Your Name: ________________________

PHYSICS 101 FINAL EXAM

January 20, 2005 3 hours

Problem	Score
1	/40
2	/16
3	/16
4	/14
5	/19
6	/16
7	/20
8	/10
Total	/151

Please Circle your section					
1	9 am	Nappi	2	10 am	Bergli
3	11 am	Hasan	4	12:30 pm	McBride
5	12:30 pm	Ziegler			

Instructions: When you are told to begin, check that this examination booklet contains all the numbered pages from 2 through 20. The exam contains 8 problems. Read each problem carefully. You must show your work. The grade you get depends on your solution even when you write down the correct answer. BOX your final answer. Do not panic or be discouraged if you cannot do every problem; there are both easy and hard parts in this exam. **If a part of a problem depends on a previous answer you have not obtained, assume it and proceed.** Keep moving and finish as much as you can!

Possibly useful constants and equations are on the last page, which you may want to tear off and keep handy.

Rewrite and sign the Honor Pledge: *I pledge my honor that I have not violated the Honor Code during this examination.*

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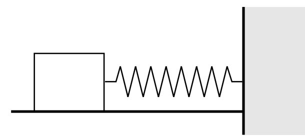
Signature________________________

Problem 1

Miscellaneous Questions

1. (*6 points*)
A 3.0 kg mass attached to a spring oscillates on a frictionless table with an amplitude $A = 8.0 \cdot 10^{-2}$ m. Its maximum acceleration is 3.5 m/s^2. What is the total energy of the system?



For a spring

$$F = -kx = ma \quad \rightarrow \quad k = \frac{ma_{\max}}{A} = 130\ \mathrm{kg/s^2}$$

Therefore

$$E_{\mathrm{pot}} = \frac{1}{2}kA^2 = 0.42\ \mathrm{J}$$

2. (*4 points*) What is the speed of a satellite of mass $m = 1.0 \cdot 10^4$ kg on a circular orbit around the moon at a distance of $4R_{\mathrm{moon}}$ from the moon's surface?

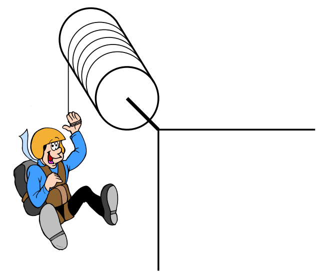
The radius is actually $r = 5R_{\mathrm{moon}}$ as the satellite is $4R_{\mathrm{moon}}$ above the moon surface.

$$F_G = G \cdot \frac{m \cdot M}{r^2} = m \cdot \frac{v^2}{r} = F_c$$

from there we get

$$v = \sqrt{G\frac{M}{r}} = \sqrt{G\frac{M}{5R_{\mathrm{moon}}}} = 762\ \frac{\mathrm{m}}{\mathrm{s}}$$

3. A man of mass $M = 75$ kg lowers himself down from the top of a building by using a rope wound on a drum (a **hollow** cylinder of radius $r = 0.50$ m and mass $2M = 150$ kg), as shown in the picture. The man and the drum start at rest.



a) (*6 points*) Find the angular acceleration of the drum.

The force for the man is $F = Mg - T = Ma \quad \rightarrow \quad T = M(g - a)$
For the torque we can write $\tau = Tr = I\alpha$
with $I_{\text{hollow cylinder}} = mr^2 = (2M)r^2$ and $a = \alpha r$
therefore $I\alpha = M(g - \alpha r)r$ and thus

$$\alpha = \frac{Mgr}{Mr^2 + I} = \frac{Mgr}{3Mr^2} = \frac{g}{3r} = 6.5\ \text{s}^{-2}$$

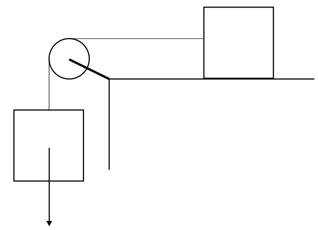
b) (*4 points*) What is the velocity of the man when he has dropped 20 m?

With $v = at$ and $s = \frac{1}{2}at^2$ we get

$$v = \sqrt{2sa} = \sqrt{2s\alpha r} = 11.4\ \frac{\text{m}}{\text{s}}$$

4. (*4 points*)

Consider the pulley system as shown in the picture. The blocks have a mass of 1.0 kg each. Suppose the pulley is massless and there is no friction. What is the tension in the rope when the blocks accelerate due to gravity only?



