Assignment 3
Physics of Music - 205
Physics 341

1 a)I attended the Marriage of Figaro a few years ago, and found that hearing the bass while he was singing his lower notes was much more difficult than hearing the tenors and the women. Could there be some Physics reason for this? What is it?

for a bass, the frequencies are very low, much lower than the knee frequency of the mouth. (the mouth diameter is about 5cm which would give a knee frequency of about 340m/s / .1m = 3.4KHz. A bass singer will sing down around 100Hz, which is 5 octaves below the knee frequency. Ie, this corresponds to an efficiency of -30dB. Compare this to a soprano who sings at around 800Hz for her fundamental, which is only two octaves below the knee frequency for an efficiency of -12dB, 18dB higher than for the bass. Of course this is not the whole story. The ear is also more sensitive around 1kHz than around 100Hz at the sound levels likely to be heard in an opera.

b) Why is an (unpowered) megaphone useful (consider the size of the radiating area)? Why do singers tend to sing with their mouths wide open? (It is not for the looks!)

In both cases the purpose is to lower the knee frequency and thus increase the efficiency of the sound radiated from the mouth. Note that the megaphone makes no difference to the energy created at the mouth or at the mouth of the megaphone (the energy goes as Area x velocity^2, and that product will be the same at the mouth and at the opening to the megaphone. Although the total energy goes as the area, the total energy coming out of the mouth is spread out over the area of whole area. However the efficiency of converting that sound energy near the mouth to sound far away is higher the larger the radiating diameter. Since the megaphone opening is probably around 50cm for a large megaphone, and the mouth has diamater around 2cm, the mouth's knee frequency will be around 340m/s / 2x.02m = 8500Kz, while the megaphone's would be about 340m/s / 2 x .5m= 340Hz. So, for the megaphone the sound would escape with unit efficienty for all frequencies about 340 Hz, vs falling at 6dB per octave for the mouth. Ie, at 340Hz, which is about 5 1/2 octaves below 8500Hz, or about 33dB quiter than from the megaphone.

c) Why, when you scream for help, do you open your mouth wide and scream at a high pitch?

Again, efficiency. The wider open the mouth, the lower the knee frequency (as in the last item, the knee freq for an open mouth is about 8KHz, and higher than that for a partially closed mouth.) Also since the efficiency increases as the pitch gets higher (6dB/octave), a high pitched sound will get out with higher intensity than a low pitched sound.

2. Figures 1 and 2 are the polar plot of the sound radiation intensity given off by a vibrating diaphram in a wall, at various frequencies. what is the the relative

intestity both as a ratio to straight ahead and as dB (relative to straight ahead) of the sound given off at 40 degrees for a frequency of twice the knee frequency? At 70 degrees? What are the relative intensities (compared to straight ahead) of the sound given off at 5 degrees and at 30 degrees for a frequency of eight times the knee frequency.

