Name:______________________________

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# Physics 202

## Final Exam

3/15/2022

Collaboration is not allowed. Allowed on your desk are: ten 8.5 x 11 inch doubled sided sheets of notes that are bound together, non-communicating graphing scientific calculator, 1 page of scratch paper, writing utensils, and the exam. You will have 110 minutes to complete this exam.

## Constants

**$k_B = 1.38 \times 10^{-23}$ J/K**

**$R = 8.31$ J/mol·K**

**$m_{nitrogen} = 4.65 \times 10^{-26}$ kg**

**$p_{atm} = 101{,}300$ Pa**

**1 cal = 4.19 J**

**1 liter = $1 \times 10^{-3}$ m$^3$,**

**$c_{water} = 4190$ J/kg·K**

**$c_{ice} = 2090$ J/kg·K**

**$L_{f,water} = 3.33 \times 10^5$ J/kg**

**$L_{v,water} = 22.6 \times 10^5$ J/kg**

**$\sigma = 5.67 \times 10^{-8}$ W/m$^2$·K$^4$**

**$\rho_{air} = 1.28$ kg/m$^3$**

**$\rho_{water} = 1000$ kg/m$^3$**

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 **9** correct answers in this section and only the first **9** filled in answers will be graded. There is no partial credit.

1. The O.H. Hinsdale Wave Research Laboratory at OSU can generate a large number of water wave types and configurations. In one experiment they send two waves traveling in opposite directions down a long channel. Both waves have the same amplitude and frequency. Which **one** of the following statements best describes the resulting phenomena?

   □ (a) This experiment generates a large wave pulse, consistent with the non-linear addition of wave theory.
   x (b) This experiment generates a standing wave, consistent with the linear superposition of waves theory.
   □ (c) This experiment generates completely destructive wave interference everywhere in the channel, consistent with Riverton's addition of waves theory.
   □ (d) This experiment generates completely constructive wave interference everywhere in the channel, consistent with the Nessian addition of waves theory.

2. Consider the sound intensity from a constant power spherical source. Which of the following statements are correct?

   □ (a) If you move to a distance twice as far from the source, the sound intensity will **double**.
   □ (b) If you move to a distance twice as far from the source, the sound intensity will **half**.
   □ (c) If you move to a distance twice as far from the source, the sound intensity will **quadruple**.
   x (d) If you move to a distance twice as far from the source, the sound intensity will be a **quarter** of what it was.

3. Consider the sound intensity level (dB) from a constant power spherical source. Which of the following statements are correct?

   x (a) If the sound intensity level goes from 1 dB to 10 dB, the factor by which ***sound intensity*** changes is **less than 10**.
   □ (b) If the sound intensity level goes from 1 dB to 10 dB, the factor by which ***sound intensity*** changes is **equal to 10**.
   □ (c) If the sound intensity level goes from 1 dB to 10 dB, the factor by which ***sound intensity*** changes is **greater than 10**.

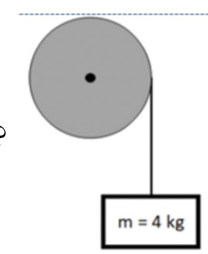
4. Which of the following situations describe a scenario where the entropy of the system decreases?

□ (a) Jupiter has excess thermal energy, causing a storm more than three times the size of the Earth which radiates heat into the solar system. The system is our universe.
x (b) A refrigerator cools a refreshing drink for after this exam. The system is the refreshing drink.
□ (c) Liquid water ($H_2O$) changes phase directly from a solid (ice) to a gas (water vapor) in a process known as sublimation. The system is the H2O.

5. Before your final exam, you have a nightmare of accurate physics. In your nightmare, a demented ice cream truck drives towards you at a high constant velocity, playing a constant tone. The truck passes you, then the truck slows down to a stop. Which of the following describe the frequency you hear compared to the frequency of the tone emitted by the truck?

x (a) While the truck is approaching you, the frequency you observe is **higher** than the emitted frequency.
□ (b) While the truck is approaching you, you observe the same frequency **that** is emitted.
□ (c) While the truck is approaching you, the frequency you observe is **lower** than the emitted frequency.
□ (d) While the truck is approaching you, the frequency you observe is **increasing**.
x (e) While the truck is approaching you, the frequency you observe is **constant**.
□ (f) While the truck is approaching you, the frequency you observe is **decreasing**.
x (g) After it has passed you, when the truck is slowing down, the frequency you observe is **increasing**.
□ (h) After it has passed you, when the truck is slowing down, the frequency you observe is **constant**.
□ (i) After it has passed you, when the truck is slowing down, the frequency you observe is **decreasing**.