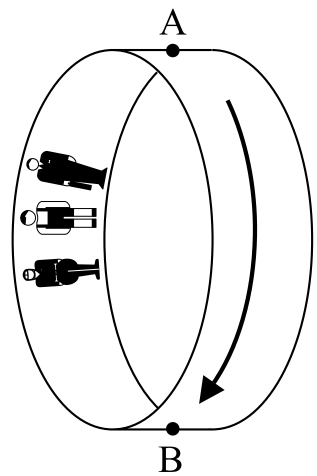
For the force on the left mass we can write $F_1 = mg - T = ma \quad \rightarrow \quad T = m(g-a)$
For the right mass this is $F_2 = T = ma$.
From there we finally get

$$mg - ma = ma \quad \rightarrow \quad a = \frac{g}{2} = 4.9\ \frac{\text{m}}{\text{s}^2}$$

5. (*4 points*) A piece of ice at a temperature of 0.0°C with a mass of 100 g is converted into water at 0.0°C. What is the change of entropy in this process? (Latent heat of water is 33.5×10^4 J/kg)

$$\Delta S = \frac{\Delta Q}{T} = \frac{Lm}{T} = 122\ \frac{\text{J}}{\text{K}}$$

6. In an amusement park ride, riders are pressed against a wall that revolves in a vertical circle of radius $r = 5.00$ m and angular velocity $\omega = 1.60$ rad/s. Determine the force that the wall exerts on a 60.0 kg rider at the



a) (*3 points*) top of the loop at point A,

With the coordinate system pointing upward:

$$F = m\omega^2 r - mg = 180 \text{ N}$$

b) (*3 points*) bottom of the loop at point B.

Again, with the coordinate system pointing upward:

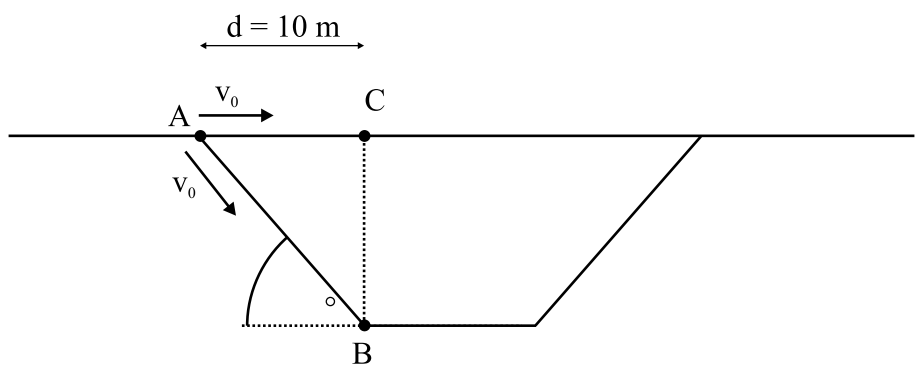
$$F = m\omega^2 r + mg = 1360 \text{ N}$$

7. (*6 points*) A man is sitting in a boat on a swimming pool. In the boat there is a rock of mass $M = 100$ kg and density $\rho_{\text{rock}} = 5.00 \cdot 10^3$ kg/m^3. He throws the rock into the water. By what amount and in what direction will the water level of the pool change? The density of water is $\rho_{\text{water}} = 1.00 \cdot 10^3$ kg/m^3 and the area of the pool surface is 50.0 m^2.

Calculate the volume of the displaced water for
rock in boat: $V_{\text{in}} = \frac{m_{\text{rock}}}{\rho_{H_2O}} = 10^{-1}\ \text{m}^3$
rock in pool: $V_{\text{out}} = \frac{m_{\text{rock}}}{\rho_{\text{rock}}} = 2 \cdot 10^{-2}\ \text{m}^3$
$\Delta V = 8 \cdot 10^{-2}\ \text{m}^3 \quad \rightarrow \quad d = \frac{\Delta V}{A} = 1.6 \cdot 10^{-3}\ \text{m}$

Problem 2

Two identical sleds start moving at the same time from the same point A. One goes on a bridge with initial speed v_0, the other goes down into the ditch with the same initial speed v_0 at point A. Assume that v_0 is 10.0 m/s, the angle of the slope is $\theta = 45.0°$ and d is 10.0 m. Neglect any friction in this problem.



