PHY 103 Percussion: Bars and Bells

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Reading

- Reading for this week:
  - Hopkin, Chapter 4
  - Fletcher and Rossing, Chapters 2-3 (for more advanced background material)

Percussion Instruments

- Percussion instruments are divided into two types:
  - Membranophones
    - Drums
  - Idiophones
    - Chimes, xylophones, marimbas, jaw harps, boos, tongue drums, bells, gongs
- Could also be divided into instruments with pitch and instruments without pitch
- This week we are talking about idiophones

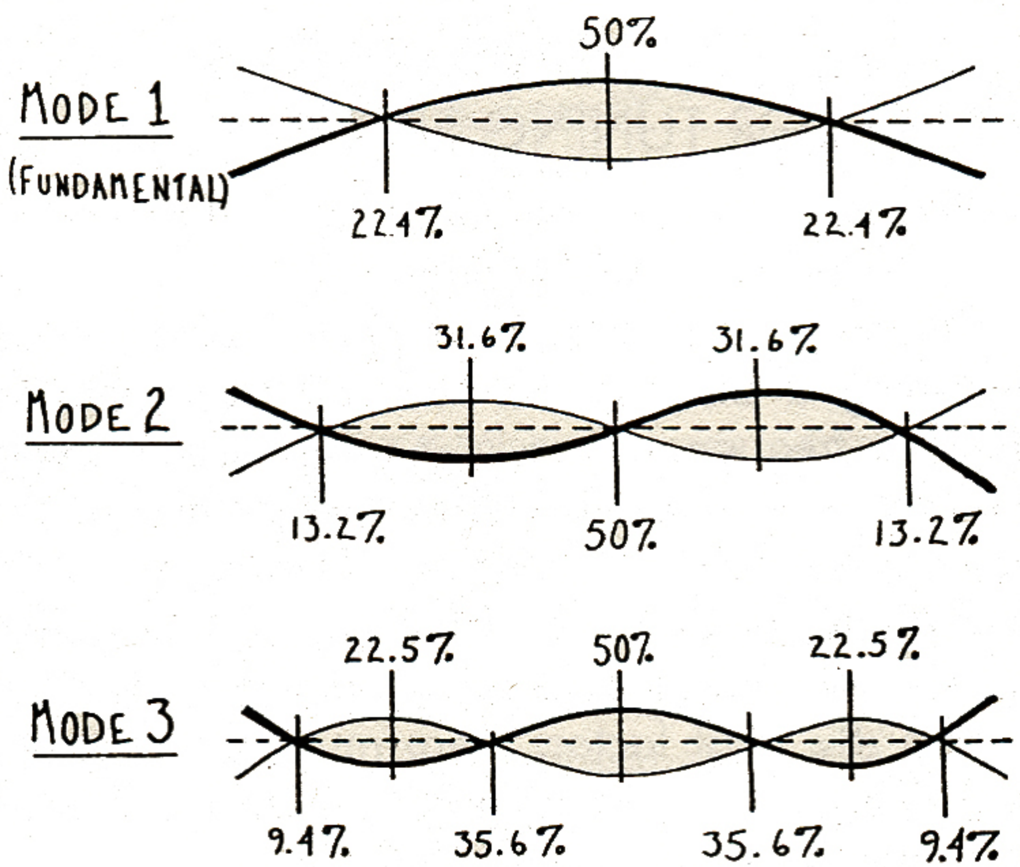
Divisions of the Idiophones

- Struck: vibrations produced by being struck
  - E.g., wood block, triangle, marimba, xylophone
- Plucked: vibrations excited by plucking
  - Jaw harp (Jew's harp), music box, etc.
- Friction: vibrations produced by friction
  - Glass harmonica, musical saw, singing bowl, etc.
- Blown: vibrations excited by blowing air
  - Very rarely encountered

Modes of a Free Bar

- Vibrational modes of a bar, rod, or tube of uniform shape and free at both ends

Bart Hopkin, *Musical Instrument Design*



Mode	Frequency Ratio	Pitch
1	f_1	tonic
2	2.756 f_1	1 octave + sharp 4th
3	5.404 f_1	2 octaves + sharp 4th

- Ex: xylophone/marimba bars. Notice that unlike what we have seen thus far in class, the partials are not harmonic!