6. A disk is able to freely rotate (negligible friction) around an axel fixed at a distance h above level ground. A light string wraps around the edge of the disk and connects to a box at the other end. The box starts from rest initially and falls downwards unraveling the string, spinning the disk. Which of the following statements are true during the time the box is falling towards the ground?

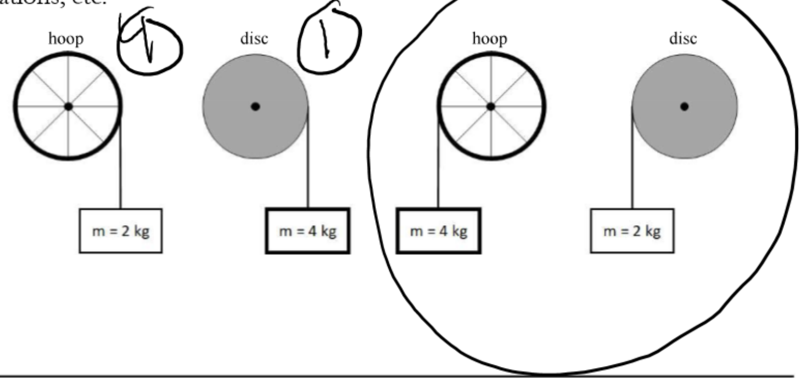



□ (a) The rotational kinetic energy of the disk is decreasing.
x (b) **The rotational kinetic energy of the disk is increasing**.
□ (c) The rotational kinetic energy of the disk is constant.
□ (d) The angular momentum of the disk is decreasing.
x (e) **The angular momentum of the disk is increasing**.
□ (f) The angular momentum of the disk is constant.

7. (5 points) Two identical hoops and two identical discs are fixed on frictionless pivots the same distance above the ground. All of the hoops/discs have the same weight and radius. Each hoop/disk has a box with a given mass hung from strings wound around them, as shown in the figure. All boxes are released from identical heights, from rest, and at the same time. What is the order in which the boxes first hit the ground? Explain using words, diagrams, equations, etc.

$$I_{disc} = \frac{1}{2}mr^2$$

$$I_{hoop} = mr^2$$




$\tau$

$f_{net} = m_b a$

$m_b g - F^T = m_b a$

$\Rightarrow F^T = m_b(g-a)$

$\tau = I\alpha$

$\Rightarrow F^T r = I\alpha$

disk or hoop

$\frac{1}{2}$ or $1$

$\Rightarrow m_b(g-a)\cancel{r} = (\gamma M r^{\cancel{2}})\left(\frac{a}{\cancel{r}}\right)$

$\Rightarrow m_b g - m_b a = \gamma M a$

$\Rightarrow m_b g = a(\gamma M + m_b)$

$\Rightarrow a = \frac{m_b}{\gamma M + m_b}(g)$

energy

$m_b g h = \frac{1}{2} m_b v^2 + \frac{1}{2} I \omega^2$

$m_b g h = \frac{1}{2} m_b v^2 + \frac{1}{2} \gamma M \cancel{r^2} \frac{v^2}{\cancel{r^2}}$

$m_b g h = \frac{1}{2} m_b v^2 + \frac{1}{2} \gamma M v^2$

$2 m_b g h = v^2(m_b + \gamma M)$

$\Rightarrow v^2 = \frac{m_b}{m_b + \gamma M}(2gh)$

Both solutions show that as $M_b$ = mass of box increase, the box falls faster. They both also show that for hoops ($\gamma = 1$), the box will fall slower than for discs with $\gamma = \frac{1}{2}$.

