Section: Monday / Tuesday (circle one)

Name: ______________________________

Partners: ______________________________

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PHYSICS 107 LAB #8: PERCUSSION PT 1 - DISCS

Equipment: *earplugs, cardboard box lid, function generator, 2 banana wires, PASCO oscillator, round Chladni plate, sand shaker, 2-meter stick, sound intensity level meter, one speaker and function generator in dome.*

OBJECTIVES

1. Identify a cymbal's modes and determine whether or not they're harmonically related

Readings:

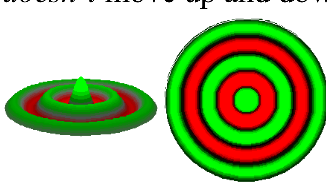
Chapter 9

Overview

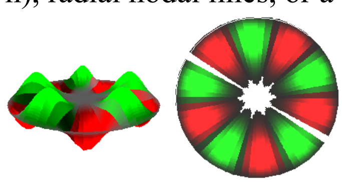
String and Wind instruments owe much of their 'musical' sounds to the fact that their possible modes of oscillation are harmonically related, so when one plays a complex tone it can have a defined and steady pitch since it's comprised of members of a harmonic series (all are integer multiples of a common fundamental). This is thanks to the simplicity of their resonating medium – a string or a column of air.

Percussion instruments are another matter. A drum head and a symbol can support a much greater variety of oscillations, which may or may not happen to be harmonically related. So many percussion instruments do not have identifiable 'pitch', and when a pitch is desired (as with a kettle drum) great pains are taken to design the instruments to enhance and approximate harmonically-related modes.

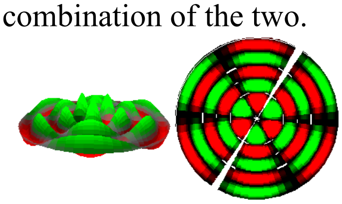
A disc or membrane that's fixed at the edges, like a drum head, has basic modes of oscillation with circular nodal lines (black in the images below – where the drum head *doesn't* move up and down), radial nodal lines, or a combination of the two.



(circular nodal lines)



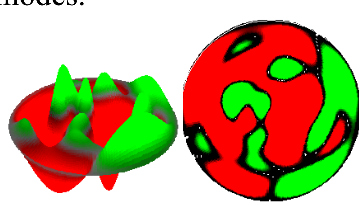
(radial nodal lines)



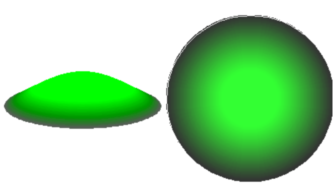
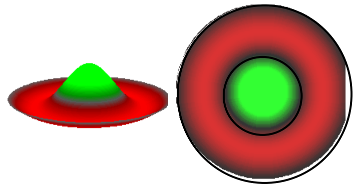
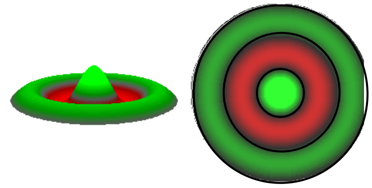
(circular and radial nodal lines)

All images from http://www.falstad.com/circosc/.

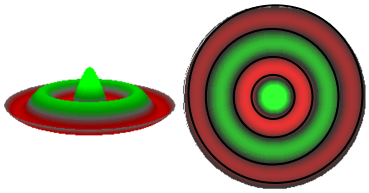
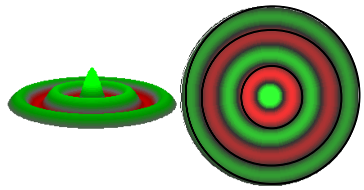
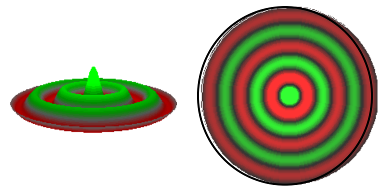
In general, the actual oscillation of a drum head can be a combination of many different modes.