Predicted Frequencies

- The frequencies of the free-free vibrational modes of bars and tubes are quite a bit more complex than for vibrating strings and air columns
  - Need to account for bar/tube material properties
  - Need to account for bar/tube shape
- Fundamental frequency and overtones of free-free bar:

$$f_1 \approx 1.028 \frac{a}{L^2} \sqrt{\frac{Y}{\rho}}$$

$$f_n \approx 0.441 \left[n + \frac{1}{2} \right]^2 f_1$$

a = thickness
L = length
Y = Young's Modulus
ρ = density

Material Properties

- You know what density is. What's Young's modulus?
- Young's modulus describes the relationship between the stress (force/area) on a material and the strain (proportional deformation $\Delta L/L$) it undergoes

Material	Density [kg / m³]	Young's Modulus [10^9 N / m²]	$\sqrt{Y / \rho}$
steel	7860	400	0.23
glass	2190	50	0.15
wood	525	13	0.16

HyperPhysics

- More dense materials that require a lot of force to deform tend to have a higher f_1

Mounting: Xylophone

- To build an idiophone, the mounting should be rattle-free, support the bars near the nodes, and have soft/padded points of contact (why?)

Homemade copper xylophone: https://www.youtube.com/watch?v=5KU4NyvZCYw

Mounting: Chimes

- Chimes are typically suspended by strings.
- Musical chimes and wind chimes are made of metal and have long sustain times

- The chimes' amplitudes are large enough that they can be dipped in water, lowering their frequency, and still be heard

Bar Modes in Baseball

- A baseball that strikes the barrel of a wooden bat can excite its bending modes

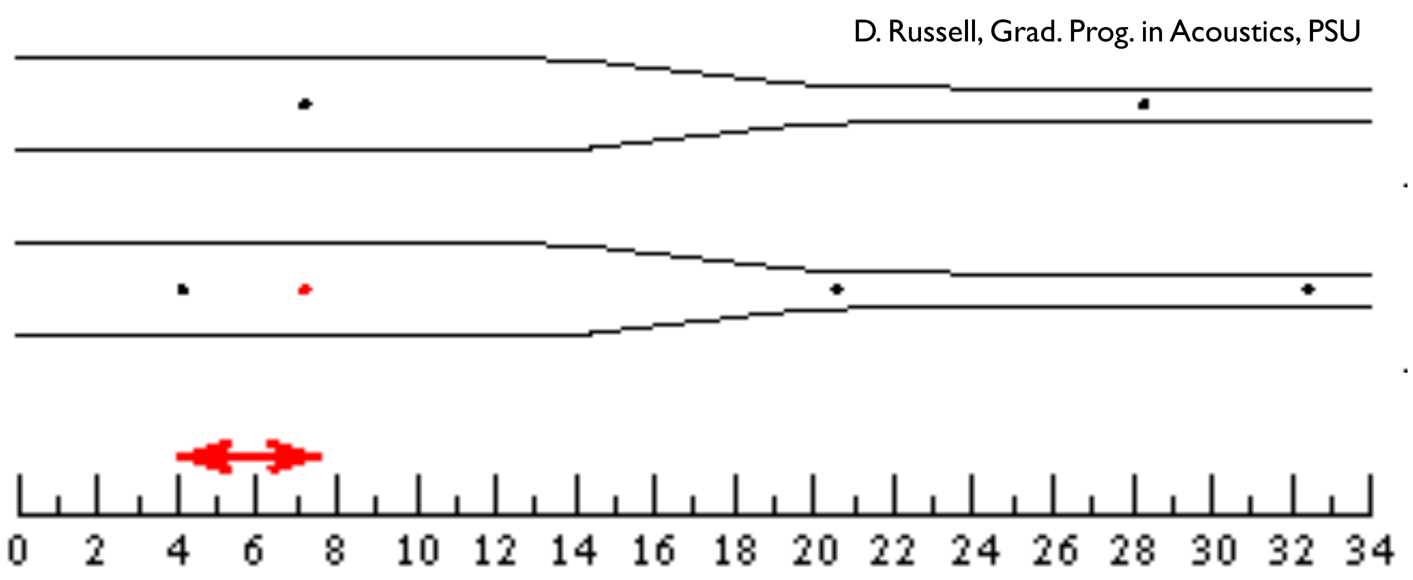
5000 fps video of Yadier Molina, 2012 NLCS (Fox Sports)

