Name:______________________________ ID:________________________________

Physics 202

Final Exam

8/15/2024

Collaboration is not allowed. Allowed on your desk are: four 8.5 x 11 inch doubled sided sheets of notes, any "survival sheets", a non-communicating graphing scientific calculator, a page of scratch paper, writing utensils, and the exam. You will have 110 minutes to complete this exam.

For questions 1 through 6 **fill in the square** next to all correct answers. A given problem may have more than one correct answer. Each correctly bubbled answer will receive two points. There are **13** correct answers in this section and only the first **13** filled in answers will be graded. There is no partial credit.

1. A guitar string has harmonics at **440 Hz**, **880 Hz**, and **1100 Hz**. Which of the following frequencies **must** also be harmonics of the same string?

   ☑ (a) 220 Hz

   ☐ (b) 330 Hz

   ☐ (c) 550 Hz

   ☑ (d) 660 Hz

   ☐ (e) 1210 Hz

2. Three and a half opera singers are finishing the final cadenza (song). Changing which of the following will affect the time it takes the sound to travel to you?

   ☐ (a) Frequency of the sound

   ☐ (b) Wavelength of the sound

   ☐ (c) Volume of the sound

   ☑ (d) Temperature of the room

   ☐ (e) Each singer has a different sound velocity and thus each sound will reach you at different times

   ☑ (f) Distance from the singers to you

3. You see a flash of lightning, then **18.5 seconds** later you hear the thunder. How far away from you was the lightning?

   ☐ (a) 1.0 km

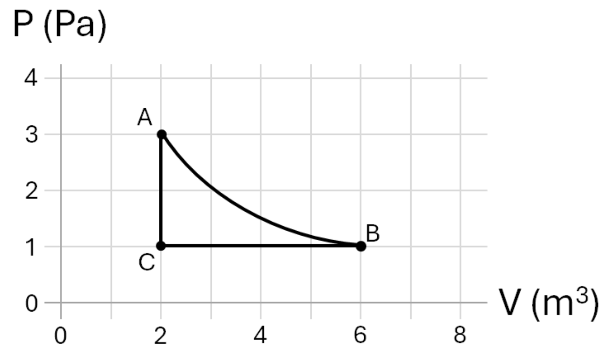
   ☐ (b) 18.5 km

   ☐ (c) 8.03 km

   ☑ (d) 6.35 km

   ☐ (e) It is not possible to calculate this with the given information

4. An ideal, monatomic gas goes through the cycle depicted in the graph, starting at point A, moving to point B, then C, then back to A. Which of the following statements are true about this cycle?



- ☐ (a) The temperature at A is **greater than** the temperature at B.
- ☑ (b) The temperature at A is **equal to** the temperature at B.
- ☐ (c) Process A→B could be an adiabatic process
- ☑ (d) This is a heat **engine**
- ☐ (e) This is a heat **pump**
- ☐ (f) Process B→C occurs at a constant temperature
- ☑ (g) The isochoric process increases the temperature in the gas.

5. A simple harmonic oscillator's **amplitude doubles**. Which of the following statements are true?

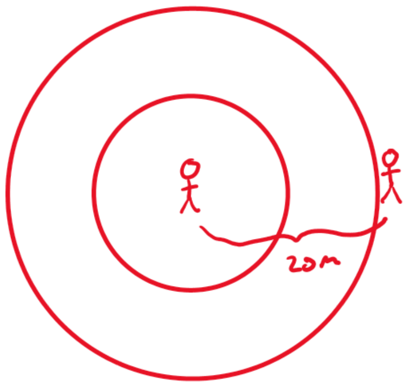
- ☐ (a) If the oscillator is a mass-spring oscillator, decreasing its mass by **1/4** could have caused the amplitude change
- ☐ (b) If the oscillator is a pendulum, **quadrupling** its length could have caused the amplitude change
- ☑ (c) The oscillator's maximum kinetic energy increased by a factor of **4**
- ☑ (d) The oscillator period was **unaffected** by the amplitude change
- ☐ (e) The oscillator period **doubled** when the amplitude doubled

6. In a heat engine, which of the following will result in an **increased efficiency**? Assume the engine is not heating up or cooling down, but is in thermodynamic equilibrium with its surroundings.

