(2010)

Homework #4

1) $f = 440\text{ Hz}$ A4

6 points

speed of sound

a) Doppler shift $\Rightarrow$ $\ddot{f}_d = f \cdot \frac{v_s}{v_s - u}$

2 see page 229

perceived actual speed relative to stationary listener

$$f_d = 440 \cdot \frac{340}{340-170} = 440 \cdot \frac{340}{170} = 880\text{ Hz},\ A5$$

(aaah!!!)

(shifted one octave up)

b) $f_d = f \cdot \frac{v_s}{v_s + u} = 440 \cdot \frac{340}{340+170} = 440 \cdot \frac{2}{3} = 293.3\text{ Hz}$

2

$= \frac{4}{3} \cdot \frac{1}{2} \rightarrow$ just 4th and 1 octave down

$f_d = 293\text{ Hz}$, D4 (perfect 5th down)

c) $f_d = f \cdot \frac{v_s + u}{v_s} = 440 \cdot \frac{340+170}{340} = 440 \cdot \underbrace{\frac{3}{2}}_{\text{perfect 5th up}} = 660\text{ Hz}$, E5

2

Bonus: 1-2 extra:

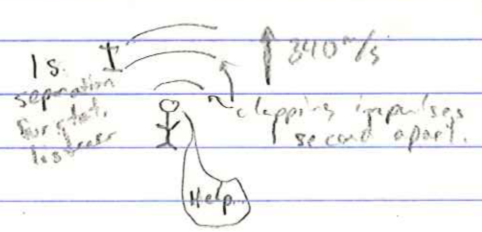
Frequencies change at 440 $\frac{\text{cycles}}{s}$

say musical tempo is 1 $\frac{\text{cycle}}{s}$

- we're clapping our hands once per second, no pitch

170 m/s

$\Rightarrow$ Yes, will definitely hear pulses faster than 1 m/s if moving towards the clapper.



$$1 \cdot \frac{340}{340-170} = 2\text{ Hz}$$

Should sound twice as fast in part (a), etc.

Homework #4

2. a) speed $= 43 \text{ mph} \times \dfrac{0.45 \text{ m/s}}{\text{mph}} = 19.35 \text{ m/s}$

$f = C5$ (3 semitones above A440) $\cdot$ $f = 440 \cdot 2^{3/12} = 523.25 \text{ Hz}$

• Traveling sound source, stationery listener

$$f_{obs} = \frac{f}{1 + v/c} \qquad v = \text{velocity away from listener} = -19.35 \text{ m/s}$$

$$f_{obs} = \frac{523.25}{1 - 19.35/340} = 554.83 \text{ Hz}$$

$554.83 \text{ Hz} \Rightarrow$? semitones above 440 Hz

$$\frac{12 \times \ln\left(\frac{554.83}{440}\right)}{\ln(2)} = 4.014 \approx 4 \text{ semitones above } 440 = C^{\#}5$$

$$\left(\text{or } 12 \times \frac{\ln\left(\frac{554.83}{523.25}\right)}{\ln(2)} = 1 \text{ semitone above } C5 = C^{\#}5\right)$$

The note we hear is $\underline{C^{\#}5}$, one semitone higher than that emitted.

b) $v = -19.35 \text{ m/s}$; $f = 523.25$

• Stationery sound source, moving listener

$$f_{obs} = f\left(1 + v/c\right) = 523.25 \cdot \left(1 + 19.35/340\right) = 553.03 \text{ Hz}$$

$$12 \times \ln\left(\frac{553.03}{523.25}\right) / \ln(2) = 1.01 \text{ semitones above } C5$$

The note we hear is $C^{\#}5$, one semitone higher than that emitted. , basically same as part (a) since $v \ll c$.

c) 1% change in frequency?