See discussion of physics on website of Alan Nathan, UIUC

- It's bad for the hitter; the energy of the collision is wasted exciting vibrations in the bat, and it also *stings*

Bending Modes of the Bat

- A bat vibrates just like a bar that is free at both ends



- Shown above are the first two bending modes of a softball bat
- Baseball bats are solid (unless they've been "corked"); softball bats are hollow. Do you think there are differences between their vibrations as a result?

Broken Bats

- If the vibrational excitations are strong enough and aligned with the grain of the wood, the bat can shatter

5000 fps video of Miguel Cabrera, 2012 World Series (Fox Sports)

See discussion of physics on website of Alan Nathan, UIUC

- Which bending mode do you see excited here? What kind of sound might it make?

The Sweet Spot

- The sweet spot is a location that, when struck, minimally excites the vibrational modes of the bat

5000 fps video of Macro Scutaro, 2012 NLCS (Fox Sports)

See discussion of physics on website of Alan Nathan, UIUC

- This is bad if you want vibrations but great for the hitter; it results in a clean hit with more energy imparted to the ball

A Bat-o-phone?

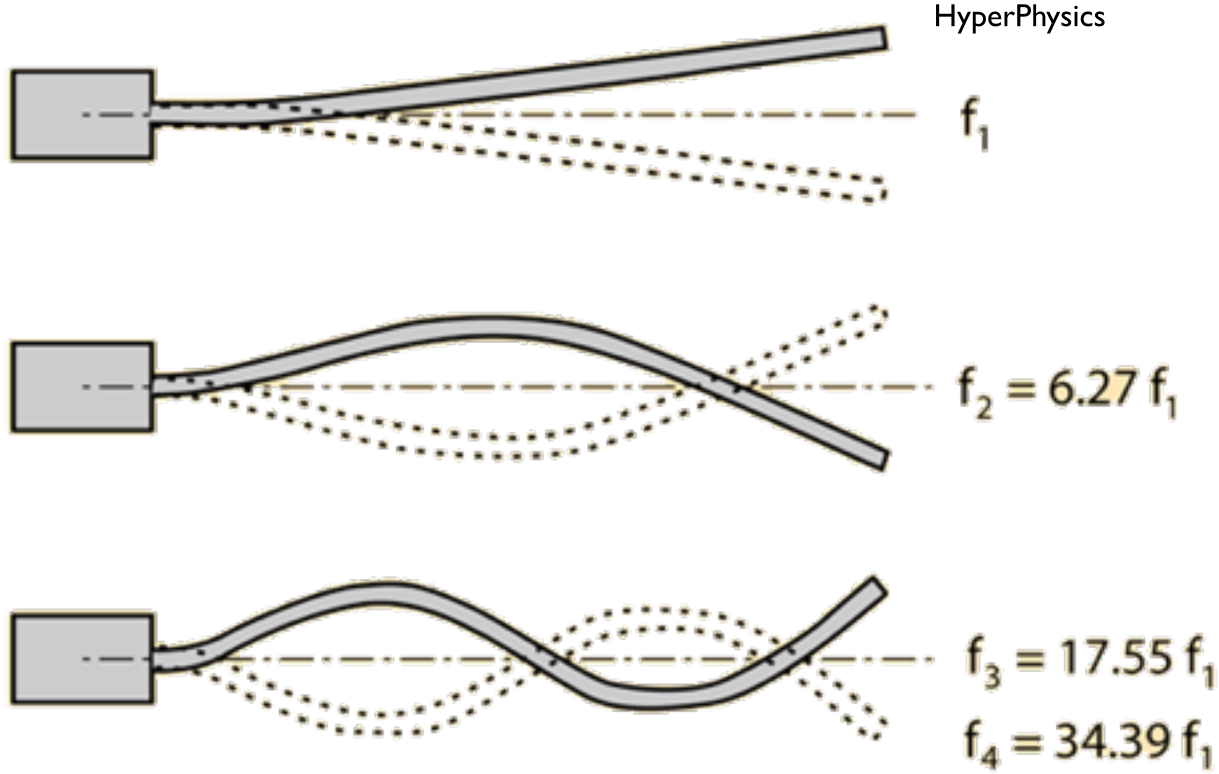
- Could you make a decent musical instrument out of a collection of baseball bats? Like wooden blocks?

