R_1)^4 (P_1 - P_2)}{8\eta (3L_1)} = \frac{(2^4)\pi (R_1)^4 (P_1 - P_2)}{3(8\eta L_1)} = \frac{16}{3}\frac{\pi R_1^{\,4}(P_1 - P_2)}{8\eta L_1} = \frac{16}{3}Q_1 \quad \text{(B)}$$

A7. Two simple pendula, A and B, have the same length. Pendulum A is at a location where the acceleration due to gravity is 6% lower than at the location of pendulum B. Which one of the following statements correctly relates the periods, T_A and T_B, of the two pendula?

(A) $T_A = T_B$ (B) $T_A = 0.97\ T_B$ (C) $T_A = 0.94\ T_B$
(D) $T_A = 1.03\ T_B$ (E) $T_A = 1.06\ T_B$

The period of a simple pendulum is given by $T = 2\pi\sqrt{\frac{L}{g}}$. Since Pendulum A is at a location where the acceleration due to gravity is 6% lower than at the location of pendulum B, $g_A = (1 - 6\%)\ g_B = 0.94 g_B$

$$T_A = 2\pi\sqrt{\frac{L}{g_A}} = 2\pi\sqrt{\frac{L}{0.94 g_B}} = \left(\sqrt{\frac{1}{0.94}}\right)\left(2\pi\sqrt{\frac{L}{g_B}}\right) = 1.03 T_B \quad \text{(D)}$$

A8. The distance between consecutive crests of a water wave is 2.0 m. As the wave passes a duck floating on the water, you notice that the interval between times when the duck is at maximum upward displacement is 2.0 s. The speed of the water wave is

(A) 0.25 m/s (B) 0.50 m/s (C) 1.0 m/s (D) 2.0 m/s (E) 4.0 m/s

The wavelength of the wave is 2.0 m and the period is 2.0 s. $\upsilon = \frac{\lambda}{T} = \frac{2.0\ \text{m}}{2.0\ \text{s}} = 1.0\ \text{m/s}$ (C)

A9. As you travel down the highway in your car, an ambulance moves away from you at a high speed, sounding its siren at a frequency of 400 Hz. Which one of the following statements is **TRUE**?

(A) You and the ambulance driver both hear a frequency greater than 400 Hz.
(B) You and the ambulance driver both hear a frequency less than 400 Hz.
(C) You and the ambulance driver both hear a frequency of 400 Hz.
(D) You hear a frequency greater than 400 Hz, whereas the ambulance driver hears a frequency of 400 Hz.
(E) You hear a frequency less than 400 Hz, whereas the ambulance driver hears a frequency of 400 Hz.

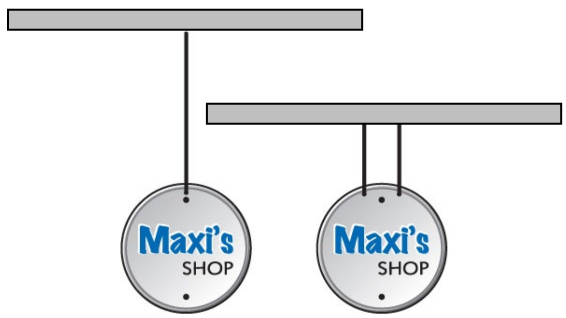
The ambulance driver is moving with the siren, so hears a frequency of 400 Hz. Since the siren is moving away from you, you will hear a frequency lower than 400 Hz. (E)

A10. A sound wave travelling in air has a frequency f and wavelength λ. A second sound wave travelling in air has a wavelength of $\lambda/4$. What is the frequency of the second sound wave?

(A) $\frac{1}{4}f$ (B) $\frac{1}{2}f$ (C) f (D) $2f$ (E) $4f$

The speed of sound in air has a specific value at a specific temperature. Since speed equals frequency times wavelength, if the second wavelength is ¼ of the first wavelength, then the second frequency must be 4× the first frequency. (E)

A11. A sign is hanging from a single metal wire, as shown in the left part of the accompanying figure. The shop owner notices that the wire vibrates at a fundamental resonance frequency of f, which irritates his customers. In an attempt to fix the problem, the shop owner cuts the wire in half and hangs the sign from the two halves, as shown in the right part of the figure. Assuming the tension in each of the two wires is now half the original tension, what is the new fundamental frequency of each wire?