**5 pts - High level rotational mechanics - Makes a fully complete argument that addresses and proves that the two systems on the right side will hit at same time.**

**4.5 pts - High level rotational mechanics - Uses relevant physics to make a nearly complete argument. Asserts, but does not prove that the two systems on the right hand side will hit at the same time.**

**3.5 pts - Mid level rotational mechanics - Uses relevant physics to make a partially correct argument. Argument is incomplete or has flaws.**

**2.5 pts - Low level rotational mechanics - makes an argument using relevant physics. Can assert correct answer with no explanation.**

**1.5 pts - relevant physics mentioned**

8. (8 points) An experiment involves taking an equal mass of solid aluminum and iron, both at 100.0° C, and placing them in a very well insulated and sealed container. The container holds an unknown liquid substance that has the same mass as one of the solids, and is initially at a temperature of 20.00° C. After some time it is observed that the three substances have come to an equilibrium temperature of 48.36° C.

(a) Use related quantities sensemaking to determine if the final equilibrium temperature of 48.36° C seems reasonable. Related quantities sensemaking involves comparing the value of two or more quantities and their expected relationship.

(b) What is the unknown liquid? Assume the temperature change for the insulated container is negligible and there are no phase changes.

**(a) Heat transfers from objects of greater temperature to objects of lower temperature. I would expect some of the thermal energy in the hot metals to transfer to the cooler liquid. This would reduce the temperature of the metals and increase the temperature of the liquid. Since 48.36° C is between the hot 100° C of the metals and the cooler 20° C of liquid, it seams like a reasonable equilibrium temperature.**

**Table of Specific Heats**

| Substance | Specific Heat ($J\cdot kg^{-1}\cdot K^{-1}$) |
|---|---|
| Ammonia (liquid) | 4700 |
| Gasoline (liquid) | 2200 |
| Ethanol (liquid) | 2440 |
| Mercury (liquid) | 140 |
| Polyethylene (solid) | 2939 |
| Aluminum (solid) | 890 |
| Granite (solid) | 790 |
| Iron (solid) | 450 |
| Glass (solid) | 840 |

(b) $\Sigma Q = 0 \Rightarrow Q_{Al} + Q_{Fe} + Q_{liq} = 0$

$$M_{Al} C_{Al}(T_{f,Al} - T_{i,Al}) + M_{Fe} C_{Fe}(T_{f,Fe} - T_{i,Fe}) + M_{liq} C_{liq}(T_{f,liq} - T_{i,liq}) = 0$$

w/ $M_{Al} = M_{Fe} = M_{liq}$, mass cancels

Solving for $C_{liq}$ yields

$$C_{liq} = \frac{\cancel{M_{Al}} C_{Al}(T_{f,Al} - T_{i,Al}) + \cancel{M_{Fe}} C_{Fe}(T_{f,Fe} - T_{i,Fe})}{\cancel{M_{liq}}(T_{f,liq} - T_{i,liq})} = \underline{2440} \frac{J}{kg\cdot K}$$

$\boxed{\text{Ethanol}}$ specific Heat

**Rubric**

**(a) 1.5 pts total**
**(b) 6.5 pts total**
- **1.5 pt - sum of Q = 0**
- **1.5 pt - Q=mCΔT equation**
- **3 pts - application and algebra**
- **0.5 pt - correct answer**

9. (7 points) On a nice spring day you find yourself relaxing under an old oak tree. You pull the end of one of the tree's branches down (negative maximum displacement) about 2 ft and let it go (t = 0 s). You note that the resulting motion appears to be from a simple harmonic oscillator with a period of about 2.5 seconds. It takes the branch about 8 oscillations to decrease the amplitude by a factor of 2.

(a) What evidence could you have to claim the branch undergoes simple harmonic motion? (be brief)

(b) Describe the energy transfers in the branch + earth system during an entire cycle of the motion. Focus on the three most important types of energy in the system. Feel free to use a plot or diagram to illustrate how/when the energy changes forms.

(c) What is the time constant τ for the amplitude as a function of time during the damping of the oscillation.