$f_{obs} = 1.01 f$ or $f_{obs} = 0.99 f$

$12 \times \frac{\ln(1.01)}{\ln(2)} = 0.172$ semitones; $12 \times \frac{\ln(0.99)}{\ln(2)} = -0.174$ semitones

$\boxed{\therefore \text{ 1\% change in frequency} = 17 \text{ cents}}$

d) Stationary source, moving listener speed $= 4 \times 0.45 = 1.8\ m/s$

$v = -1.8\ m/s$

$f_{ob} = f \cdot \left(1 + \frac{v}{c}\right)$

$\frac{f_{obs}}{f} = 1 + \frac{1.8}{340} = 1.0053 \approx .5\%$ change in frequency

↳ By 1% → 17 cents rule, .5% → 8.5 cents.

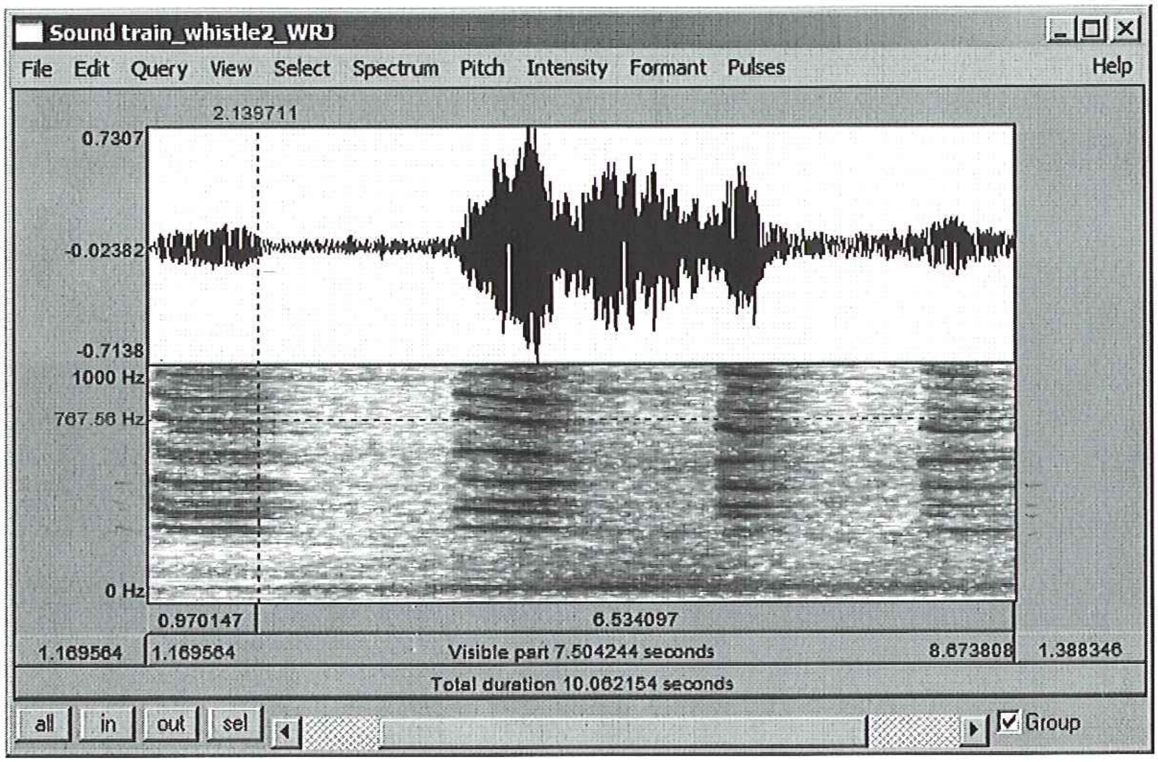
Orchestra will appear 8 or 9 cents sharp to the walker.