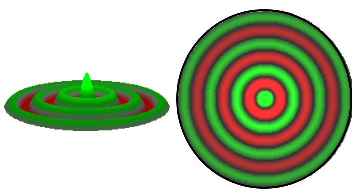
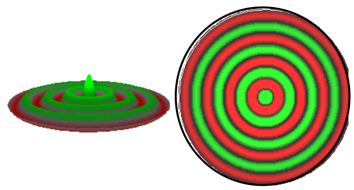
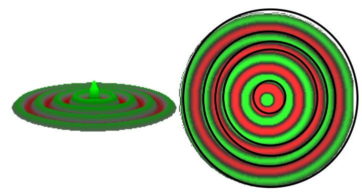
Exactly which modes are and aren't excited depends upon where the drum head is struck / driven. In this lab, you'll be driving a disc by oscillating its center point; that will exclude all modes with radial nodal lines since they would all require that the center remain stationary. For a drum head struck/driven in the middle, the first nine nodal patterns that could be excited are as shown on the next page.

f_{01} $\quad$ $f_{02} = 2.295\ f_{01}$ $\quad$ $f_{03} = 3.599\ f_{01}$ so $f_{03}/f_{02}=1.598$

$f_{04} = 4.903\ f_{01}$ so $f_{04}/f_{02}= 2.148$ $\quad$ $f_{05} = 6.209\ f_{01}$ so $f_{05}/f_{02} = 2.705$ $\quad$ $f_{06} = 7.515\ f_{01}$ so $f_{06}/f_{02}=3.275$

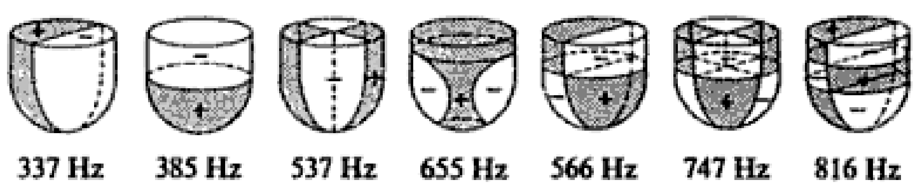




$f_{07} = 8.821\ f_{01}$ so $f_{07}/f_{02}= 3.844$ $\quad$ $f_{08} = 10.126\ f_{01}$ so $f_{08}/f_{02}= 4.412$ $\quad$ $f_{09} = 11.432\ f_{01}$ so f_{09}/f_{02} 4.981

Notice that the number in the subscript is the number of black nodal rings including that at the rim. The frequencies are not harmonically related (not integer multiples of a fundamental), but they are related to each other according to a relatively simple mathematical function. [1]

Unlike the drum head, the disc that you'll drive will be *free* at the rim, so the rim will be an *anti-node* for each mode. Aside from that, the patterns that you obtain will be quite similar. The question that you'll explore is how are their frequencies related – the same as for a drum head, harmonically, some other way?

While all this is happening on the drum *head,* something equally interesting can be happening to the air throughout the drum's body. Here are some of the modes of a kettle drum (+ and – signs correspond to anti-nodes.)



f_{110} $\quad$ f_{011} $\quad$ f_{200} $\quad$ f_{021} $\quad$ f_{111} $\quad$ f_{211} $\quad$ f_{113}

(From Fig 2.6 of Rossing's Science of Percussion Instruments)

[1] $f_{mn} = \frac{1}{2r}\sqrt{\frac{T}{D}}\beta_{mn}$ where β_{mn} is the n^{th} root of the m^{th} Bessel function; considering just circular nodal lines, m = 0, and so $\beta_{mn} = \beta_n$ where $J_o(\beta_n) = 0$.

Disk

As discussed above, the frequencies for a drumhead are related in a specific way, you'll see how the frequencies for this disc (whose rim is free to vibrate) are related.

Set-up

1. A black metal disk should be attached to the PASCO driver, and the driver should be plugged into the Function Generator,
2. Set the function generator to 350 Hz and set it so that you can adjust frequencies in 10 Hz increments (when you find you're close to a mode, you can switch down to 1Hz resolution to zero in.)
3. Set the voltage around 0.6 V.
4. Sprinkle some sand on the plate – a light sprinkling will do (you can always sprinkle on more as you go).

Note: there are earplugs available, you'll probably want to put them in at some point.

Experiment

You're going to dial the frequency higher and higher until the plate resonates – you'll hear that when the tone gets louder and you'll see it because the sand will jump around and accumulate along nodal lines. As you get to a resonance, feel free to dial down the voltage, and as you leave it you can always dial the voltage back up.