**(a)**

1. **Constant period - measure if the period changes as the amplitude of the oscillation decreases.**
2. **Linear restoring force - measure the deflection of the branch as a function of the force you pull it down with.**
3. **Quadratic potential energy - probably have to get the force data from (2) and find it's gradient.**
4. **Sinusoidal motion - tape a marker to the branch and have it draw out it's position on a long white board you slide behind it. See if it yields a sine/cosine function.**

**(b) The three most prevalent forms of energy in the system is the kinetic energy of the branch, the potential energy of gravity between the Earth and the branch, and the elastic "spring" potential energy in the bonds of the tree fiber. In general the spring and kinetic energy transform between each other, with gravitational potential energy changing based on the height of the branch during it's motion. To be more specific (T= period):**

**t = 0 s | max negative displacement | zero KE, max spring PE, min gravitational PE**
**t = T/4 | moving upwards through equilibrium | max KE, zero spring PE, mid gravitational PE**
**t = 2T/4 | max positive displacement | zero KE, max spring PE, max gravitational PE**
**t = 3T/4 | moving downwards through equilibrium | max KE, zero spring PE, mid gravitational PE**
**t = T | back to initial time; cycle repeats**

(c)

$$X_{max}(t) = X_{max}(t=0)\, e^{-t/\tau}, \quad \underline{\text{given:}}\ @\ t = 8T,\ X_{max}(8T) = \frac{X_{max}(t=0)}{2}$$

$$\text{so, } \frac{\cancel{X_{max}(t=0)}}{2} = \cancel{X_{max}(t=0)}\, e^{-8T/\tau} \Rightarrow \ln\left(\tfrac{1}{2}\right) = -\frac{8T}{\tau}$$

$$\tau = -\frac{8T}{\ln\left(\frac{1}{2}\right)} = \boxed{28.9\,s}$$

**Rubric**

**(a) 1 point total**
**(b) 2.5 points total**
**0.5 pts - gravitational PE**
**2 pts - explanation of energy transfers**

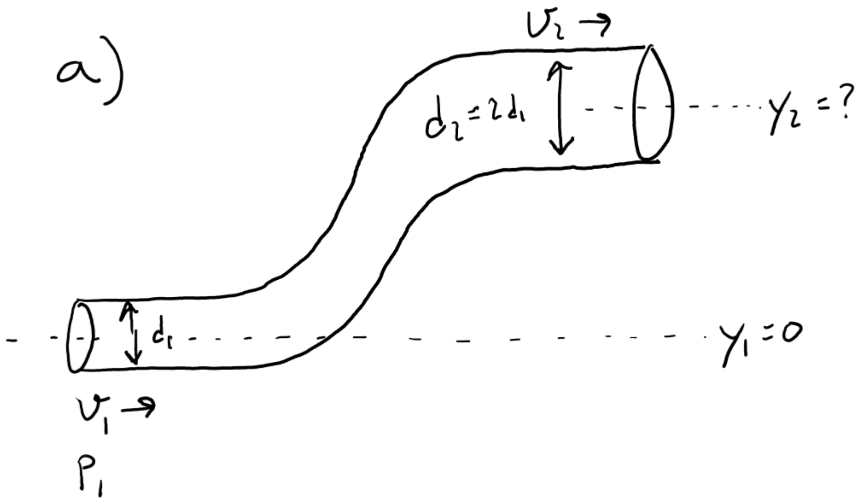
**(c) 3.5 points total**
**1 pt - exponential decay equation**
**1 pt - applying it @ t = 8T**
**1 pt - natural log math**
**0.5 pts - correct answer and units**

10. (8 points) In order to take a nice relaxing bath after this final, you fill up a bathtub with warm water. To fill the tub, water travels at 9 m/s in a pipe under your house. The faucet (where the water exits into the tub) in your house has a diameter twice that of the pipe under your house. The water pressure in the pipe/faucet is the same everywhere.

(a) What is the height of your faucet, relative to the pipe under your house?