a.) (*4 points*) What is the speed of the second sled at the bottom of the ditch (at point B)?

$$\frac{1}{2}mv_0^2 + mgh = \frac{1}{2}mv^2 \quad \text{with} \quad h = d = 10.0\ \text{m}$$
$$v = \sqrt{v_0^2 + 2gh} = 17.2\ \frac{\text{m}}{\text{s}}$$

b.) (*4 points*) Find the time that the second sled needs to reach the bottom of the ditch (A $\rightarrow$ B).

$$v = v_0 + a \cdot t \quad \text{where} \quad a = g \cdot \sin\theta = \frac{g}{\sqrt{2}}, \text{then}$$
$$t = \frac{v - v_0}{a} = \sqrt{2} \cdot \frac{v - v_0}{g} = 1.04\ \text{s}$$

c.) (*2 points*) Is the time that the first sled takes to move from point A to point C on the bridge larger, equal or less than the time the second sled takes to go to the bottom of the ditch (A $\rightarrow$ B)?

$$t = \frac{s}{v_0} = \frac{10\ \text{m}}{10\ \frac{\text{m}}{\text{s}}} = 1.00\ \text{s}$$

shorter

d.) (*6 points*) Suppose that, instead of two sleds, two spherical snow balls of the same mass are released at A with a center-of-mass speed of v_0. What would be the speed of the second ball when it reaches the bottom of the ditch? (Assume that the two snow balls roll without slipping.)

The total energy is

$$E = \frac{1}{2}mv_0^2 + mgh + \frac{1}{2}I\omega_0^2 = \frac{1}{2}mv_0^2 + mgh + \frac{1}{2}I\frac{v_0^2}{r^2} \quad (1)$$

$$= \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2 = \frac{1}{2}mv^2 + \frac{1}{2}I\frac{v^2}{r^2} \quad (2)$$

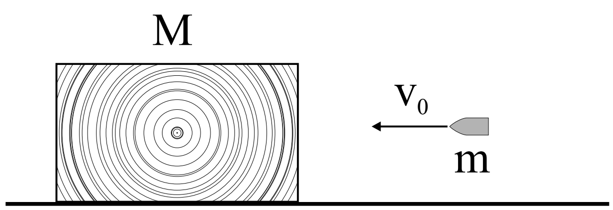
and with $I_{\text{full sphere}} = \frac{2}{5}mr^2$ we can deduce

$$v = \sqrt{v_0^2 + \frac{10}{7}gh} = 15.5\ \frac{\text{m}}{\text{s}}.$$

The answer does not depend on the radius of the snowball!

Problem 3

A lead bullet of mass $m = 10.0$ g is travelling with a velocity of $v_o = 100$ m/s when it strikes a wooden block. The block has a mass of $M = 1.00$ kg and is at rest on the table, as shown in the diagram below. The bullet embeds itself in the block and after the impact they slide together. All the kinetic energy that is lost in the collision is converted into heat. Assume that all this heat goes into heating up the bullet.



a.) (*4 points*) What is the speed of the wooden block after the collision?

$$p_{\text{tot}} = mv_0 = (m+M)v$$
$$\rightarrow v = \frac{m}{m+M}v_0 = 1.00\ \frac{\text{m}}{\text{s}}$$

b.) (*4 points*) How much heat is generated as a result of the collision?

$$E_i = \frac{1}{2}mv_0^2 = 50.0\ \text{J}$$
$$E_f = \frac{1}{2}(m+M)v^2 + Q = 0.5\ \text{J} + Q$$
$$\rightarrow Q = 49.5\ \text{J}$$

c.) (*4 points*) By how many degrees does the temperature of the bullet rise after the collision? (The specific heat of the bullet is 128 J/(kg °C).)

$$Q = cm\Delta T \quad \rightarrow \quad \Delta T = \frac{Q}{cm} = 38.7°\text{C}$$

d.) (*4 points*) Suppose that the table has a coefficient of kinetic friction of $\mu = 0.2$. At what distance will the block stop?