Can also do by $\frac{1.8\ m/s}{340\ m/s} \approx .005$ velocity percent

~~(8 pt 2008)~~ [3.] (2010)

~~9.~~ 8 points

Spectrogram with given settings:



Analyze partials with clearest shifts:

Frequency shifts:	Ratios f2/f1:
f1 = 322.68 → 298.84	.92611
f2 = 513.34 → 481.56	.93809
f3 = 640.45 → 592.78	.92557

Frequency shift is ~ .93

Doppler shift

$$f_d = f_{source} \cdot \frac{c_s}{c_s - u}$$

$u > 0$ moves towards listener
$u < 0$ " away from "

1st blast while train approaching:

$$f_1 = f\frac{c_s}{c_s - u} = \frac{340}{340-u} \cdot f_{source}$$

2nd blast, train leaves:

$$f_2 = f \cdot \frac{c_s}{c_s + u} = \frac{340}{340+u} f_{source}$$

$$\frac{f_2}{f_1} = .93 = \frac{\cancel{f_{source}} \cdot \frac{c_s}{c_s+u}}{\cancel{f_{source}} \cdot \frac{c_s}{c_s-u}}$$

$$.93 = \frac{c_s - u}{c_s + u}$$

$$.93\, c_s + .93u = c_s - u$$

$$1.93u = .07\, c_s$$

$$u = \frac{.07}{1.93} \cdot 340 \tfrac{m}{s}$$

$$\boxed{u = 12.3 \tfrac{m}{s}}$$

$\times \frac{3600s}{1hr} \times \frac{1km}{1000m}$

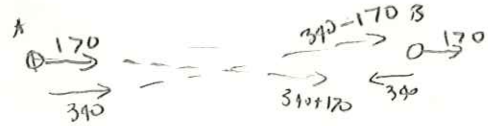
check relative speed makes sense:
(= 44.4 km/hr
= 28 miles per hour)

Bonus - A specific alteration of the harmonic spectrum due to reflection off of a nearby wall or tunnel.

1 point

Bonus: $d = vt$

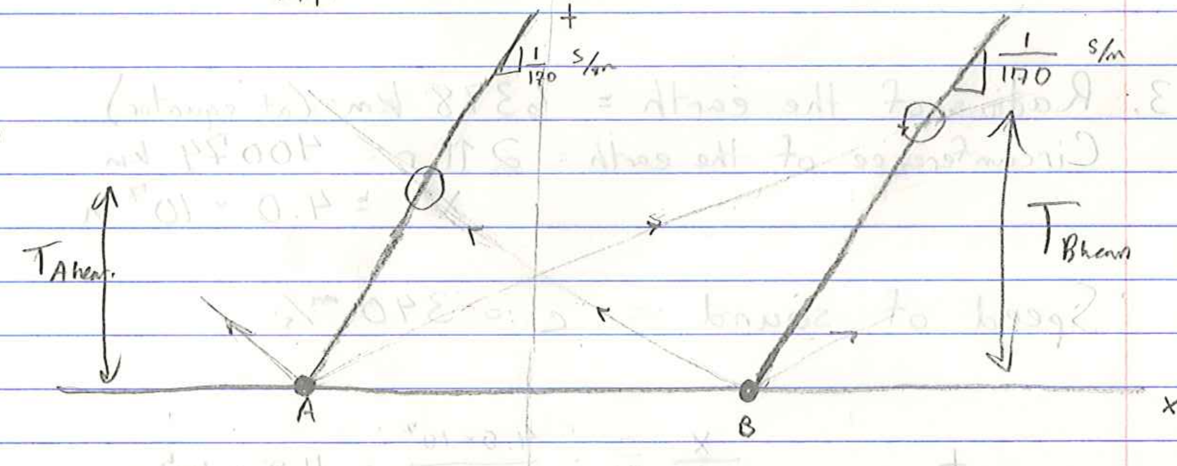
$B \to A$ $\quad 255 = (340+170)t$
$\quad t = .5\text{ s}$



$A \to B$ $\quad 255 = (340-170)t$
$\quad t = 1.47\text{ s}$

$t_{delay} = t_{B\to A} - t_{A\to B} = .5\text{s} - .147\text{ s} = \boxed{.97\text{ s}}$

4.



$v \rightarrow \sim 170\,m/s$

- A and B are not stationary listeners, not represented by vertical lines. Represented by lines with slope $\frac{1}{170}$ s/m (since $\frac{\Delta y}{\Delta x} = m = \frac{\Delta t}{\Delta x}\left(\frac{s}{m}\right)$).

