

PHYSICS 112

Exam #1

February 9, 2012

NAME: R. Herman SIGNATURE: _____

Print your name and sign it legibly in the spaces provided above.

This exam consists of several questions, each consisting of possibly several parts of varying difficulty. If you cannot do one part, move on to the next part. Partial credit will be given throughout this exam. Show your line of reasoning; a final answer itself is not sufficient. To get **ANY** credit, you must show **CLEARLY** how you obtained your answers. If I can't read your work, or find your single answer, you won't get credit.

Please **CIRCLE OR BOX YOUR ANSWERS**, and always **STATE THE UNITS** if appropriate. If you need more space than what is provided, use the extra paper supplied by me.

If you are confused about a question, **ASK** for an explanation. Otherwise, I assume you understand **EXACTLY** what I was asking.

No exams will be accepted after 8:50 PM.

Some things you might want for this exam.

$$k = 1.38 \times 10^{-23} \text{ J/K}$$

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

$$R = 8.314 \text{ J/mol} \cdot \text{K}$$

$$1 \text{ day} = 86400 \text{ s}$$

$$1 \text{ year} = 3.16 \times 10^7 \text{ s}$$

$$A_{\text{sphere}} = 4\pi R^2$$

$$v_{\text{sound}} = 343 \text{ m/s}$$

$$1 \text{ Pa} = 1 \text{ N/m}^2$$

I. Down jackets - dry and wet (20 points)

Goose down is one of the best insulators you can make clothing with, as long as it doesn't get wet. Assume that you purchased a new down jacket for snowboarding. The jacket covers an area of 0.984 m^2 of your body and is 0.0352 m thick. Assume your body temperature is 36.0°C at the skin and that the outside air temperature is -20.0°C .

- (a) (8 points) The thermal conductivity of dry goose down is $k = 0.0235 \text{ W/m} \cdot ^\circ\text{C}$. What is the power lost through the jacket when dry?

$$P = \frac{kA\Delta T}{L} = \frac{(0.0235 \frac{\text{W}}{\text{m}\cdot^\circ\text{C}})(0.984 \text{ m}^2)(36^\circ\text{C} - (-20^\circ\text{C}))}{0.0352 \text{ m}}$$

$$P = 36.8 \text{ Watts}$$

- (b) (8 points) Now assume that the jacket gets soaked, so now the down is wet. When soaked, the feathers are compressed and the jacket is now only 0.00542 m thick and the thermal conductivity is increased to essentially the conductivity of water, $k = 0.542 \text{ W/m} \cdot ^\circ\text{C}$. What power is lost through the jacket now that it is wet?

$$P = \frac{kA\Delta T}{L} = \frac{(0.542 \frac{\text{W}}{\text{m}\cdot^\circ\text{C}})(0.984 \text{ m}^2)(36^\circ\text{C} - (-20^\circ\text{C}))}{0.00542 \text{ m}}$$

$$P = 5510 \text{ Watts}$$

- (c) (4 points) Recall from homework that humans have a net power loss at room temperature of approximately 60 W due solely to radiation. How does the power lost via conduction through the jacket in the above two cases compare to that value? Explain in words your comparison.

When the jacket is dry, your heat loss is certainly less. But when the jacket is wet, you're going to lose your heat too quickly to maintain your body temperature. ¹

II. Stars (20 points)

Consider two different stars: a white dwarf which is the final endpoint of the evolution of a star like the Sun and a red giant which can be considered the "old age" state of stars. In either case, you may assume the star acts like a perfect blackbody - in other words assume its emissivity is unity ($e = 1$).

- (a) (8 points) White dwarf stars are essentially the cores of stars similar to the Sun. Immediately after forming this final state the star's surface will be quite hot with a temperature of $T = 92400 \text{ K}$ and its radius will be quite small, $R = 8.52 \times 10^6 \text{ m}$. What is the power output of the white dwarf?

$$\begin{aligned}
 P &= e\sigma A T^4 = e\sigma 4\pi r^2 T^4 \\
 &= (1)(5.67 \times 10^{-8} \frac{\text{W}}{\text{m}^2 \text{K}^4}) 4\pi (8.52 \times 10^6 \text{ m})^2 (92400 \text{ K})^4 \\
 P &= 3.77 \times 10^{27} \text{ Watts}
 \end{aligned}$$

- (b) (8 points) A red giant star has a surface temperature cooler than the Sun with a temperature of $T = 4950 \text{ K}$. It will have a radius that is much larger than the Sun's, in fact larger than the Earth's orbital radius, typically the radius will be $R = 2.15 \times 10^{11} \text{ m}$. What is the power output of the red giant?