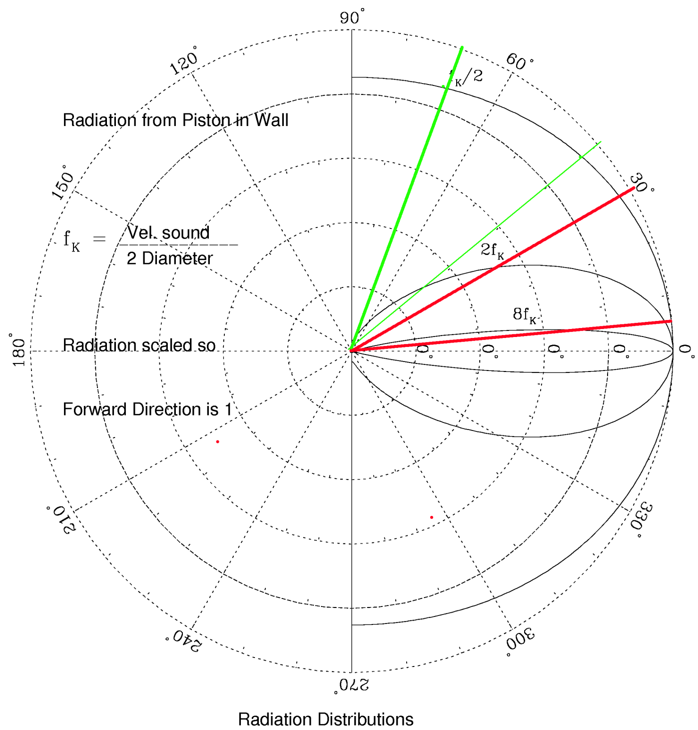

Figure 1

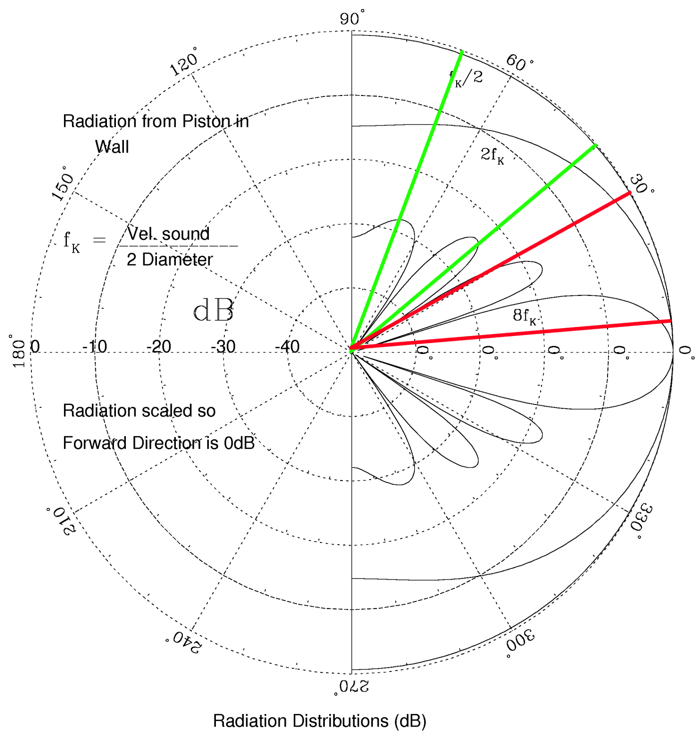

Figure 2

The green lines in the plots are at 40 degrees and 70 degrees for the twice knee freq, and the red lines are at 5 degrees and 30 degrees for 8 times.

40deg: from the (reletive intensity) first graph, The intersection with the $2f_k$ curve occurs at a radius of roughly .35. At 70 degrees, the intersection is very near the center, with perhaps something like .05, but it is hard to estimate. However, lookin at the green line at 30 degrees on the dB graph, apporx. -5dB. (which would be a fractional ratio of .32 which is close enough to the .35 read of from the fraction graph).

At 70 degrees it is essentially impossible to read it off from the fractioal graph, since it is too close to 0. From the dB graph, we get approx -12dB, which would be four powers of 2 (12=4x3, and 3dB is a factor of 2) so that would be 1/16 (1/(2x2x2x2))=.0625– no wonder it is hard to read off from the fraction graph.

For the $8f_k$ curve, at 5 degrees, from the fractional graph, I get about .75 as the fractional intensity. For 30 degrees, it is again totally impossible to read off from the first graph. From the second graph, I get about -23dB (each step from one circle to the next is 10dB) which is about .005 (3dB-¿ factor of 2 less than -20dB which is 1/100=.01. So 23dB-¿ .01/2=.005) which would be totally impossible to read off from the first graph.

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3) The critical band is the range of frequencies around which the vibration on the basilar membrane overlaps (ie, if one has two frequencies, the widths of the region which which each causes to vibrate overlap with each other). This is taken to roughly be a minor third (ie, if two frequencies differ by less than a minor third, their regions of membrane excitation overlap). Consider the series of harmonics of a note. By which harmonic do successive harmonics have overlapping excitations on the basilar membrane?

Successive notes of the harmonics– the nth harmonic and the $n+1$st harmonic have a frequency ration of $\frac{n+1}{n}$. Thus the fifth and sixth harmonics have a frequency ratio of $\frac{6}{5}$. The frequency ratio of a minor third is $\frac{6}{5}$ in the just tuning. Ie, by the fifth harmonic the successive harmonics are overlaping, the next harmonic is overlaping. This means that the two notes begin to excite the same region on the membrane, and the same cells send signals to the brain. There will in general be some beating (interference) between the two. However the brain often can still differentiate the two notes, but not always.

There is a very interesting demonstration at

http://languagelog.ldc.upenn.edu/nll/?p=2074#more-2074

where a major and minor chord can be discriminated by some people and not by others. Is this a case where the critical band of some people overlap more than for others? In each case the chord has an interval of a minor third and a major third, but in opposite order (in pitch progression), and some people have real problems telling which is which (and others have no trouble at all). The evidence seems to be that this is not a matter of musical training– some good musicians cannot tell and some naive listeners can.

