UNIVERSITY OF SASKATCHEWAN

Department of Physics and Engineering Physics

Physics 117.3

MIDTERM EXAM – Alternative Sitting

February 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

INSTRUCTIONS:

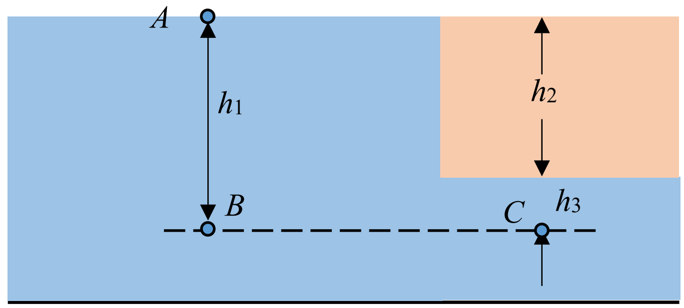
1. This is a closed book exam.
2. The test package includes a test paper (this document), an exam booklet, a formula sheet, a scratch card and an OMR (OpScan / bubble) sheet. The test paper consists of 8 pages, including this cover page. **It is the responsibility of the student to check that the test 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 **not** 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, $-F_{\text{grav}} + F_{\text{spring1}} = 0$, so $F_{\text{grav}} = F_{\text{spring1}} = 12$ 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, $-F_{\text{grav}} + F_{\text{spring2}} + B = 0$, so $B = F_{\text{grav}} - F_{\text{spring2}} = 12\text{ N} - 8\text{ N} = 4\text{N}$. (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. $F_2 = 2F = 2F_1$, ΔL_2 = ?, and $L_2 = 1$ 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.

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

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. $Q = \dfrac{\Delta V}{\Delta t} = \dfrac{\pi R^4 (P_1 - P_2)}{8\eta L}$

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 $T = 2\pi\sqrt{\dfrac{L}{g}}$. 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. $\upsilon = \dfrac{\lambda}{T} = \dfrac{2.0\ \text{m}}{2.0\ \text{s}} = 1.0\ \text{m/s}$ (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.

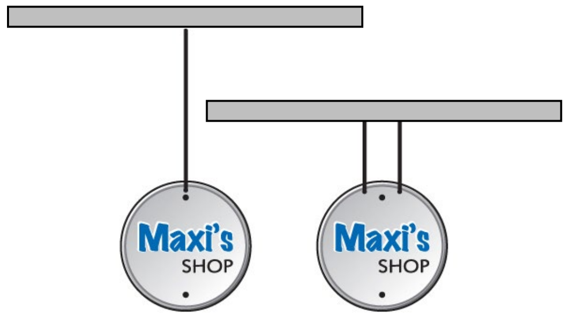
The ambulance driver is moving with the siren, so hears a frequency of 400 Hz. Since the siren is moving away from you, you will hear a frequency lower than 400 Hz. (E)

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.

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

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) $4I$

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

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).

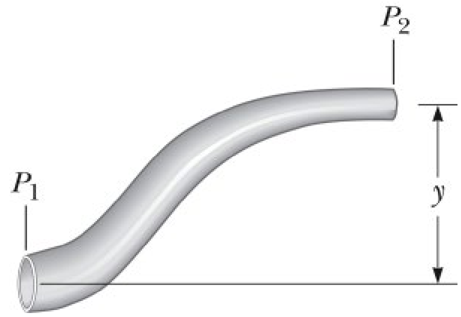
If you do not reveal a star with your first scratch, try to find the error in your solution. If you reveal a star with your second scratch, you receive 1.2 marks out of 2.

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. Water moves through the pipe shown below in steady, ideal flow. Region 2 is higher than region 1 and the cross-sectional area at region 2 is less than at region 1.



Which one of the following statements is correct concerning the pressure and flow speed in region 2 compared to region 1?

(A) The pressure is higher in region 2 but the flow speed is lower than in region 1.
(B) The pressure is lower in region 2 than in region 1 but the flow speed is the same.
(C) Both the pressure and flow speed are lower in region 2 than in region 1.
(D) Both the pressure and flow speed are higher in region 2 than in region 1.
(E) The pressure is lower in region 2 but the flow speed is higher than in region 1.