- ☑ (a) Increasing the amount of heat that enters the gas during the cycle while holding the amount of heat leaving the gas constant
- ☐ (b) Doubling both the work done by the gas and the heat exhausted to the cold resevoir
- ☑ (c) Increasing the temperature of the **hot** reservoir while keeping the **cold** reservoir temperature the same (assume Carnot cycle)
- ☐ (d) Increasing the temperature of the **cold** reservoir while keeping the **hot** reservoir temperature the same (assume Carnot cycle)
- ☑ (e) Increasing the area inside the cycle on a PV graph while the amount of heat that enters the gas during the cycle stays the same

7. (9 points) An opera singer is singing his triumphant aria (a song). Assume the singer is emitting a spherical wave. You are **20 meters** away from him, and notice that the sound meter you are holding reads an intensity of **1.8×10^{-4} J/m²s**.

(a) With what power is the opera singer singing?



$$I = \frac{P}{A}$$

$$\Rightarrow P = IA = (1.8\times10^{-4})(4\pi(20)^2)$$

$$= 0.905\ \text{W}$$

(b) You switch your sound meter to decibel mode. How many decibels does it read?

$$\beta = 10\,\text{dB}\,\log_{10}\left(\frac{1.8\times10^{-4}}{10^{-12}}\right)$$

$$\beta = 82.6\ \text{dB}$$

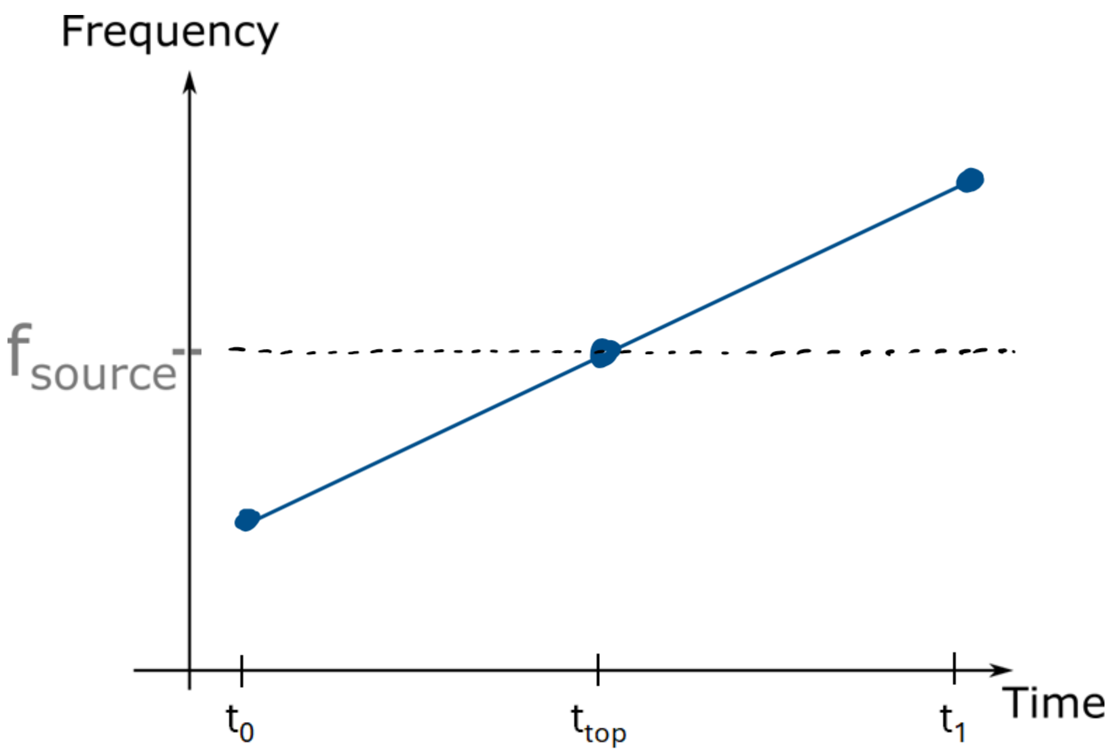
(c) If there were instead two identical opera singers at the same distance, what would your decibel meter read?