4)a) How much sharper or flatter (give a ratio) is a just major third (5/4) to two Pythagorian whole tones?

b)Three major thirds (four semitones) could be said to be an octave (twelve semitones). How mistuned would that octave be if each of those major thirds were just major thirds?

A Pythagorean whole tone is obtained by going up two major Pyth fifths, and then down an octave. Ie, $\frac{3}{2}\frac{3}{3}\frac{1}{2}=\frac{9}{8}$. Two Pythag. whole tones are $\frac{9}{8}\frac{9}{8}=\frac{81}{64}$, But one Just major third is $\frac{5}{4}=\frac{80}{64}$ Thus two Pythag whole tones are $\frac{81}{80}=1.0125$ sharper than one just major third. Since a semitone is 1.058, this is just under a quarter of a semitone sharper.

Three just major thirds is $\frac{5}{4}\frac{5}{4}\frac{5}{4}=\frac{125}{64}=1.953$. A semitone below an octave has a ratio of 1.888. Thus three just major thirds are just under half a semitone flat of an octave. If one tried to make sure that all major thirds were just major thirds, one would make a mess of the octaves.

5)a) A workman is exposed to a sound of 60dB for 7 hours, and 100dB for one hour without hearing protection. What is the average energy rate of the sound that he received during the course of the day? The Workman's compensation says that if the average energy rate is higher that 90dB during 8 hours, hearing protection must be provided. Is the company in compliance?

The second sound is 40dB louder than the first which is 10000 times louder. Thus for 7 hours, the sound is a certain level, and the last hour it is 10000 times as much. On average it is therefor (10000+7x1)/8 times as loud as the reference, which was the 60dB sound. This is on average 10000/8 times as lound, or 40dB-9dB=31dB louder than the 60dB. Ie the average is 91 dB which is 4dB (about 2.5 times) higher than the limit. Remember that 10000 is 40dB and 8=2x2x2 or 3+3+3 dB (the difference between 10000 and 10007 is completely negligible as far as dB are concerned) . Since we divide by 8 the 8 decreases the 10000 level so that is why we get 40dB-9dB

We could also do this referencing everything to 0 dB ($10^{-12} w/m^2$) Thus 60dB would be a million times as intense, or one millionth of watt per square meter. 100dB would be 10 billion times louder, of one hundredth of a watt per square meter. Thus the average would be $7 \times amillionth + 1 \times ahundredth$ divided by 8 hours total, or one 8 hundredths of a watt per meter squared. This would be 100dB- 9dB= 91dB.

b) The standard in BC for Railway workers is that the average noise level must not exceed 87dB for an 8 hour day. BC mandates the 3dB rule, namely that the time of exposure must be halved for each 3dB rise in the average noise level. How long could a railway worker work in a place (eg a disco) with an average noise level of 120dB? In Ontario, the requirement is that the worker is allowed to be exposed to 90 dB for an 8 hour day, and that the time is halved for each 5dB rise in noise level. How long would a Ontario worker be allowed to work in that same disco.

In BC, that 120dB sound is 33dB above the limit, which is 11 factors of 3dB. Thus you need to divide 8 hours by two eleven times, which is very close to dividing by 2000 ($2^1 1 = 2048$) . Ie, the worker could be in that disco only (8x60x60)sec/2000=14.4 seconds.(15 seconds)

In Ontario, that sound is just 30dB above the limit (since the limit is higher) , which is 6 times the 5dB halving time. The limit would be 8hr/(2x2x2x2x2x2)=1/8 hr, or 7.5 min. which is about 30 times as long as the BC worker could be there.

6. 6) Two notes, tuned a equal tempered perfect fifth apart are played together. How many beats per second would you get between the first three harmonics of the two notes that have the same frequency in Just tuning if the lower note was 220Hz?

In just tuning every third harmonic of the lower note has the same frequency as every second harmonic of the sound a perfect fifth higher. This is not the same in equal temperament The fifth is 1.4983 higher in frequency and thus would have a frequency of 220x1.4983= 329.63 instead of 330Hz. The third harmonic of the lower note is 660Hz. The second harmonic of the higher is 659.26 Hz, so the difference is .74 Hz, which would give a beat freq of .74Hz (about 3 beats in 4 sec).

The next harmonics which should have the same freq. in just tuning is the 6th of the lower note and the 4th of the higher. This would be a freq. of 1320 for the lower note, and 1318.52 for the higher, which would thus beat at about 1.48Hz (1 1/2 beats per second). Ie, the higher harmonics beat faster. The higher harmonics tend to be quieter but the ear still hears this as a change in the tone colour of the note and a slight harshness to the chord.