Recall Bernoulli's Equation, $P_1 + \frac{1}{2}\rho\upsilon_1^2 + \rho g y_1 = P_2 + \frac{1}{2}\rho\upsilon_2^2 + \rho g y_2$, and the Continuity Equation, $A_1\upsilon_1 = A_2\upsilon_2 = Q$. $A_2 < A_1$, so $\upsilon_2 > \upsilon_1$. Also, $y_2 > y_1$. Therefore, from Bernoulli's Equation, $P_1 > P_2$.

B2. The radius of the pipe at location 1 is 4.00 cm and the radius of the pipe at location 2 is 2.00 cm. The height difference between the two locations, y, is 56.7 cm. The volume flow rate of water through the pipe at location 1 is 3.33×10^{-3} m^3/s. Calculate the flow speed of water at location 1.

$$Q = A_1\upsilon_1 = \pi r_1^2 \upsilon_1 \quad \Rightarrow \quad \upsilon_1 = \frac{Q}{\pi r_1^2} = \frac{3.33\times10^{-3}\ \text{m}^3/\text{s}}{\pi(0.0400\ \text{m})^2} = 0.662\ \text{m/s}$$

B3. Calculate the flow speed of water at location 2.

$$Q = A_2\upsilon_2 = \pi r_2^2 \upsilon_2 \quad \Rightarrow \quad \upsilon_2 = \frac{Q}{\pi r_2^2} = \frac{3.33\times10^{-3}\ \text{m}^3/\text{s}}{\pi(0.0200\ \text{m})^2} = 2.65\ \text{m/s}$$

B4. Calculate the pressure difference, $P_1 - P_2$, between locations 1 and 2.

$$P_1 + \tfrac{1}{2}\rho\upsilon_1^2 + \rho g y_1 = P_2 + \tfrac{1}{2}\rho\upsilon_2^2 + \rho g y_2 \quad \Rightarrow \quad P_1 - P_2 = \tfrac{1}{2}\rho(\upsilon_2^2 - \upsilon_1^2) + \rho g(y_2 - y_1)$$

$$P_1 - P_2 = \tfrac{1}{2}\rho(\upsilon_2^2 - \upsilon_1^2) + \rho g y$$

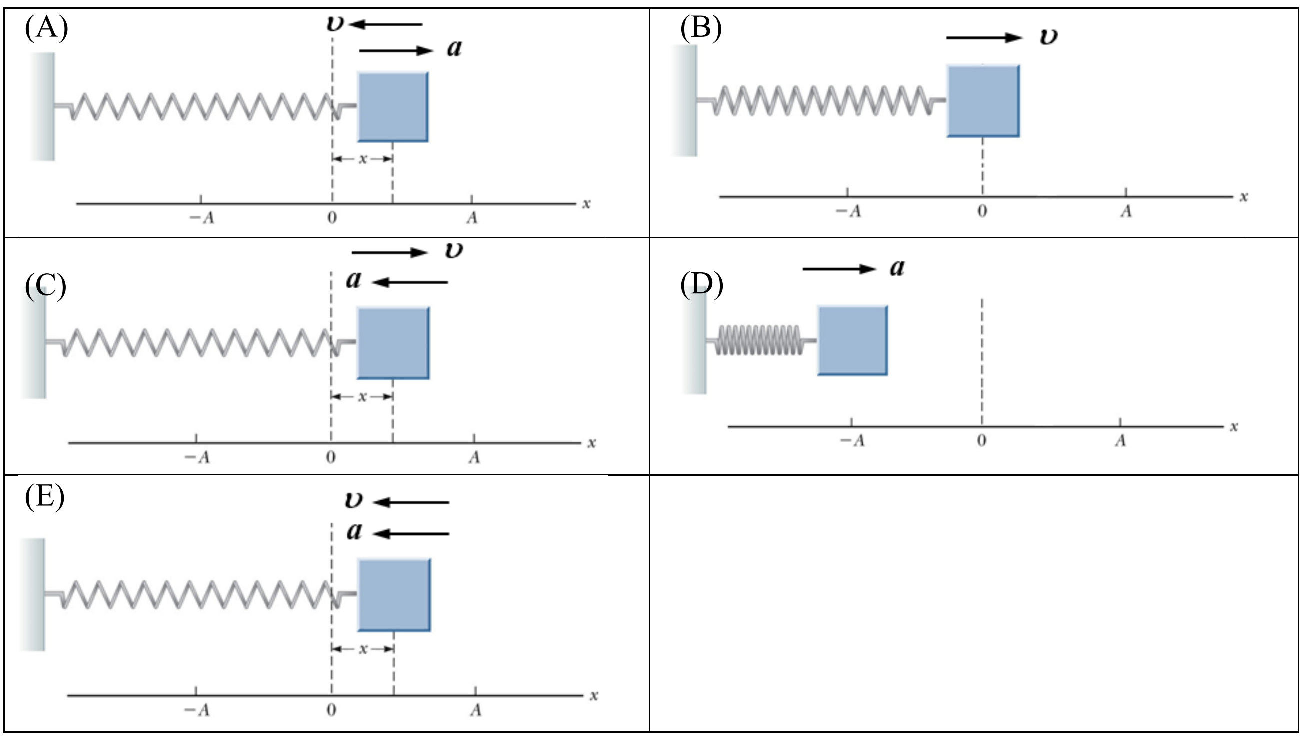
$$P_1 - P_2 = \tfrac{1}{2}(1.00\times10^3\ \text{kg/m}^3)((2.65\ \text{m/s})^2 - (0.662\ \text{m/s})^2) + (1.00\times10^3\ \text{kg/m}^3)(9.80\ \text{m/s}^2)(0.567\ \text{m})$$