For the force

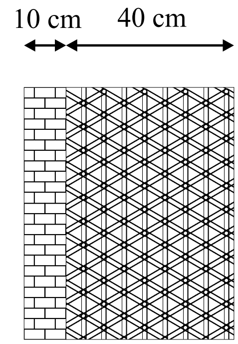
$$F = \mu F_N = \mu mg = ma \quad \rightarrow \quad a = \mu g$$

$$s = v_0 t - \frac{1}{2}at^2 \quad \text{and} \quad v_0 = at.$$

Therefore

$$s = v_0 \frac{v_0}{a} - \frac{1}{2}a\frac{v_0^2}{a^2} = \frac{1}{2}\frac{v_0^2}{a} = 0.25 \text{ m}$$

Problem 4



Suppose that the insulating qualities of the wall of a house come mainly from a 0.100 m layer of brick with thermal conductivity $k_B = 10.0$ J/(s m °C) and a 0.400 m layer of insulation with thermal conductivity $k_I = 9.00 \cdot 10^{-2}$ J/(s m °C). The temperature on the side of the brick is $T_B = 10.0$°C, while the temperature on the side of the insulating material is $T_I = 30.0$°C.

a.) (*6 points*) What is the temperature at the interface brick/insulator?

From

$$\frac{Q}{t} = k_B \frac{A}{l_B}(T - T_B) = k_I \frac{A}{l_I}(T_I - T)$$

we get

$$T = \left(\frac{k_I T_I}{l_I} + \frac{k_B T_B}{l_B}\right) / \left(\frac{k_B}{l_B} + \frac{k_I}{l_I}\right) = 10.04°\text{C}$$

b.) (*4 points*) What is the total rate of heat loss Q/t through such a wall, if the total area is 10.0 m^2?

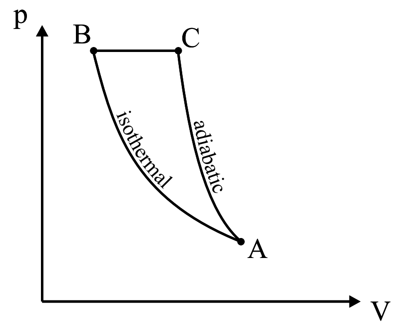
$$\frac{Q}{t} = k_I \frac{A}{l_I}(T_I - T) = 42.8 \text{ J}$$

c.) (*4 points*) A copper water pipe of length 1.00 m is moved from inside the house (at 30.0°C) to the outside of the house (at 10.0°C). What is the change in the length of this pipe after it adapts to the temperature? The coefficient of thermal linear expansion for copper is $\alpha = 1.70 \cdot 10^{-5}$ $(\mathrm{C}^\circ)^{-1}$.

$$\Delta L = \alpha L \Delta T = 3.40 \cdot 10^{-4} \text{ m}$$

Problem 5

One mole of an ideal monoatomic gas undergoes the following thermodynamic cycle:



a.) (*6 points*) Fill in the empty entries in the following table. (Show your calculations.)

state	P(N/m^2)	V(m^3)	T(K)
A	$2.08 \cdot 10^5$		500
B			
C			600

State A: $PV = nRT \rightarrow V_A = \frac{nRT_A}{P_A} = 2.00 \cdot 10^{-2}$ m^3

State C: $P_A V_A = nRT_A$ and $P_C V_C = nRT_C$
and for the adiabatic process: $P_A V_A^\gamma = P_C V_C^\gamma$ so we can write $P_A V_A^\gamma = \frac{nRT_C}{V_C} V_C^\gamma$
from which we can calculate the volume $V_C = \sqrt[\gamma-1]{\frac{P_A V_A^\gamma}{nRT_C}} = 1.52 \cdot 10^{-2}$ m^3
$P_C = \frac{nRT_C}{V_C} = 3.28 \cdot 10^5 \ \frac{\mathrm{N}}{\mathrm{m}^2}$

State B: $T_B = 500\ K$
$P_B = P_C = 3.28 \cdot 10^5 \ \frac{\mathrm{N}}{\mathrm{m}^2}$
$V_B = \frac{RT_B}{P_B} = 1.27 \cdot 10^{-2}$ m^3

state	P(N/m^2)	V(m^3)	T(K)
A	$2.08 \cdot 10^5$	$2.00 \cdot 10^{-2}$	500
B	$3.28 \cdot 10^5$	$1.27 \cdot 10^{-2}$	500
C	$3.28 \cdot 10^5$	$1.52 \cdot 10^{-2}$	600

b.) (*9 points*) Fill in the empty entries in the following table. If you are not sure about the numbers derived in the previous part, just insert the answers in formulas. (Again, please show your calculations.)