Glenn Donnellan, National Symphony Orchestra, Washington, DC

- Patented: a bat + pick-up amp = electric violin

Modes of a Clamped Bar

- Plucked idiophones look like a bar or rod (or tube) clamped down on one end



Mode	Frequency Ratio	Pitch
1	f_1	tonic
2	6.27 f_1	2 octaves + flat minor 6th
3	17.55 f_1	4 octaves + flat major 2nd

- The clamped end of the bar is always a vibrational node
- Examples: music box tines, Jew's harp, tuning fork, …
- Does the wave pattern in the figure remind you of anything?

Clamped Bar Frequencies

- As with the free-free bar, the fundamental frequency of a clamped bar is nontrivial to calculate
- The overtones are also inharmonic, i.e., they are not simple integer multiples of the fundamental frequency

$$f_1 \approx 0.162 \frac{a}{L^2} \sqrt{\frac{Y}{\rho}}$$

$$f_n \approx 2.81 \left[n - \frac{1}{2} \right]^2 f_1$$

a = thickness
L = length
Y = Young's Modulus
ρ = density

Tuning Fork

- Tuning forks behave like two separate clamped bars with the node located at the shared stem

Dan Russell, Grad. Prog. Acoustics, PSU

- The lateral motion of the tines is converted into a low-amplitude longitudinal wave in the stem
- If the stem is touched to a table or resonating cavity these longitudinal waves can be greatly amplified

Tuning Fork Modes

- When you strike a tuning fork against a hard object, you are probably exciting the "clang mode," where each tine vibrates in the second clamped bar mode