$$P_1 - P_2 = 8.85\times10^3\ \text{Pa}$$

B5. A 501-g block resting on a frictionless, horizontal surface is attached to a spring that has a spring constant of 85.0 N/m. An externally-applied horizontal force $\vec{F}$ causes the spring to stretch a distance of 7.60 cm from its equilibrium position. Calculate the magnitude of applied force $\vec{F}$.

The applied force is equal in magnitude to the force exerted by the stretched spring.
$\left\|F_{spring}\right\| = \left\|-kx\right\| = (85.0\ \text{N/m})(0.0760\ \text{m}) = 6.46\ \text{N}$

B6. After the externally-applied force is removed, the block oscillates between the amplitude A and $-A$ in simple harmonic motion. Which one of the following diagrams is **<u>not</u> physically possible** regarding the velocity $\vec{v}$ and acceleration $\vec{a}$ of the block?



The acceleration is always directed opposite to the displacement from equilibrium.

B7. Calculate the frequency of oscillation of the block-spring system.

$$\omega = \sqrt{\frac{k}{m}} \quad \Rightarrow \quad f = \frac{1}{2\pi}\sqrt{\frac{k}{m}} = \frac{1}{2\pi}\sqrt{\frac{85.0\ \text{N/m}}{0.501\ \text{kg}}} = 2.07\ \text{Hz}$$

B8. Calculate the total mechanical energy of the block-spring system.

The total mechanical energy of the system is constant. At maximum displacement, all the mechanical energy is in the stretched spring because the block is at rest at this instant.

$E_{tot} = PE_{\max} = \frac{1}{2}kx_{\max}^2 = \frac{1}{2}kA^2 = \frac{1}{2}(85.0\text{ N/m})(0.0760\text{ m})^2 = 0.245\text{ J}$

Two train whistles have identical frequencies of 180.0 Hz. The speed of sound is 343.0 m/s.

B9. When Train 1 is at rest at the station and Train 2 is moving toward the station, a commuter standing on the station platform hears beats with a frequency of 6.00 Hz when the train whistles operate together. Calculate the frequency that the commuter detects for Train 2's whistle.

Since Train 2 is approaching the commuter, the commuter will hear a higher frequency than from the whistle of the stationary Train 1. Since the beat frequency equals the difference in the frequencies of the two sounds, the commuter will detect a frequency of 180 Hz + 6.00 Hz = 186 Hz from Train 2.

B10. If the two trains were both moving toward the stationary commuter, but from opposite directions and at a speed of 15.0 m/s, what would be the beat frequency?

Since both trains are approaching the commuter at the same speed, the commuter will detect the same, higher, frequency from each train's whistle. Therefore, there will be no beats (beat frequency of 0).

B11. For the case that Train 2 is coming toward the commuter and Train 1 is stationary (the case of B9), calculate the speed of Train 2.