process	ΔU	W	Q
$A \to B$			
$B \to C$			
$C \to D$			

we will use: $\Delta U = Q - W$
Process $A \to B$ (isothermal):
$\Delta U = 0$ J, $\quad Q = W = nRT_A \ln \frac{V_B}{V_A} = -1890$ J
Process $B \to C$ (isobaric):
$W = P\Delta V = 820$ J, $\Delta U = \frac{3}{2}nR\Delta T = 1250$ J, $Q = \Delta U + W = 2070$ J
Process $C \to A$ (adiabatic):
$Q = 0$ J, $\Delta U = \frac{3}{2}nR\Delta T = -1250$ J $= -W$

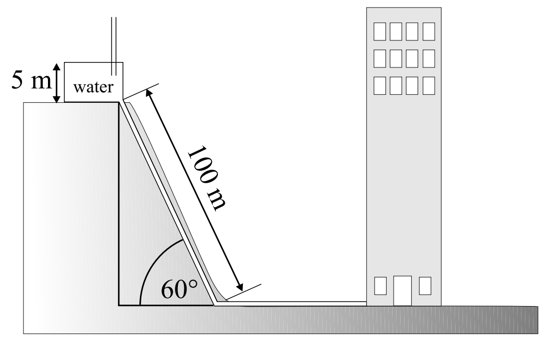
process	ΔU	W	Q
$A \to B$	0 J	-1890 J	-1890 J
$B \to C$	1250 J	820 J	2070 J
$C \to D$	-1250 J	1250 J	0 J

c.) (*4 points*) What is the efficiency of an engine operating in this cycle? Again, a detailed formula will do.

$$\epsilon = \frac{W}{Q_H} = \frac{-1890\ \text{J} + 820\ \text{J} + 1250\ \text{J}}{2070\ \text{J}} = \frac{180\ \text{J}}{2070\ \text{J}} = 8.7\%$$

Problem 6

A water tank ($\rho_{\text{water}} = 1.00 \cdot 10^3$ kg/m^3) is placed on top of a hill, as shown in the figure. The atmospheric pressure is $P_{\text{atm}} = 1.013 \times 10^5$ N/m^2. The level of the water in the tank is 5.00 m high. The length of the pipe is 100 m, and the inclination is $\theta = 60.0°$.



a.) (*4 points*) Determine the pressure in the pipe at the bottom of the hill. Assume that the water is not flowing through the pipe (static case).

$$h = h_{\text{water}} + l_{\text{pipe}} \cdot \sin\theta = 91.6 \text{ m}$$
$$p = p_0 + \rho g h = 10.0 \cdot 10^5 \ \frac{\text{N}}{\text{m}^2}$$

b.) (*4 points*) At what velocity will the water exit from a faucet on the 6$^{\text{th}}$ floor, 41.0 m above the ground?

For the general case

$$p_0 + \rho g h_0 + \frac{1}{2}\rho v_0^2 = p_1 + \rho g h_1 + \frac{1}{2}\rho v_1^2$$

and with $\quad p_0 = p_1 = 1$ atm, $\quad h_0 = (91.6 - 41.0)$ m, $\quad v_0 = 0$ m/s, $\quad h_1 = 0$ m
we get

$$\rho g h_0 = \frac{1}{2}\rho v_1^2 \quad \rightarrow \quad v_1 = \sqrt{2gh_0} = 31.5 \ \frac{\text{m}}{\text{s}}.$$

On the 12th floor (at a height of 95.0 m), there is no water pressure. An engineer has the bright idea to add a long thin tube to the water tank (see picture).

c.) (*4 points*) How high should the water level be in the tube for the water to reach the 12th floor?

$$h_{\text{tube}} = 95.0 \text{ m} - 91.6 \text{ m} = 3.40 \text{ m}$$

d.) (*4 points*) If the lid of the water tank (with a radius of $r = 2.00$ m) cannot withstand a force larger than 1.50×10^5 N, will the tank burst or not? Compute the force on the lid.

$$A_{\text{lid}} = \pi r^2 = 12.6 \text{ m}^2$$

$$p = \rho g h = 33.3 \cdot 10^4 \ \frac{\text{N}}{\text{m}^2}$$

$$F_{\text{H}_2\text{O on lid}} = p \cdot A = 4.20 \cdot 10^5 \text{ N}$$

This is much larger than the $1.50 \cdot 10^5$ N
→ lid will burst!