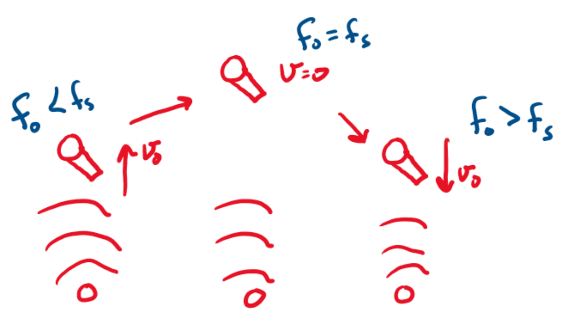
$$\beta = 10\,\text{dB}\,\log_{10}\left(\frac{2\times1.8\times10^{-4}}{10^{-12}}\right)$$

$$= 85.6\ \text{dB}$$ (only a gain of 3dB!)

8. (5 points) A toy generates a constant frequency, $\mathbf{f_{source}}$, sound. The toy is held stationary, while a microphone is held above it. The microphone is thrown upwards at time, $\mathbf{t_o}$, with an initial velocity, $\mathbf{v_o}$, reaches the top of its motion at time, $\mathbf{t_{top}}$, and then is caught at time, $\mathbf{t_1}$, at the same spot it was thrown from.

Neatly draw the frequency observed by the microphone as a function of time on the provided graph. You will be graded on the qualitative shape (relative to f_{source}) of the frequency graph, not numerical accuracy since we don't have any numerical values. This is essentially related quantities sensemaking. *(hint: do you expect the frequencies observed by the microphone to be larger, smaller, or equal to f_{source} at times t_o, t_{top}, and t_1?)*





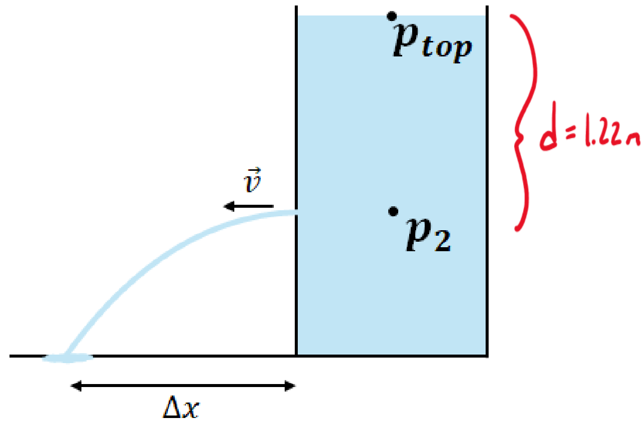
$$f_o = f_s\left(\frac{v \pm v_o}{v}\right)$$

$$= f_s \pm f_s \frac{v_o}{v}$$

$\Rightarrow$ linearly $\propto$ to v_o

$a = \text{const} = -g \Rightarrow$ slope of v_o is const $\Rightarrow$ slope of f_o is const.

9. (12 pts) Oil of density **840 kg/m³** is stored in a cylinder of radius **38 cm**. The cylinder is open at the top and rests on the floor. The cylinder is **2 meters** tall. A small hole of radius **0.25 cm** is created in the cylinder, **78 cm** from the bottom of the cylinder.