$$\begin{aligned}
 P &= e\sigma A T^4 = e\sigma 4\pi r^2 T^4 \\
 &= (1)(5.67 \times 10^{-8} \frac{\text{W}}{\text{m}^2 \text{K}^4}) 4\pi (2.15 \times 10^{11} \text{ m})^2 (4950 \text{ K})^4 \\
 P &= 1.98 \times 10^{31} \text{ Watts}
 \end{aligned}$$

- (c) (4 points) Over its lifetime (approximately 10 billion years), the Sun will radiate a total energy of $1.26 \times 10^{44} \text{ J}$. How long, in years, would it take the red giant to emit the same amount of energy?

$$\begin{aligned}
 E &= P t & 6.364 \times 10^{12} \text{ sec} \times \frac{1 \text{ year}}{24 \times 60 \times 60 \times 365 \text{ sec}} \\
 \frac{E}{P} &= t & \boxed{t = 2.02 \times 10^5 \text{ years}} \\
 \frac{1.26 \times 10^{44} \text{ J}}{1.98 \times 10^{31} \frac{\text{J}}{\text{s}}} &= t = 6.364 \times 10^{12} \text{ sec}
 \end{aligned}$$

III. Helium in a cylinder (12 points)

You can buy a small helium cylinder at stores that you can then use to fill balloons. This cylinder contains enough helium to fill 55 mylar balloons. Each mylar balloon has a volume of $1.25 \times 10^{-2} \text{ m}^3$.

(a) (2 points) What is the total volume of helium required to fill 55 balloons?

$$V_{\text{tot}} = 55 \times 1.25 \times 10^{-2} \text{ m}^3$$

$$V_{\text{tot}} = 0.6875 \text{ m}^3 \approx 0.688 \text{ m}^3$$

(b) (5 points) What is the total number of moles of helium contained in all of the balloons? Assume the pressure in a filled mylar balloon is $P_{\text{mylar}} = 1.74 \times 10^5 \text{ Pa}$ at room temperature, $T = 298 \text{ K}$.

$$PV = nRT \Rightarrow n = \frac{PV}{RT}$$

$$\text{also: } n = \frac{PV}{RT}$$

$$n = 2.907 \times 10^{25}$$

$$n = \frac{2.907 \times 10^{25}}{6.022 \times 10^{23}}$$

$$n = 48.3 \text{ moles}$$

$$n = \frac{(1.74 \times 10^5 \frac{\text{N}}{\text{m}^2})(0.6875 \text{ m}^3)}{(8.314 \frac{\text{J}}{\text{Kmol}})(298 \text{ K})}$$

$$n = 48.3 \text{ moles}$$

(c) (5 points) Since all of the helium in the balloons came from the cylinder, what was the total volume of helium stored in the cylinder at the same temperature if the pressure in the full cylinder was $P_{\text{cylinder}} = 1.41 \times 10^7 \text{ Pa}$?

$$\frac{P_2 V_2}{P_1 V_1} = \frac{nRT_2}{nRT_1} = 1 \quad \leftarrow n, R, T \text{ all the same}$$

$$V_2 = V_1 \frac{P_1}{P_2} = 0.6875 \text{ m}^3 \frac{1.74 \times 10^5 \frac{\text{N}}{\text{m}^2}}{1.41 \times 10^7 \frac{\text{N}}{\text{m}^2}}$$

$$V_2 = 8.48 \times 10^{-3} \text{ m}^3$$

pts: 15

IV. Amusement park physics (15 points)

You are at an amusement park, riding the shuttle train towards the west at a speed of 8.0 m/s . Ahead of you is a portion of the roller coaster track that runs east-west. Your friend, who happens to be an opera singer, is on the roller coaster. You know from previous experience that when scared your friend always screams at a frequency of 440 Hz (concert A). For all parts of this problem, assume the speed of sound in air is 343 m/s .

- (a) (2 points) As you approach the roller coaster, which you cannot see, you hear your friend screaming. Your handy physics microphone measures the frequency of his voice at 415 Hz . Circle one of the following choices which best describes the motion of the roller coaster.