Problem 7

A guitar string of length 0.500 m and linear mass density of $\rho_{\text{string}} = 8.00 \cdot 10^{-2}$ kg/m is held with a tension of 5.00×10^3 N. It is plucked so as to excite the fundamental frequency alone.

a.) (*4 points*) What is the velocity of a wave on the string?

$$v = \sqrt{\frac{F}{m/L}} = 250\ \frac{\text{m}}{\text{s}}$$

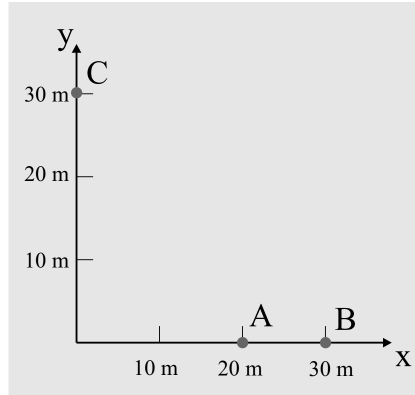
b.) (*4 points*) What is the wavelength and frequency of the fundamental harmonic?

$$f_1 = 1\left(\frac{v}{2L}\right) = 250\ \text{Hz}$$
$$\lambda_1 = 1\ \text{m} \quad \text{(2 times the string length)}$$

c.) (*4 points*) What is the wavelength of the sound in air?

$$\lambda_1 = \frac{v_{\text{sound}}}{f_1} = 1.37\ \text{m}$$

The following figure shows a park with 2 paths in the x- and y-direction. The guitarist is sitting on a bench at position A (20,0) as shown in the figure. The sound radiates in all directions.



d.) (*4 points*) At the origin (0,0) an old lady is disturbed by the bad playing and asks the guitar player to move further away. He moves to point B at coordinate (30,0) as shown in the figure. What is the ratio between the intensities of the guitar sound I_A/I_B at the origin as heard by the old lady?

With

$$I = \frac{I_0}{4\pi r^2}$$

we get

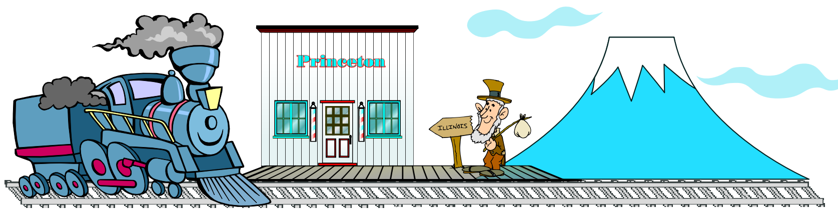
$$\frac{I_A}{I_B} = \frac{r_B^2}{r_A^2} = \frac{30^2}{20^2} = \frac{9}{4} = 2.25$$

e.) (*4 points*) While the guitar player is still sitting in position B (30,0), a second guitar player starts playing in unison in position C (0,30). The two sounds interfere constructively at the origin. What is the minimum distance that the player in C must move along the y-axis for the interference in the origin to be destructive?

$$y = \frac{\lambda}{2} = 0.69 \text{ m}$$

Problem 8

A whistling train is moving with a velocity of $v_{\text{train}} = 25$ m/s towards a station. The frequency of the train whistle is 500 Hz.



a.) (*4 points*) Compute the frequency of the sound heard by a passenger on the platform in the station.

Moving sender (the train) towards stationary observer (the stationary driver):

$$f_0 = f_{\text{whistle}} \cdot \left(\frac{1}{1 - \frac{v_{\text{train}}}{v_{\text{sound}}}} \right) = 539 \text{ Hz}$$

b.) (*4 points*) The sound of the whistling train is reflected by a nearby mountain and the reflected sound is heard by the train conductor. If the train moves towards the mountain with the same speeed $v_{\text{train}} = 25$ m/s as given above, what is the frequency of the reflected sound as heard by the train conductor?

Moving observer (the train) towards the stationary sender (the mountain that reflects the whistle). The frequency of the reflected sound is as above $f_{\text{refl}} = 539$ Hz.

$$f_1 = f_{\text{refl}} \left(1 + \frac{v_{\text{train}}}{v_{\text{sound}}}\right) = 578 \text{ Hz}$$

c.) (*2 points*) What is the beat frequency between the emitted and reflected sound as heard by the train conductor?