(a) What is the pressure in the fluid, p_2, **78 cm** from the bottom of the cylinder?

$$P_2 = \overset{P_{atm}}{P_{top}} + \rho g d$$

$$= 101{,}325 + (840)(9.8)(1.22) = 111{,}368 \text{ Pa}$$

$$= 1.11 \times 10^5 \text{ Pa}$$

(b) With what velocity, **v**, does the fluid exit the hole?

$$\underbrace{P_{outside}}_{P_{atm}} + \cancel{\rho g \underbrace{y_{out}}_{y_2}} + \frac{1}{2}\rho \underbrace{v_{out}^2}_{v} = P_2 + \cancel{\rho g y_2} + \frac{1}{2}\rho \underbrace{v_2^2}_{0}$$

$$P_{atm} + \frac{1}{2}\rho v^2 = P_2 \Rightarrow \boxed{v = 4.89 \text{ m/s}}$$

(c) If the volume flow rate of oil out of the hole was constant at this initial rate, how long would it take for the oil to drain down to the level of the hole? *(if you did not answer part (b), assume the oil exits the hole with a velocity of 1.0 m/s)*

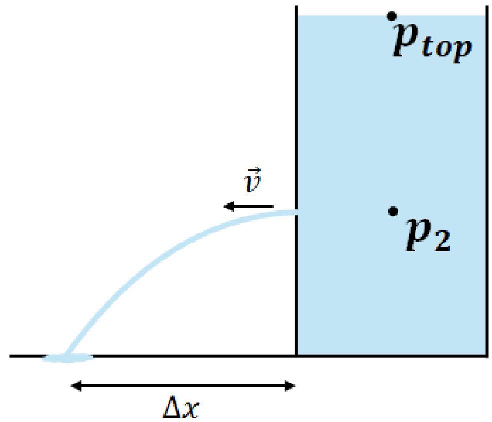
$$Q = vA = v\pi r^2 = (4.89)(3.14)(0.0025)^2 = 9.6 \times 10^{-5} \text{ m}^3/\text{s}$$

$$\text{Volume in cyl} = \pi R^2 h = \pi (0.38)^2 (1.22) = 0.553 \text{ m}^3$$

$$\Delta t = \frac{\text{Vol}}{Q} = 5{,}764 \text{ sec} = 1.60 \text{ hrs}$$

… 9. continued

Problem statement: Oil of density **840 kg/m³** is stored in a cylinder of radius **38 cm**. The cylinder is open at the top and rests on the floor. The cylinder is **2 meters** tall. A small hole of radius **0.25 cm** is created in the cylinder, **78 cm** from the bottom of the cylinder.



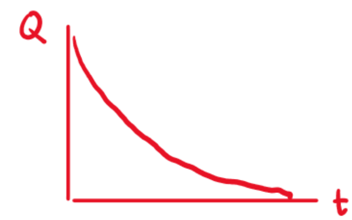
(d) Do you expect the answer to (c) to be an over-estimate, an under-estimate, or just right? Explain using any combination of words, graphs, diagrams, mathematical expressions, etc.

1.6 hrs will be an underestimate

as oil drains, the depth at P_2 will decrease

$\Rightarrow$ P_2 will decrease $\left(\underbrace{P_2}_{\downarrow} = P_{atm} + \rho g \underbrace{d}_{\downarrow}\right)$

$\Rightarrow$ v will decrease $\left(\underbrace{P_2}_{\downarrow} = P_{atm} + \frac{1}{2}\rho \underbrace{v^2}_{\downarrow}\right)$

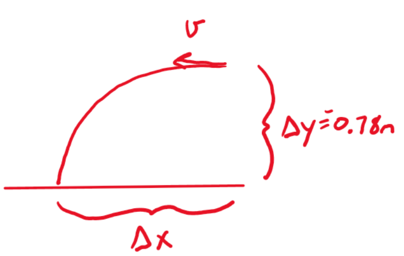


$\Rightarrow$ $Q = vA$ will decrease $\Rightarrow$ rate of fluid drain will decrease

$\Rightarrow$ Δt will increase

$\underbrace{\Delta t}_{\uparrow} = \frac{Vol}{Q}\,]\downarrow$

(e) (1 pt extra credit) How far does the fluid travel, **Δx**, before it lands on the ground?