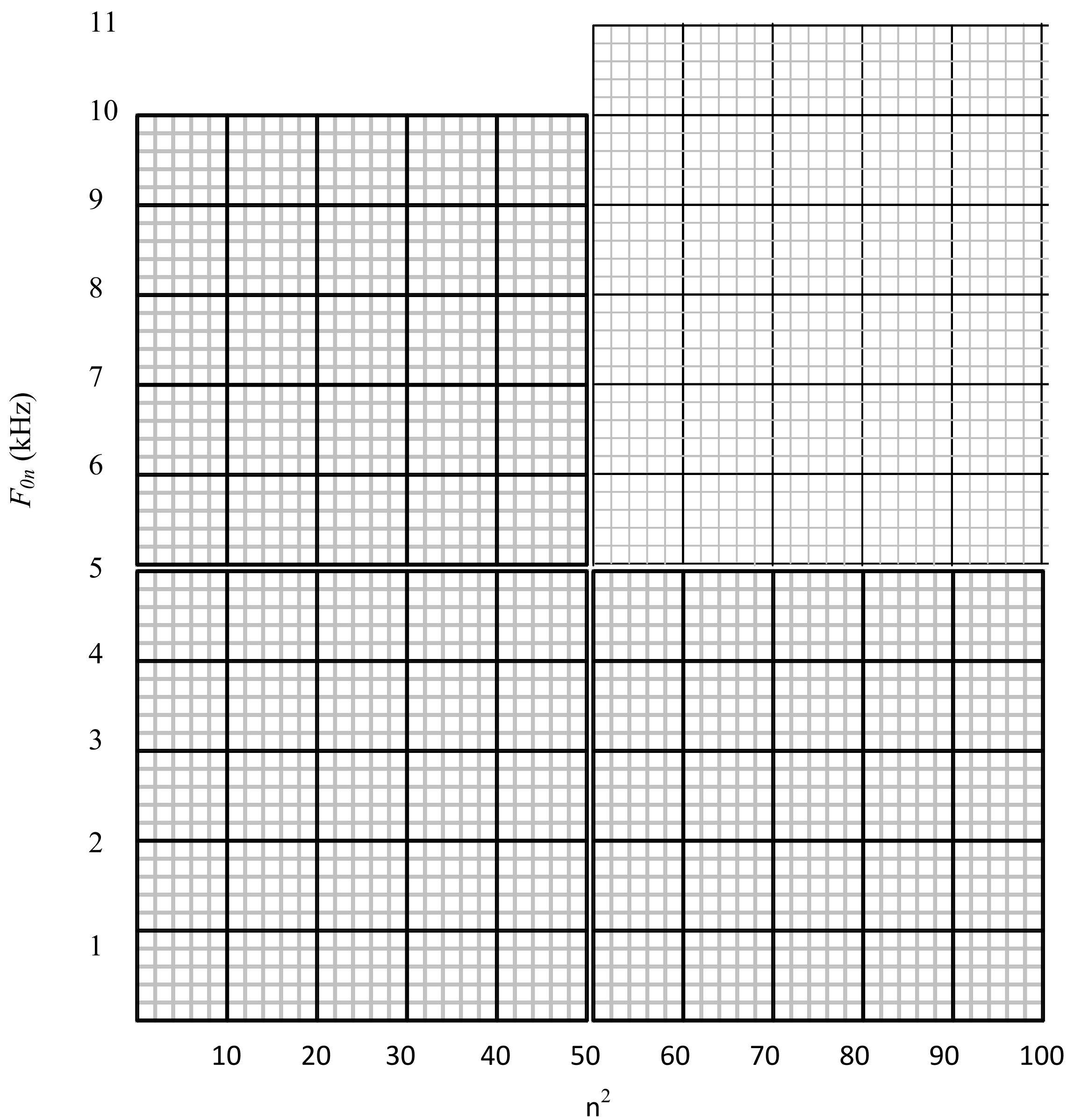
1. Dial up the frequency (and adjust voltage and reapply sand as needed) until the sand jumps into a pattern of nodal lines. The first pattern you should see will have two concentric rings. Home in on the frequency at which the effect is strongest (the sound should be loudest and the sand should move most violently toward the nodal lines). Enter that frequency in the first row of the table below.