(A) $\frac{f}{2}$ (B) $\frac{f}{\sqrt{2}}$ (C) f (D) $\sqrt{2}f$ (E) $2f$

Let L_1 be the original length of the wire. At the fundamental mode of resonance, the length of the wire corresponds to ½ the wavelength because there will be a node at each end of the wire.

$$L_1 = \tfrac{1}{2}\lambda_1 \;\Rightarrow\; \lambda_1 = 2L_1. \quad f_1 = \frac{\upsilon_1}{\lambda_1} = \frac{\upsilon_1}{2L_1} = \frac{1}{2L_1}\sqrt{\frac{F_1}{m_1/L_1}} = \frac{1}{2L_1}\sqrt{\frac{F_1 L_1}{m_1}} = \frac{1}{2}\sqrt{\frac{F_1}{L_1 m_1}}$$

Let the subscript 2 refer to one of the cut pieces of wire and let f_2 be the fundamental resonant frequency of one of these pieces. $F_2 = ½\, F_1$, $L_2 = ½\, L_1$, and $m_2 = m_1$.

$$f_2 = \frac{1}{2}\sqrt{\frac{F_2}{L_2 m_2}} = \frac{1}{2}\sqrt{\frac{\frac{1}{2}F_1}{\frac{1}{2}L_1\,\frac{1}{2}m_1}} = \sqrt{\frac{\frac{1}{2}}{\frac{1}{2}\times\frac{1}{2}}}\left(\frac{1}{2}\sqrt{\frac{F_1}{L_1 m_1}}\right)\sqrt{2}f_1 \quad \text{(D)}$$

A12. A sound source radiates sound uniformly in all directions. The power of the source is constant. The sound intensity is I at a distance of r from the source. If the distance from the source is doubled (that is, $2r$), what is the new intensity in terms of I?

(A) $\frac{1}{4}I$ (B) $\frac{1}{2}I$ (C) I (D) $2I$ (E) $4I$

$$I = \frac{P}{A} = \frac{P}{4\pi r^2} \;\Rightarrow\; I_2 = \frac{P}{A_2} = \frac{P}{4\pi r_2^2} = \frac{P}{4\pi (2r)^2} = \tfrac{1}{4}\frac{P}{4\pi r^2} = \tfrac{1}{4}I \quad \text{(A)}$$

PART B

Work out the answers to the following Part B questions.

Before scratching any options, be sure to double-check your logic and calculations.

You may find it advantageous to do as many of the parts of a question as you can before scratching any options.

When you have an answer that is one of the options and are confident that your method is correct, scratch that option on the scratch card. if you reveal a star on the scratch card then your answer is correct (full marks, 2/2).

If you do not reveal a star with your first scratch, try to find the error in your solution. If you reveal a star with your second scratch, you receive 1.2 marks out of 2.

Revealing the star with your third, fourth, or fifth scratches does not earn you any marks, but it does give you the correct answer.

You may answer all four Part B question groupings (B1-4, B5-8, B9-12, and B13-16) and you will receive the marks for your best 3 groupings.

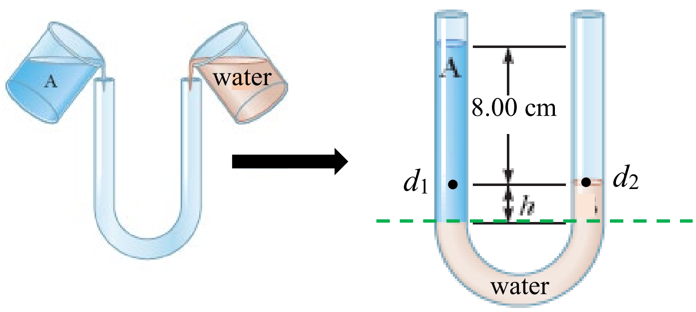
Use the provided exam booklet for your rough work.