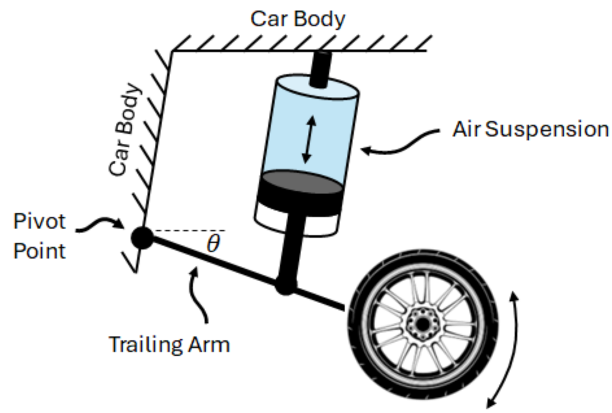
y: $\Delta y = \cancel{v_{iy}}^{0} \Delta t - \frac{1}{2} g \Delta t^2$

$\Delta t = \sqrt{\frac{2\Delta y}{g}}$

x: $\Delta x = v_{ix}\Delta t + \frac{1}{2}\cancel{a_x}^{0}\Delta t^2$

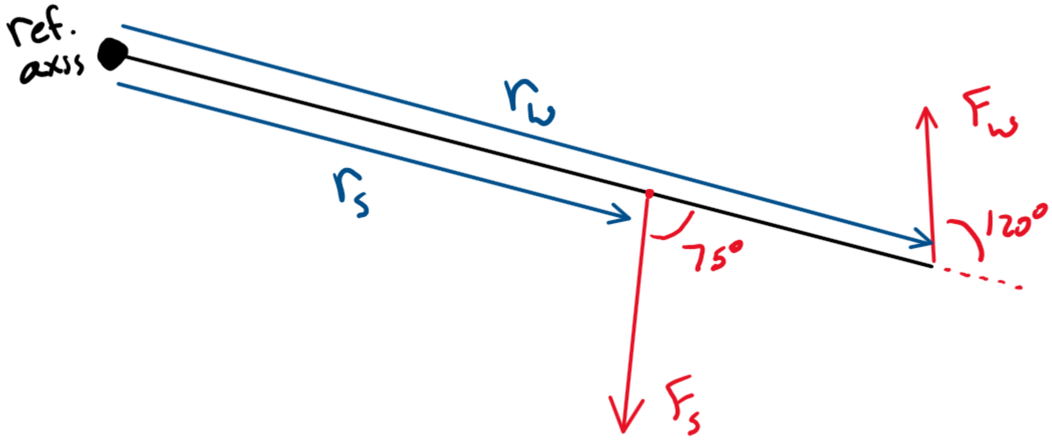
$\Delta x = v\sqrt{\frac{2\Delta y}{g}} = (4.89\,m/s)\sqrt{\frac{2(0.78m)}{9.8\,m/s^2}} = 1.95m$

10. (7 points) An example of air suspension is depicted in the diagram. A "trailing arm" is a rigid piece of metal which pivots about a point attached to the car body (the "pivot point" in the diagram). The trailing arm is attached to the wheel. When a bump in the road pushes the wheel upwards, a piston is pushed into a cylinder of air, also attached to the trailing arm.



For this situation, let us assume that in its equilibrium position, the air suspension is attached to the trailing arm **43 cm** from the pivot point, making an angle of **75 degrees** with the arm, and the wheel is attached at a point **20 cm** further away from the pivot. Let us also assume that the trailing arm makes an angle of **30 degrees** with the horizontal.