2. Dial up the frequency until you find modes with 3, 4, 5, …9 circular nodal lines and enter their frequencies in the table as you go. So you know where you're hunting, the first digit of each frequency is given in the table. Also calculate each frequency's ratio the first one you'd identified.

n	n^2	f_{0n} (Hz)	f_{0n}/f_{02}
2	4	3_ _	1
3	9	8 _ _	
4	16	1, _ _ _	
5	25	2, _ _ _	
6	36	4, _ _ _	
7	49	5, _ _ _	
8	64	7, _ _ _	
9	81	9, _ _ _	

Question: Comparing the ratios f_{0n}/f_{02} that you found for the disc with those quoted for a drumhead (page 2), would you say these frequencies are related to each other the same way that the drum's frequencies are?

3. To a rough approximation, these frequencies scale with the square of the number of nodes, i.e., n^2 and so are *approximately* members of a harmonic series (with many other members missing from the series). To see this, plot the frequency against n^2.



4. Sketch in the best-fit straight line.

Question: If this is a good theoretical fit to the data, then you should be able to use it to predict the next mode's frequency; based on your plot, around what frequency would you expect to find the $n^2 = 100$, $n = 10$ mode?

f_{010} predicted = _________________________ kHz

5. Dial up the frequency on the function generator and experimentally find this mode.

f_{010} experimental = _________________________ kHz

Question: what's the percent difference between these two values?

Kettle Drum / Timpani

When a drum head is stretched over a closed bowl, or "kettle" as with the timpani, the air within the kettle will itself have modes as illustrated on page 2. Appleton Hall's east entry is similar to an upside-down kettle drum, and it supports similar modes (only much larger and lower frequency). A particularly pronounced mode is between 190 and 200 Hz. You'll find this mode and map out its nodal planes.

Set-up

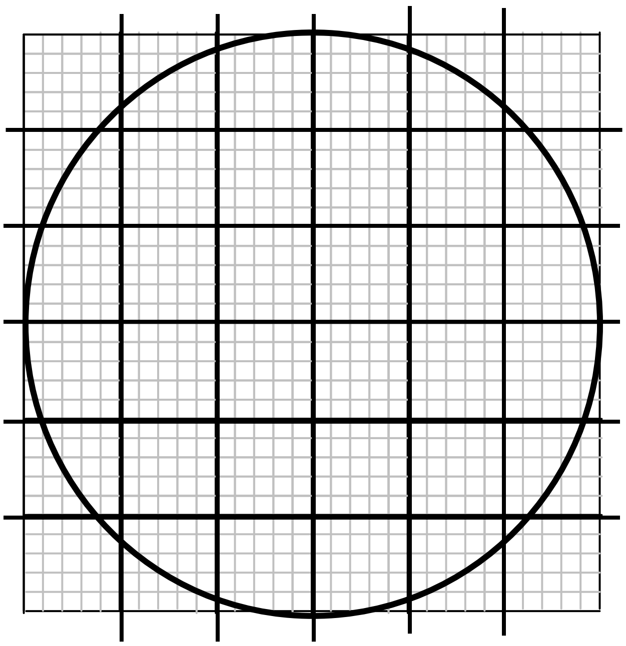
1. Bring a 2-meter stick and sound level meter (SLM) with you and go out to the east entry; there you'll find a function generator plugged into a speaker lying face up on a cart in the center of the entry way.

Experiment

2. Turn on the function generator and dial it up to 190 Hz and set the voltage so that the sound is fairly loud throughout the entry.
3. Dial the frequency up (using the 0.1 Hz scale) until you find the mode / the sound is loudest.

f_{036} = ______________________ Hz

4. Move radially in and out in the entry until you find distances at which the sound is quietest to your ear and the SLM (given the circular symmetry of the entry, you should find that there are circular nodal cylinders extending floor to ceiling.
5. Sketch the nodal rings (each faint square represents a tile on the entry's floor).



6. Aside from vertical nodal cylinders, there should also be horizontal nodal planes. Go to a location where the sound is fairly strong (an anti-node) and crouch down / stretch up to find a height at which it is quiet. On the sketch below, mark that point (its height from the floor and its horizontal distance from the center.)
7. Now move radially in / out and find a few more quiet points and mark them on the sketch as well (you'll find that they're a little lower near the edge and higher near the center.) Smoothly connecting the dots, to illustrate the whole nodal plane.
8. Assuming that such nodal planes are evenly spaced along the height of the dome, mark their heights on the figure below (the dome's roughly 4 meters tall).