B1. Let h be the depth below the surface of the ocean at which the absolute pressure is twice atmospheric pressure (i.e. $2P_{atm}$). The absolute pressure at a depth of $2h$ below the surface of the ocean is

Recall that pressure increases with depth according to $P_2 = P_1 + \rho g(y_1 - y_2)$, where y_1 and y_2 are the heights of points 1 and 2 above some arbitrary reference. Let 1 correspond to the point at a depth of h and 2 correspond to the point at a depth of $2h$.

$$P_1 = P_{atm} + \rho gh = 2P_{atm} \quad \Rightarrow \quad \rho gh = P_{atm}$$
$$P_2 = P_{atm} + \rho g(2h) = P_{atm} + 2\rho gh = P_{atm} + 2P_{atm} = 3P_{atm}$$

Equal volumes of unknown fluid A and water are carefully added to the empty U-shaped pipe as shown in the figure below. The pipe is open at both ends and the fluids come to equilibrium without mixing. The density of the water is 1.00×10^3 kg/m^3 and the atmospheric pressure is 1.01×10^5 Pa.



B2. Which one of the following statements is correct?

(A) Both fluids have the same density.
(B) The density of fluid A is larger than the density of the water.
(C) The density of fluid A is smaller than the density of the water.
(D) The absolute pressure at the point d_1 is same as the pressure at the point d_2 at the same height.
(E) The absolute pressure at the point d_1 is lower that the pressure at the point d_2 at the same height.

Note that the pressure is the same on each side of the U-tube along the dashed green line. The pressure at this location in the left side is $P_{atm} + \rho_A g(8.00\text{ cm} + h)$ and the pressure at this location in the right side is $P_{atm} + \rho_w gh$. Therefore,

$$P_{atm} + \rho_A g(8.00\text{ cm} + h) = P_{atm} + \rho_w gh \quad \Rightarrow \quad \rho_A(8.00\text{ cm} + h) = \rho_w h \quad \Rightarrow \quad \rho_A = \frac{h}{(8.00\text{ cm} + h)}\rho_w$$

B3. If h = 2.00 cm, calculate the density of unknown fluid A.

From the solution for B2:

$$\rho_A = \frac{h}{(8.00\text{ cm} + h)}\rho_w = \frac{(2.00\text{ cm})}{(8.00\text{ cm} + 2.00\text{ cm})}(1.00\times10^3\text{ kg/m}^3) = 0.200\times10^3\text{ kg/m}^3$$

B4. Calculate the "*gauge*" pressure at the points d_1 and d_2.

d_1 is at a depth of 8.00 cm in liquid A, so $P_1 = P_{\text{atm}} + \rho_A g(0.0800\text{ m})$.

$P_{1\text{gauge}} = P_{\text{atm}} + \rho_A g(0.0800\text{ m}) - P_{\text{atm}} = \rho_A g(0.0800\text{ m}) = (0.200 \times 10^3\text{ kg/m}^3)(9.80\text{ m/s}^2)(0.0800\text{ m})$

$P_{1\text{gauge}} = 157\text{ Pa}$

d_2 is at the surface of the water, so $P_2 = P_{\text{atm}} = 1.01 \times 10^5$ Pa. $P_{2\text{gauge}} = P_{\text{atm}} - P_{\text{atm}} = 0$.

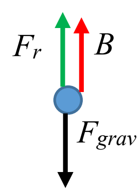
B5. A spherical object of radius r falls with a terminal speed υ through a fluid with viscosity η. Which one of the following statements is true?

(A) The net force on the object has magnitude mg.
(B) The object has an acceleration of magnitude g.
(C) The viscous drag force is the only force acting on the object.
(D) The viscous drag force is in the same direction as the force of gravity on the object.
(E) The viscous drag force causes the net force on the object to be zero.