The beat frequency is the difference of the two frequencies:

$$f_{\text{beat}} = (578 - 500) \text{ Hz} = 78 \text{ Hz}$$

POSSIBLY USEFUL CONSTANTS AND EQUATIONS
You may want to tear this out to keep at your side

$x = x_0 + v_0 t + \frac{1}{2}at^2$	$v = v_0 + at$	$v_2 = v_0^2 + 2ax$
$F = \mu F_N$	$F = -kx$	$F = -G\frac{Mm}{r^2}$
$s = r\theta$	$v = r\omega$	$a = r\alpha$
$p = mv$	$F\Delta t = \Delta p$	$x_{cm} = \frac{1}{M_{\rm tot}}\sum_i x_i m_i$
$\omega = \omega_0 + \alpha t$	$PE = \frac{1}{2}kx^2$	$PE = mgh$
$KE = \frac{1}{2}I\omega^2$	$KE = \frac{1}{2}mv^2$	$W_{nc} = \Delta KE + \Delta PE$
$W = Fs\cos\theta$	$L = I\omega$	$\sum \tau = I\alpha$
$a_c = \frac{v^2}{r}$	$\omega^2 = \omega_0^2 + 2\alpha\Delta\theta$	$\Delta\theta = \omega_0 t + \frac{1}{2}\alpha t^2$
$\tau = F\ell\sin\theta$	$\omega = \sqrt{k/m}$	$\omega = \sqrt{g/l}$
$I_{\rm full\ cylinder} = \frac{1}{2}mr^2$	$2\pi r^{3/2} = T\sqrt{GM}$	$I = \sum m_i r_i^2$
$I_{\rm full\ sphere} = \frac{2}{5}mr^2$	$I_{\rm hollow\ cylinder} = mr^2$	$Q = \pi R^4 \Delta P/8\eta L$
$F = YA\frac{\Delta L}{L_0}$	$\Delta L = \alpha L_0 \Delta T$	$Q = Av$
$PV = nRT$	$P_1 V_1^\gamma = P_2 V_2^\gamma$	$P + \rho g h + \frac{1}{2}\rho v^2 = \text{const}$
$Q = mL$	$PV = nkT$	$\Delta S = \frac{\Delta Q}{T}$
$W_{\rm iso} = nRT\ln\frac{V_f}{V_i}$	$Q = cm\Delta T$	$\Delta U = Q - W$
$\frac{Q}{t} = k\frac{A}{L}\Delta T$	$\gamma = C_P/C_V$	$U = \frac{3}{2}nRT$
$Q = \epsilon\sigma T^4 At$	$v = \sqrt{\frac{\gamma kT}{m}}$	$v = \sqrt{\frac{F}{m/L}}$
$v = \lambda f$	$v = \sqrt{B_{\rm ad}\rho}$	$v = \sqrt{Y\rho}$
$\beta = (10\text{ dB})\log\frac{I}{I_0}$	$f_0 = f_s\left(\frac{1\pm\frac{v_0}{v}}{1\mp\frac{v_s}{v}}\right)$	$f_0 = f_s(1 \pm \frac{v_0}{v})$
$f_0 = f_s/\left(1 \mp \frac{v_s}{v}\right)$	$f_n = n\left(\frac{v}{2L}\right)$	$f_n = n\left(\frac{v}{4L}\right)$
$\sin\theta = \frac{\lambda}{D}$	$\sin\theta = 1.22\frac{\lambda}{d}$	
Monatomic:	$C_V = 3R/2$	$C_P = 5R/2$
Diatomic:	$C_V = 5R/2$	$C_P = 7R/2$
$R = 8.315\,\text{J/K/mol}$	$\sigma = 5.67\times10^{-8}\,\text{W/m}^2/\text{K}^4$	$k = 1.38\times10^{-23}\,\text{J/K}$
$u = 1.66\times10^{-27}\,\text{kg}$	$N_A = 6.022\times10^{23}\,\text{mol}^{-1}$	
$M_{\rm earth} = 6.0\times10^{24}\,\text{kg}$	$R_{\rm earth} = 6.4\times10^{6}\,\text{m}$	$G_{\rm Newton} = 6.67\times10^{-11}\text{Nm}^2/\text{kg}^2$
$M_{\rm moon} = 7.4\times10^{22}\,\text{kg}$	$R_{\rm moon} = 1.7\times10^{6}\,\text{m}$	
$0°C = 273.15$ K	1 kcal = 4186 J	$v_{\rm sound} = 343$ m/s