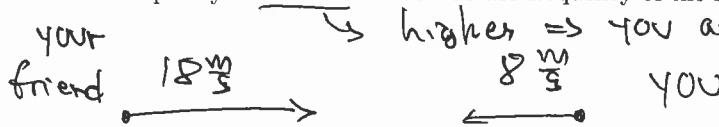
- The roller coaster is moving the ~~same~~ speed and direction as you on the shuttle.
- Ⓐ The roller coaster is moving in the same direction as you on the shuttle.
- The roller coaster is moving in the ~~opposite~~ direction as you on the shuttle.
- This question cannot be answered with the information given.

observed is lower so roller coaster moving away

- (b) (5 points) Explain your reasoning clearly and concisely for the choice you made above. No reasoning means no credit.

You hear a lower frequency (415 Hz) than what was emitted (440 Hz). Thus the roller coaster must be getting further from you. Since you are moving towards the roller coaster it must be moving in the same direction as you, but at a greater speed.

- (c) (8 points) While still riding on the shuttle to the west at 8.0 m/s , a second friend, who it just so happens is also an opera singer, is on the log ride moving east at 18 m/s . You measure the frequency of this friend's scream to be at a frequency of 490 Hz . What was the frequency of the scream emitted by your friend?



higher => you and friend getting closer if emitted was lower

$$f_{\text{observed}} = f_{\text{emit}} \left(\frac{1 + \frac{v_{\text{obs}}}{v_{\text{sound}}}}{1 - \frac{v_{\text{source}}}{v_{\text{sound}}}} \right)$$

$$f_{\text{obs}} \left(\frac{1 - \frac{v_{\text{source}}}{v_{\text{sound}}}}{1 + \frac{v_{\text{obs}}}{v_{\text{sound}}}} \right) = f_{\text{emit}} = 490 \text{ Hz} \left(\frac{1 - \frac{18 \frac{m}{s}}{343 \frac{m}{s}}}{1 + \frac{8 \frac{m}{s}}{343 \frac{m}{s}}} \right)$$

If you assumed you ← friend →

$$f_{\text{emit}} = f_{\text{obs}} \left(\frac{1 + \frac{v_{\text{source}}}{v_{\text{sound}}}}{1 - \frac{v_{\text{obs}}}{v_{\text{sound}}}} \right)$$

$$f_{\text{emit}} = f_{\text{obs}} \left(\frac{1.05248}{0.97668} \right) = 528 \text{ Hz}$$

$$= 490 \text{ Hz} \left(\frac{0.94752}{1.02332} \right)$$

$$= 490 \text{ Hz} (0.92893)$$

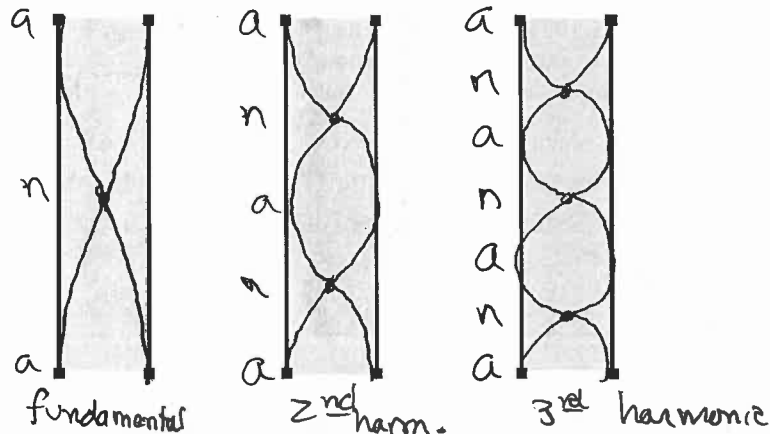
$$f_{\text{emit}} = 454 \text{ Hz}$$

pts: 15

V. Standing wave problem (15 points)

Pipe organs use large open-ended pipes to create sound. The lowest audible C-note has a frequency of 32.7 Hz.

- (a) (6 points) In the space below draw a picture of the first three allowed standing wave patterns for a tube open at both ends.



- (b) (4 points) How long would the pipe have to be to play this note as its fundamental frequency? Assume the speed of sound is 338 m/s.

$$\lambda_1 = 2L \text{ according to first picture} \Rightarrow$$

$$\lambda_1 = \frac{v}{f_1} = \frac{338 \frac{m}{s}}{32.7 \text{ Hz}}$$

$$\lambda_1 = 10.3 \text{ m} \Rightarrow L = \frac{1}{2} \lambda_1 = \frac{1}{2} (10.3 \text{ m}) = 5.17 \text{ m}$$

(10.36m)

- (c) (5 points) If the speed of sound changes to 352 m/s due to a change in temperature in the pipe, what would the frequency of the 3rd harmonic be in the same pipe? Will this frequency be higher or lower than the 3rd harmonic's frequency if the sound speed hadn't changed?