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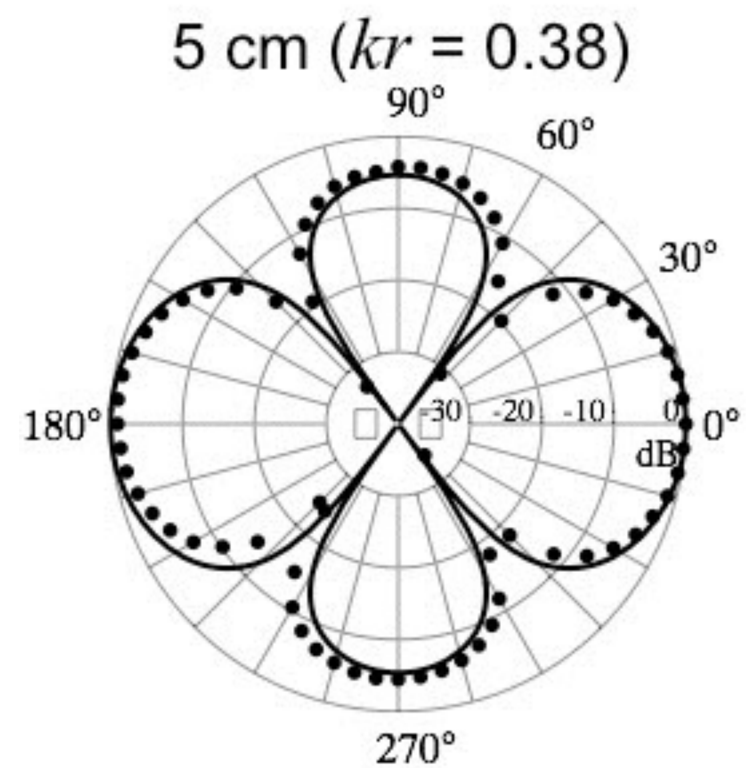
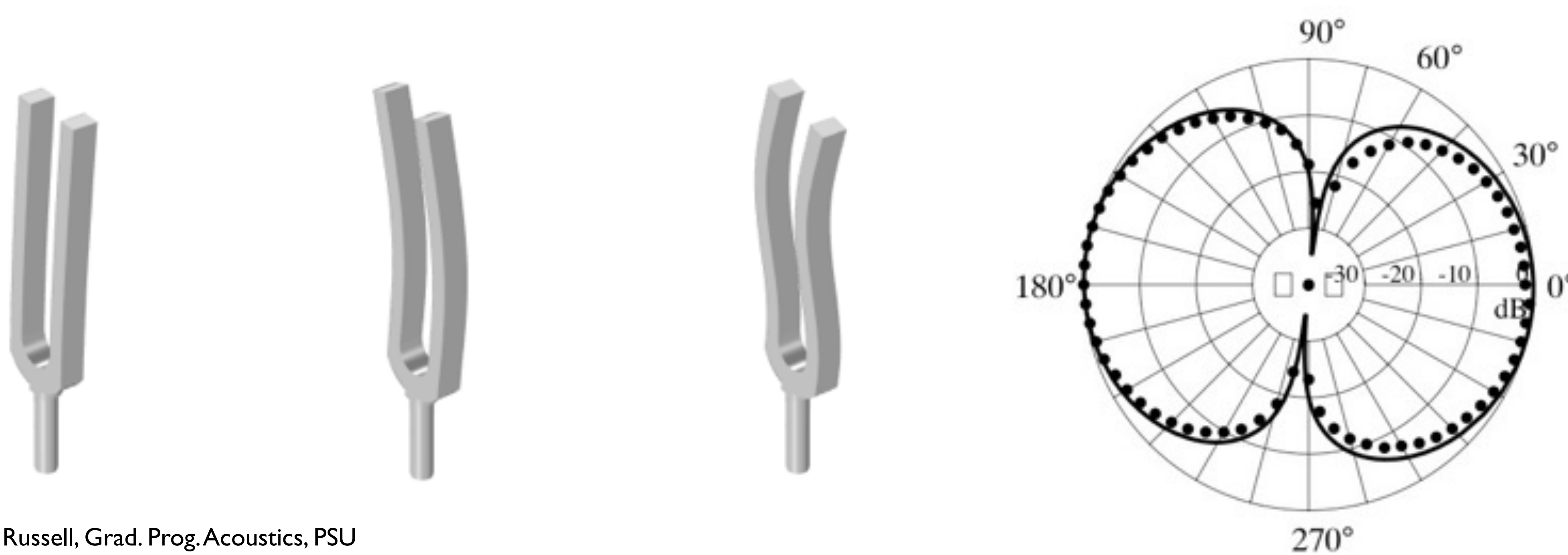
Fundamental Mode　　Clang Mode



- These modes are quadrupolar: as you walk around the fork, there are 4 points where the sound is a maximum and 4 where the sound is a minimum