- Sound doesn't care whether it's propagating outside a bullet train or a classroom → always travels (relative to air, told fixed) $c = 340\,m/s$. Represented by lines starting at A and B @ $t=0$ for their claps. Lines have slope $\frac{1}{340}\frac{s}{m}$, or half as steep based on the slope of the train velocity for the t vs. x graph.

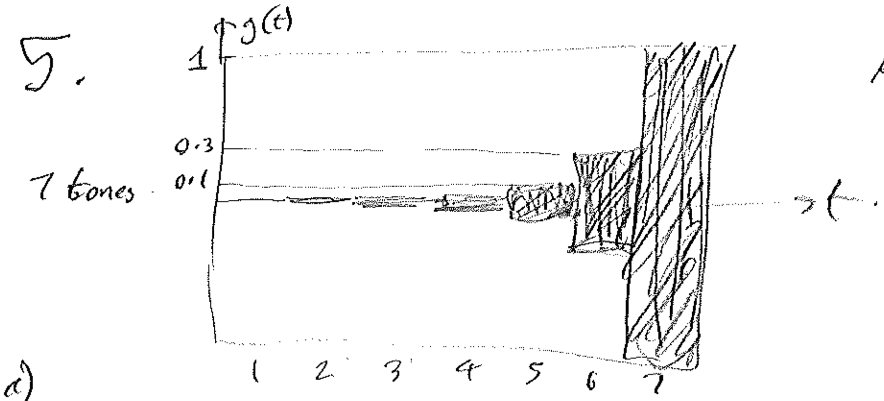
- Mark the intersections as circles. Which comes sooner? (the lower position, vertical axis). ⇒ A
  Which comes later ⇒ B.

↳ Alice and Bob do not hear the claps simultaneously. Alice hears first since she is traveling towards the emitted sound at half its speed. Bob hears second because he is traveling away from the emitted sound.

$\frac{255}{340+170}$

BONUS: $T_{A\,hears} = \frac{1}{2}$ sec, $T_{B\,hears} = \frac{3}{2}$ sec $\leftarrow 255/(340-170)$ so difference $= 1$ sec.

5.



Audacity picture

← note you can click on Waveform (dB) on the track name to see dB directly!

a) ampl: .001 .003 .01 .03 .1 .3 1

(hard to see)

b) dB 17 27 37 47 57 67 77 ← increases by +10 dB each time.

I_1 … I_7 change = +60 dB

so $+60 = 10 \log_{10} \frac{I_7}{I_1}$ intensity ratio. check this below.

c)

Use amplitudes (ratio): $\frac{I_7}{I_1} = \left(\frac{A_7}{A_1}\right)^2 = \left(\frac{1}{0.001}\right)^2 = 10^6$

convert to dB change: change in dB $= 10 \log_{10} \frac{I_7}{I_1}$

$= 10 \log_{10} 10^6$

$= +60$, agrees.

Or use dB to get I ratio (& avoid ampl. altogether):

$I_1 = I_r 10^{\frac{dB_1}{10}} = I_r 10^{1.7} \approx I_r (50.1)$

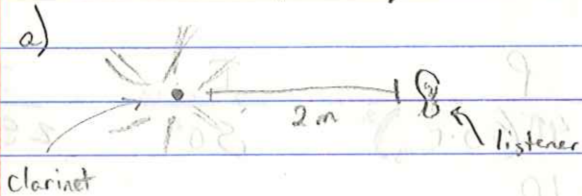
$I_7 = I_r 10^{\frac{dB_7}{10}} = I_r 10^{7.7} \approx I_r (5.01 \times 10^7)$

ratio $I_7/I_1 = \frac{I_r (5.01 \times 10^7)}{I_r (50.1)} = 10^6 = 1000000$.

But, using $\frac{I_2}{I_1} = 10^{\left(\frac{dB_2 - dB_1}{10}\right)}$ is neatest!