$$3^{\text{rd}} \text{ harmonic} \Rightarrow \frac{3}{2} \lambda_3 = L$$

$$\lambda_3 = \frac{2}{3} L = \frac{2}{3} (5.17 \text{ m})$$

$$\lambda_3 = 3.45 \text{ m}$$

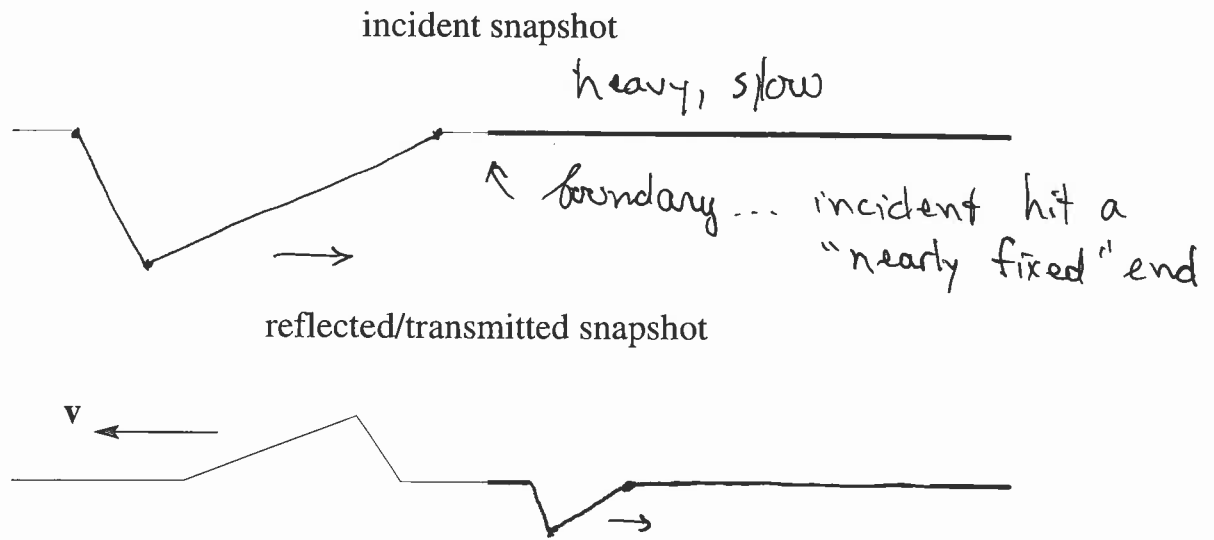
$$f_3 = \frac{v}{\lambda_3} = \frac{352 \frac{m}{s}}{3.45 \text{ m}} = \boxed{102 \text{ Hz}} \quad @ 352 \frac{m}{s}$$

If speed of sound had not changed, $f_3 = 98.0 \text{ Hz}$.

\Rightarrow Raising speed of sound raised the frequency because the wavelength λ_3 did not change.

VI. Transmitted/reflected wave problem (8 points)

In the figure below, the visible wave pulse is traveling to the left as shown. This pulse is the reflected wave. The two different springs are made of different materials and the spring on the right has a greater linear density than the one on the left. Draw the incident wave in the space on the left spring on the incident snapshot and the transmitted wave on the right spring of the reflected/transmitted snapshot. When drawing your wave pulses consider wave speed, amplitude, width and which side of the spring the pulses will be on.



VII. Waves on a string problem (10 points)

A tightrope walker is standing at the edge of a deep chasm and leans down to test the tension in the tightrope. The tightrope is strung with a tension of 3020 N and has a length of 65.4 m . When plucked a wave is found to traverse from one end of the rope to the other in 0.572 s . What is the total mass of the rope?

$$v = \frac{x}{t} = \sqrt{\frac{\text{Tension}}{\left(\frac{m}{L}\right)}} \Rightarrow v^2 = \frac{T}{\left(\frac{m}{L}\right)}$$

$$\frac{x}{t} = \frac{65.4\text{ m}}{0.572\text{ s}} = 114.3 \frac{\text{m}}{\text{s}}$$

$$v^2 = \frac{T}{\frac{m}{L}}$$

$$\frac{m}{L} = \frac{T}{v^2} \Rightarrow m = L \frac{T}{v^2} = 65.4\text{ m} \frac{3020\text{ N}}{(114.3 \frac{\text{m}}{\text{s}})^2}$$

$$m = 15.1\text{ kg}$$