Asymmetric Fork Modes

- The previous modes are called symmetric because the tines are mirror images of each other
- There are also asymmetric modes



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- These modes are dipolar: as you walk around the fork, you will encounter 2 points where the sound is a maximum and 2 points where it's a minimum

Tongue Drum

- The tongue drum is an African instrument using vibrating wooden “tongues” above a resonant cavity

- Each tongue, which vibrates like a clamped bar, produces one tone in the instrument

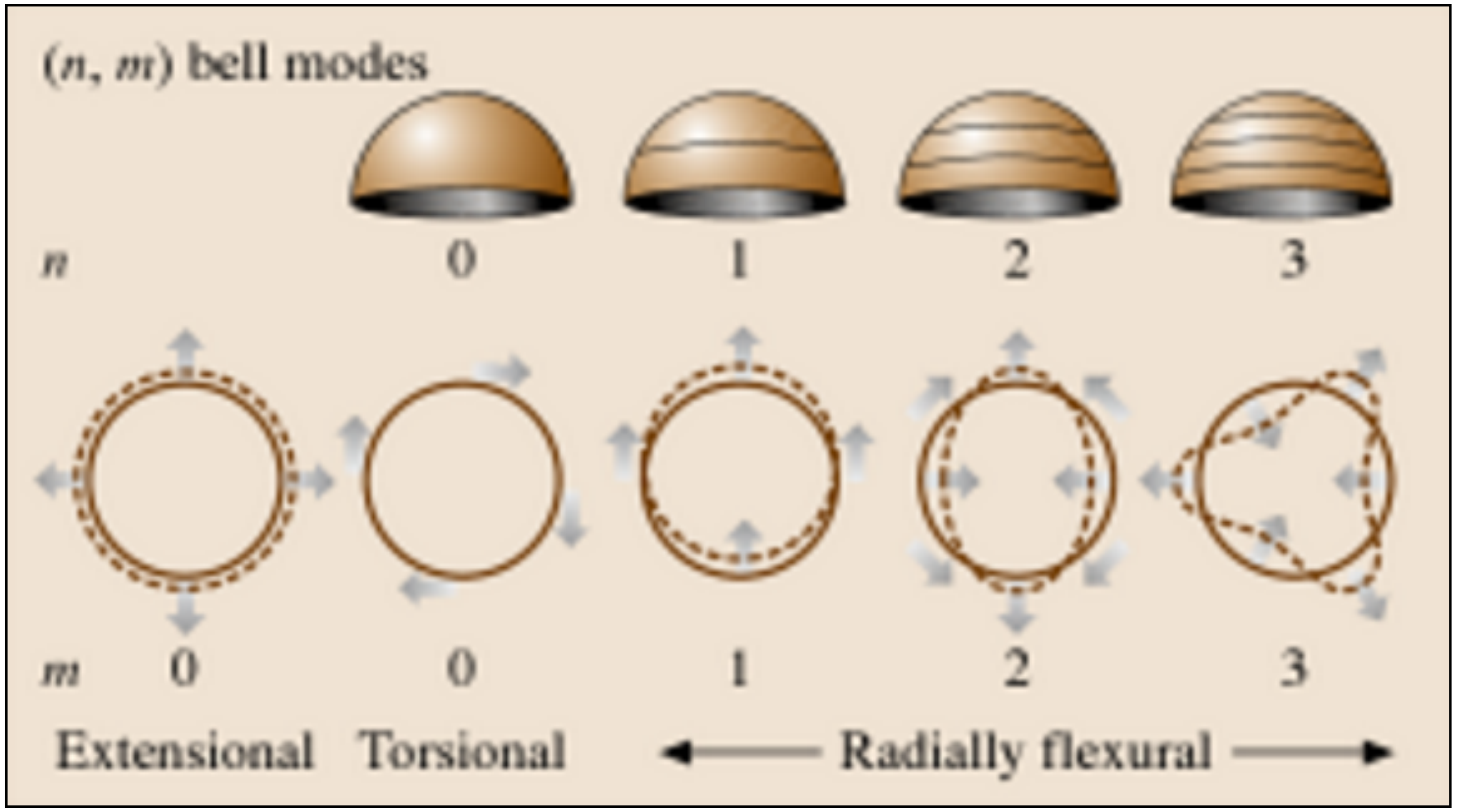
Bells

- Bells come in a few types:
  - Roughly spherical with a slit-like opening (sleigh bells)
  - Roughly cylindrical, domed and closed on one end and open on the other (church bells)

- Bells are almost always inharmonic and have complex 2D vibrational modes
- Overtones can be tuned, based on centuries of casting experience

Bell Modes

- Cylindrical bells can vibrate in 2D modes in which:
  - The walls of the bell vibrate (mode denoted by *n*)
  - The rim of the bell vibrates (mode denoted by *m*)



From *Springer Handbook of Acoustics*, Ed. T. Rossing

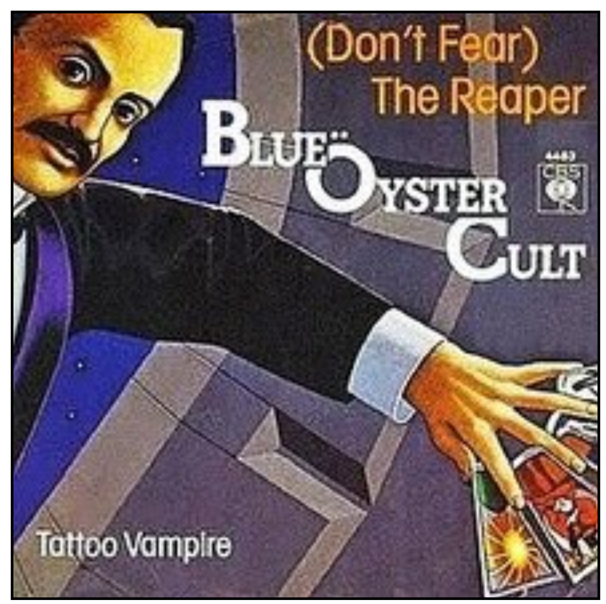
Bell Tuning

- When a bell is struck, many inharmonic partials are sounded and quickly die out
- The main note heard during the striking of the bell is called the tap note
- The remaining note during the decay is called the hum tone