The stationary commuter detects a frequency of 186 Hz from Train 2. Apply the Doppler Shift equation for source moving toward stationary observer.

$$f_o = \left(\frac{\upsilon + \upsilon_o}{\upsilon - \upsilon_s}\right) f_s \;\Rightarrow\; f_o = \left(\frac{\upsilon}{\upsilon - \upsilon_s}\right) f_s \;\Rightarrow\; f_o(\upsilon - \upsilon_s) = f_s \upsilon \;\Rightarrow\; (f_o - f_s)\upsilon = f_o \upsilon_s$$

$$\upsilon_s = \frac{(f_o - f_s)}{f_o}\upsilon = \frac{(186.0\text{ Hz} - 180.0\text{ Hz})}{186.0\text{ Hz}}(343.0\text{ m/s}) = 11.06\text{ m/s}$$

B12. Now consider the following scenario: Train 2 is approaching the station as in B11 and Train 1 is moving away from the station at a speed of 12.00 m/s. Calculate the frequency of the Train 2 whistle as heard by a passenger on Train 1.

$$f_o = \left(\frac{\upsilon + \upsilon_o}{\upsilon - \upsilon_s}\right) f_s = \left(\frac{343.0\text{ m/s} - 12.00\text{ m/s}}{343.0\text{ m/s} - 11.06\text{ m/s}}\right)(180.0\text{ Hz}) = 179.5\text{ Hz}$$

B13. Consider a pipe of length L that is open at one end and closed at the other. Let υ represent the speed of sound in air. Which one of the following is the correct expression for the fundamental frequency of standing waves in the pipe?

The open end is a displacement antinode and the closed end is a displacement node. In the fundamental mode of vibration, there are no antinodes or nodes between the ends of the pipe. The distance between consecutive antinodes and nodes is one-quarter of the wavelength.

$$L = \tfrac{1}{4}\lambda_1 \;\;\Rightarrow\;\; \lambda_1 = 4L \;\;\Rightarrow\;\; f_1 = \frac{\upsilon}{\lambda_1} = \frac{\upsilon}{4L}$$

Two pipes of equal length of 25.3 cm, that are each open at one end and closed at the other, are placed side-by-side.

B14. Calculate the speed of sound in each pipe when the air temperature is 27.0°C.

$$\upsilon = (331\text{ m/s})\sqrt{\frac{T}{273\text{ K}}} = (331\text{ m/s})\sqrt{\frac{(27.0+273)\text{ K}}{273\text{ K}}} = 347\text{ m/s}$$

B15. Both pipes are producing sound at the fundamental frequency. If the air temperature in one pipe increases to 32.0°C while the air temperature in the other pipe remains at 27.0°C, what will be the beat frequency (approximately)?

The speed of sound in the warmer pipe becomes $\upsilon = (331\text{ m/s})\sqrt{\frac{T}{273\text{ K}}} = (331\text{ m/s})\sqrt{\frac{(32.0+273)\text{ K}}{273\text{ K}}} = 349.9\text{ m/s}$ and the fundamental frequency in this pipe is now $f = \frac{\upsilon}{4L} = \frac{349.9\text{ m/s}}{4(0.253\text{ m})} = 345.7\text{ Hz}$. The fundamental frequency in the cooler pipe is $f = \frac{\upsilon}{4L} = \frac{347\text{ m/s}}{4(0.253\text{ m})} = 342.9\text{ Hz}$ and therefore the beat frequency is 345.7 Hz – 342.9 Hz = 2.8 Hz, which is approximately 3 Hz.

B16. The end of one of the pipes is cut open so that it is now open at both ends, but still has a length of 25.3 cm. Calculate the fundamental frequency of sound produced by this pipe when the air temperature is 27.0°C.

The pipe is now open at both ends. The fundamental mode of vibration corresponds to a displacement antinode at each end of the pipe, and a node in the middle of the pipe. The length of the pipe therefore corresponds to half the wavelength of the sound, because the distance between consecutive antinodes is half the wavelength.

$$L = \tfrac{1}{2}\lambda_1 = \tfrac{1}{2}\frac{\upsilon}{f_1} \quad \Rightarrow \quad f_1 = \frac{\upsilon}{2L} = \frac{347 \text{ m/s}}{2(0.253 \text{ m})} = 686 \text{ Hz}$$

END OF EXAMINATION