(b) Let's do some special cases sensemaking! If the diameter of the faucet were the same as the diameter of the pipe under your house and the pressure was the same everywhere, what would the height difference need to be? explain.

a)




Continuity

$A = \pi r^2 = \pi \left(\frac{d}{2}\right)^2$

$\Rightarrow A \propto d^2$

$\Rightarrow A_2 = 4A_1$

$A_1 v_1 = A_2 v_2$

$\Rightarrow v_2 = \frac{A_1}{A_2} v_1$

$v_2 = \frac{1}{4} v_1 = \frac{9}{4}\,\text{m/s}$

Bernoulli's

$\frac{1}{2}\cancel{\rho} v_1^2 + \cancel{\rho} g \cancel{y_1}^{0} + \cancel{P_1} = \frac{1}{2}\cancel{\rho} v_2^2 + \cancel{\rho} g y_2 + \cancel{P_2}$

$\Rightarrow \frac{1}{2} v_1^2 = \frac{1}{2} v_2^2 + g y_2$

$\Rightarrow g y_2 = \frac{1}{2}(v_1^2 - v_2^2)$

$\Rightarrow y_2 = \frac{1}{2g}(v_1^2 - v_2^2)$

$\Rightarrow y_2 = \frac{1}{2g}\left((9\,\text{m/s})^2 - \left(\frac{9}{4}\,\text{m/s}\right)^2\right)$

$\boxed{y_2 = 3.87\,\text{m}}$

b) if $d_2 = d_1$, we know $v_1 A_1 = v_2 A_2$ $\Big\}$ $v_1 = v_2$

So, if $v_1 = v_2$, let's see what happens to Bernoulli's eqn.

$\frac{1}{2}\rho v_1^2 + \rho g \cancel{y_1}^{0} + \cancel{P_1} = \frac{1}{2}\rho v_2^2 + \rho g y_2 + \cancel{P_2}$

equal

equal

this leaves $0 = \rho g y_2$

$\Rightarrow y_2 = 0$, which is the height of the pipe under ground.

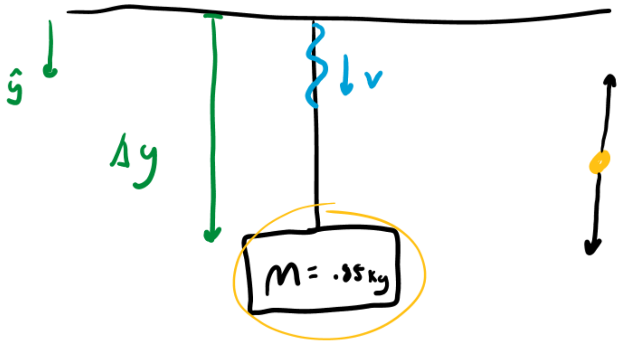
alternative b) We could also make an energy density argument:

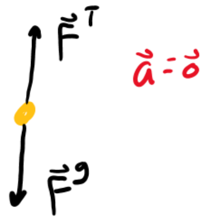
$\underbrace{P}_{\text{pressure}} + \underbrace{\frac{1}{2}\rho v^2}_{\text{KE density}} + \underbrace{\rho g y}_{\text{grav. potential energy density}} = \text{const} \rightarrow$ if the pressures are the same & the KE densities are the same $(\frac{1}{2}\rho v^2)$, then the grav. potential energy densities must be the same $(\rho g y)$

**(a) - 5 pts**
- **1.5 pts - partial problem setup**
- **2 pts - high level continuity**
- **2 pts - high level bernoulli's**
- **1 pt - correct height of 3.87 m is found**

**(b) - 3 pts**
- **3 pts - high level sensemaking**
- **1.5 pts - incomplete sensemaking**
- **0.5 pts - asserts an answer with no explanation**

11. (6 points) A 0.850-kg box is at rest hanging vertically from a light string with a linear mass density of 0.00720 kg/meter. A traveling wave was created at the top of the string and took 0.0588 seconds to reach the bottom of the string. How long is the string? (assume tension is constant throughout the rope)