Because the drag force is directed opposite to the motion, and increases as the speed of the object increases, eventually the drag force will result in the net force on the object being zero. Since the net force is now zero, the acceleration of the object is also now zero. The object then continues to move with constant speed – the terminal speed.

A ball has a radius of 0.750 cm and is made of a material with a density of 2.50×10^3 kg/m^3. The ball is fully-submerged and then released from rest in a fluid with a viscosity of 0.209 Pa.s and a density of 863 kg/m^3.

B6. Which one of the following is the correct free-body diagram for the ball? (F_r is the resistive drag force, B is the buoyant force, and F_{grav} is the weight of the ball.)



F_r is directed vertically upward (opposite to the motion), B is directed vertically-upward, and F_{grav} is directed vertically-downward.

B7. Calculate the buoyant force on the ball.

$$B = \rho_{fluid} V_{fluid} g = \rho_{fluid} V_{ball} g = \rho_{fluid} \tfrac{4}{3}\pi r_{ball}^3 g$$

$$B = (863 \text{ kg/m}^3)\tfrac{4}{3}\pi(0.750\times10^{-2}\text{ m})^3(9.80 \text{ m/s}^2)$$

$$B = 1.49\times10^{-2} \text{ N}$$

B8. Calculate the terminal speed of the ball as it falls through the fluid.

At terminal speed, the net force on the ball is zero.

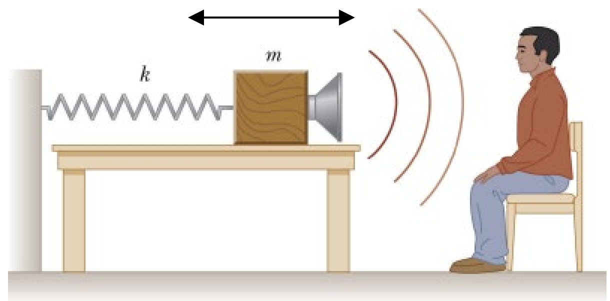
$$\sum F = 0 \;\Rightarrow\; +F_r + B - F_{grav} = 0 \;\Rightarrow\; 6\pi\eta r\upsilon_t + B - mg = 0$$

$$6\pi\eta r\upsilon_t = \rho_{ball}\tfrac{4}{3}\pi r_{ball}^3 g - B \;\Rightarrow\; \upsilon_t = \frac{\rho_{ball}\tfrac{4}{3}\pi r_{ball}^3 g - B}{6\pi\eta r}$$

$$\upsilon_t = \frac{(2.50\times10^3\ \text{kg/m}^3)\tfrac{4}{3}\pi(0.750\times10^{-2}\,\text{m})^3(9.80\ \text{m/s}^2) - 1.49\times10^{-2}\,\text{N}}{6\pi(0.209\ \text{Pa}\cdot\text{s})(0.750\times10^{-2}\,\text{m})}$$

$$\upsilon_t = \frac{4.33\times10^{-2}\,\text{N} - 1.49\times10^{-2}\,\text{N}}{6\pi(0.209\ \text{Pa}\cdot\text{s})(0.750\times10^{-2}\,\text{m})} = 0.961\ \text{m/s}$$

A block with a speaker bolted to it is connected to a spring with a spring constant of 768 N/m, as shown below. The block and speaker are in simple harmonic motion on the frictionless table. The total mass of the block and speaker is 0.400 kg, and the maximum speed of the block and speaker is 21.9 m/s. The speaker emits sound waves of frequency 896 Hz. The speed of sound is 343.0 m/s.



B9. At what point in the speaker's motion does the person sitting to the right of the speaker hear the highest frequency?

The person will hear the highest frequency when the speaker is moving toward the person at its highest speed. This will occur when the speaker is moving to the right and passing through the equilibrium position.

B10. Calculate the highest frequency heard by the person sitting to the right of the speaker.