6. Acoustical Power, $P = 0.05\,W$

a)



Area of sphere w/ radius 2 m $= 4\pi \cdot 2^2 = 16\pi = 50.3\ m^2$

$$I = \frac{P}{A} = \frac{.05}{16\pi} = \boxed{9.95 \times 10^{-4} \tfrac{W}{m^2} \ (\sim .001 \tfrac{W}{m^2})}$$

b) $dB = 10 \log_{10} \frac{I}{I_R} = 10 \log_{10} \frac{9.95 \times 10^{-4}}{10^{-12}} = \boxed{89.98 \rightarrow \sim 90\ dB}$

c) 3 clarinettists $= 3 \times I_{(a)}$

playing same intensity as first

dB difference $= 10 \log_{10} \left[\frac{3 \times I_{(a)}}{I_{(a)}} \right] = 10 \log_{10} (2) = 4.77\ dB$

Intensity (dB) of two clarinettists $= 90\ dB + 4.77\ dB$

$\boxed{\simeq 94.8\ dB}$

d) Threshold of human hearing $= 0\ dB = 10 \log_{10} \left(\frac{I}{I_R} \right)$

$\frac{I}{I_R} = 1$

$$I = I_R = 10^{-12}\ W/m^2$$

$$I = \frac{P}{A} = \frac{.05}{4\pi r^2} = 10^{-12}$$

$$4\pi r^2 = \frac{.05}{10^{-12}}$$

$$r^2 = \frac{.05}{10^{-12} \cdot 4\pi}$$

$$r = \sqrt{\frac{.05}{10^{-12}\, 4\pi}} = 63,078\ m$$

but really air absorbs sound, and there's too much background noise to hear it. So, not realistic.

Have to go out $\boxed{63\ km}$ for playing at threshold of human hearing!

$\boxed{7}$. $I = 130\ dB$ when $r = \frac{1}{5}$ mile $\times \frac{1608\ m}{mile} = 321.6\ m$

a) $I = \frac{P}{A} = \frac{P}{4\pi r^2} = \frac{P}{4\pi(\cancel{50}\cdot r_{orig})^2} = \frac{I_{orig}}{(5\cancel{0}0)^2} = \frac{I_{orig}}{\cancel{2500}\ 2500}$

$r = \frac{1}{5} \rightarrow r = 10$

dB difference $= 10 \log_{10}\left(\frac{\frac{1}{2500} I_{orig}}{I_{orig}}\right) = 10 \log_{10}\left(\frac{1}{2500}\right) = \cancel{-26.0}$
$34\ dB$.

$130\ dB - 34.0\ dB = \cancel{104\ dB}\ 96\ dB$.

Expect thunderclap at $I = \cancel{104}\ 96\ dB$ now

b) Assume light is instantaneous $\left(\overset{3\times10^8}{c_{light}} \gg \overset{340}{c_{sound}}\right)$

Time it takes sound to travel $\frac{1}{5}$ and 10 miles respectively.
" " " " " " 321.6 and 16080 meters "

$T = \frac{x}{c}\ \frac{m}{m/s} \Rightarrow T(321.6) = \frac{321.6}{340} = .946\ s \quad T(16080) = \frac{16080}{340} = 47.3$

The time delay for a $1/5$ mile (away) thunder clap is .946 s; and 47.3 s for 10 miles.

$\boxed{8.}$ [5pts.

a) $f_0 = \frac{1}{2\pi}\sqrt{\frac{k}{m}} = \frac{1}{2\pi}\sqrt{10^6} = \frac{1000}{2\pi} \approx 159\ Hz$

b) $k \rightarrow 4k$ (by ratios) so $f_0 \rightarrow \sqrt{4} f_0$ doubles freq to $318\ Hz$, octave up.

c) want $f_0 \rightarrow \frac{2}{3} f_0$ (down perfect 5^{th})

so $m \rightarrow \left(\frac{3}{2}\right)^2 m$ ie $\frac{9}{4} m = 0.00225$. (kg?)

Or $\frac{f_2}{f_1} = \frac{1/2\pi \sqrt{k/m_2}}{1/2\pi \sqrt{k/m_1}} = \sqrt{\frac{m_1}{m_2}}$ so $\frac{m_2}{m_1} = \left(\frac{f_1}{f_2}\right)^2 = \left(\frac{3}{2}\right)^2 = 9/4$ as before.