$$\Sigma F_x = m\cancel{a_x}^{0}$$

$$F^T - mg = 0$$

$$F^T = mg \sim 8.33\ N$$

$$V = \sqrt{\frac{F^T}{\mu}}$$

$$V = \sqrt{\frac{mg}{\mu}} \sim \sqrt{1156.9} \sim 34.0\ m/s$$

$$\Delta y = V_{iy}\Delta t + \frac{1}{2}\cancel{a_y}^{0}\Delta t^2$$

$$\Delta y = V_{iy}\Delta t$$

$$\Delta y = V\Delta t$$

$$\Delta y = \sqrt{\frac{mg}{\mu}}\,\Delta t \sim \boxed{2.00\ \text{SECONDS}}$$

**Rubric**

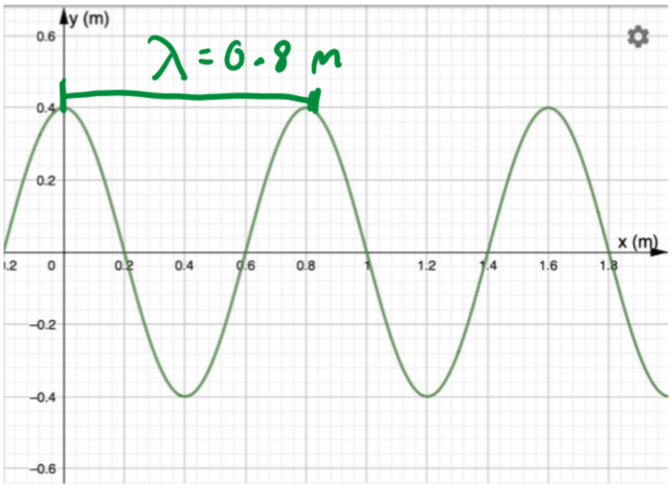
**Force analysis**
**+1.5 pts Correct force analysis attempt**
**+1.0 pts Attempts force analysis but not correct**

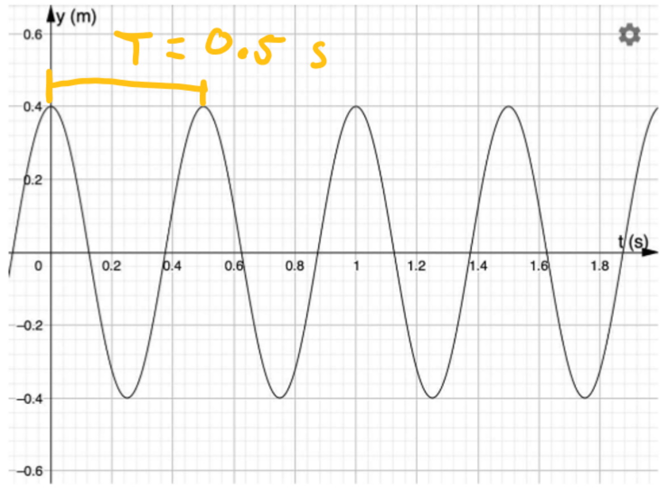
**Traveling Wave analysis**
**+2.0 pts Correct wave speed algebra**
**+1.0 pts Definition of wave speed correct but algebra not**
**+0.5 pts Attempts to find wave speed**

**Kinematics analysis**
**+2.0 pts Correct kinematics analysis**
**+1.0 pts Attempts kinematics analysis but incorrect equation/algebra**

**Answer**
**+0.5 pts for correct final answer**

12. (6 points) A water wave was observed traveling in the negative x-direction. Two plots were created to represent this water wave. Construct an equation that represents the displacement of this traveling wave. Your equation should be a function of the variables: **x**, and **t** only.




$$y(x,0) = 0.4\cos\left(\frac{2\pi}{.8}x\right) \qquad y(0,t) = 0.4\cos\left(\frac{2\pi}{.5}t\right)$$

$$= 0.4\cos\left(\frac{5\pi}{2}x\right) \qquad = 0.4\cos\left(4\pi t\right)$$

$$\boxed{y(x,t) = 0.4\cos\left(\frac{5\pi}{2}x + 4\pi t\right)}$$

$$\boxed{y(x,t) = 0.4\cos\left(7.85x + 12.6t\right)}$$

**Rubric**

**Snapshot graph analysis**
+1.5 pts Correct wavelength, correct wave number.
+1.0 pts one of two quantities correct
+0.5 pts none correct but attempted to analyze the graph

**History graph analysis**
+1.5 pts Correct period, correct angular frequency.
+1.0 pts one of two quantities correct
+0.5 pts none correct but attempted to analyze the graph

**Traveling wave construction**
+3.0 pts Correct answer (amplitude, cosine, argument signs both + or both -)
+2.5 pts two of the three correct
+2.0
+1.0 pts one of the three correct
+0.5 pts traveling wave form attempted