Apply the Doppler Effect equation for a source moving toward a stationary observer:

$$f_o = \left(\frac{\upsilon + \upsilon_o}{\upsilon - \upsilon_s}\right) f_s = \left(\frac{343.0\text{ m/s}}{343.0\text{ m/s} - 21.9\text{ m/s}}\right)(896\text{ Hz}) = 957\text{ Hz}$$

B11. Calculate the frequency of the speaker's back and forth motion.

$$\omega = 2\pi f = \sqrt{\frac{k}{m}} \quad \Rightarrow \quad f = \frac{1}{2\pi}\sqrt{\frac{k}{m}} = \frac{1}{2\pi}\sqrt{\frac{768\text{ N/m}}{0.400\text{ kg}}} = 6.97\text{ Hz}$$

B12. If the speaker is producing sound energy at a rate of 1.25 W, calculate the sound intensity level at the location of the listener when the listener is a distance of 2.00 m from the speaker.

First calculate the intensity (in W/m^2), then calculate the intensity level (in dB)

$$I = \frac{P}{A} = \frac{P}{4\pi r^2} = \frac{1.25\ \text{W}}{4\pi (2.00\ \text{m})^2} = 0.02487\ \text{W/m}^2$$

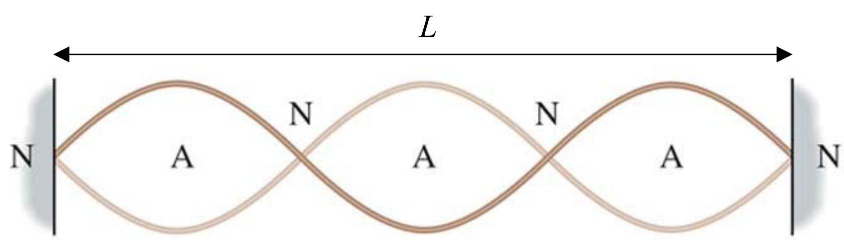
$$\beta = 10 \log\left(\frac{I}{I_o}\right) = 10 \log\left(\frac{0.02487\ \text{W/m}^2}{1.00\times10^{-12}\ \text{W/m}^2}\right) = 104\ \text{dB}$$

B13. Two speakers are placed a distance d apart and are vibrating in phase. The frequency and wavelength of the sound being produced are f and λ respectively. A person standing a distance L from one of the speakers hears no sound. Which one of the following expressions can possibly be correct for the person's distance from the other speaker?

(A) $L + d$ (B) $d + \lambda$ (C) $L + \lambda$ (D) $L - 2d$ (E) $L + ½\,\lambda$

For the person to hear no sound, the sound waves from the two speakers must be exactly out-of-phase when they arrive at the person's location. This will occur when the path length difference for the two sound waves is ½ λ or any odd multiple of half the wavelength. The only option that satisfies this condition, given that the person is a distance L from one of the speakers, is that the person's distance from the other speaker is $L + ½\,\lambda$.

The 1.60-m-long string shown below is fixed at both ends and is vibrating in the standing wave pattern of the third harmonic. The string has a mass per unit length of 8.50×10^{-3} kg/m and is under a tension of 251 N.



B14. Which one of the equations shown below correctly describes the wavelength λ of the traveling wave that makes up the standing wave?

Note that there are 3 node-node segments comprising the length of the string, L. The distance between consecutive nodes is half the wavelength. Therefore,

$$L = 3(\tfrac{1}{2}\lambda) \quad \Rightarrow \quad \lambda = \frac{2L}{3}$$

B15. Calculate the speed of the traveling wave that makes up the standing wave.

$$\upsilon = \sqrt{\frac{F}{\mu}} = \sqrt{\frac{251\text{ N}}{8.50\times10^{-3}\text{ kg/m}}} = 172\text{ m/s}$$

B16. Calculate the frequency of the traveling wave that makes up the standing wave.

$$f = \frac{\upsilon}{\lambda} = \frac{\upsilon}{\frac{2}{3}L} = \frac{3\upsilon}{2L} = \frac{3(172\text{ m/s})}{2(1.60\text{ m})} = 161\text{ Hz}$$

END OF EXAMINATION