(a) Neatly draw an extended free body diagram for the case of a car at rest in its equilibrium position. Clearly label any forces or other quantities that have not been given.



(b) The car has a mass of **2000 kg**, 1/4 of which is held up by this suspension. At equilibrium, what magnitude of force is exerted on the trailing arm by the air suspension?

$$\Rightarrow F_w = \frac{1}{4}(2000\,\text{kg})(9.8\,\text{m/s}^2) = 4900\,\text{N}$$

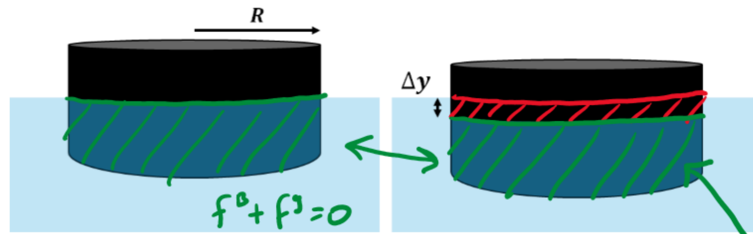
$$\Sigma \tau = I\alpha$$

$$-r_s|F_s|\sin(75°) + r_w|F_w|\sin(120°) = 0$$

$$-(.43)|F_s|\sin 75° + (.63)(4900)(\sin 120°) = 0$$

$$|F_s| = 6{,}440\,\text{N}$$

11. (9 pts) A buoy is a cylindrical object that floats in the ocean and can help to guide ships around dangerous obstacles. Assume this buoy has a radius, **R**, and a mass, **M**. Sea water density is **ρ**. Because the ocean is not perfectly calm, buoys often oscillate up and down. When the buoy is in its equilibrium position (left image above), the net force acting on it is zero.



F^B of this part $= F^g$ on buoy

(a) What are the names of the two forces acting on the buoy at equilibrium position?

Force of gravity, force of buoyancy

(b) If the buoy is displaced downwards a distance, **Δy**, which of the forces in part (a) changes?

$F^g = mg = \text{const}$ $\quad F^B$ changes

(c) If the buoy is displaced downwards a distance, **Δy**, what is the magnitude of the net force acting on it? Write your answer in terms of only numbers, **R**, **M**, **ρ**, **π**, and **g**, the gravitational acceleration on Earth.

$$\Sigma F = \underbrace{\vec{F}^B_1}_{\substack{\text{Buoyancy of part that is} \\ \text{underwater @ equilib.} \\ = -\vec{F}^g \text{ on buoy}}} + \underbrace{F^B_2}_{\substack{\text{additional volume that is submerged} \\ \text{when displaced } \Delta y \text{ downwards}}} + \underbrace{\vec{F}^g}_{\text{cancels with } F^B_1} = F^B_2 = \text{weight of displaced fluid}$$

$$= \rho_{water} V g$$

$$= \boxed{\rho \pi R^2 \Delta y\, g} = F^B_2 = |F_{net}|$$

(d) Modeling the motion of a buoy as a simple harmonic oscillation, show that the period of its motion is:

(hint: the magnitude of the restoring force of a spring is $|F| = k\Delta x$*)*

$$T = \frac{2}{R}\sqrt{\frac{M\pi}{\rho g}}$$

if $F = k\Delta x$ for spring

& $F = \rho \pi R^2 g \Delta y$ for buoy

$\Rightarrow$ "k" for buoy $= \rho \pi R^2 g$

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

$$T = 2\pi\sqrt{\frac{M}{\rho \pi R^2 g}}$$

$$T = \frac{2}{R}\sqrt{\frac{M\pi^{\cancel{2}}}{\rho \cancel{\pi} g}}$$

$$\boxed{T = \frac{2}{R}\sqrt{\frac{\pi M}{\rho g}}}$$