- Favored bell tuning, historically, is inharmonic with a minor 3rd + 5th and a few octaves
- The *m*=2 vibrational mode, the radial vibration in which the rim of the bell alternately squeezes and stretches, produces the "hum tone" of the bell

Bell Tap and Hum Tone

Cowbells

- Cowbells are rectangular, so the sides vibrate independently of each other (edges are the nodes)
- Made from sheet metal, featured quite a bit as a percussion instrument in 1970s and 1980s



- Spoofed in famous SNL "More Cowbell" sketch

Glass Xylophone

- The glass xylophone is actually more like a bell or gong than like a xylophone

- The pitch of the glasses is adjusted by adding or removing water
- The xylophone is played by percussion, exciting the radial modes of the glasses much like a bell

Glass Harp

- Musical glasses are played by fingertip friction

- A table covered in wineglasses is historically a mainstay of talent shows. Odd associations aside, it is fun to do this…

Glass Harmonica

- Mechanized sets of graduated musical bowls invented by Benjamin Franklin (1761)
- Glass bowls are placed in a row on a rotating spindle, allowing for more complex music to be played

- Quite a bit of music written for this instrument by Mozart, Beethoven, Strauss, through to Saint-Saëns at the end of the 1800s

Summary

- Idiophones are a class of percussion instrument based on the excitation of tubes, bars, and blocks by plucking, striking, or even friction
- The overtones in idiophones are usually inharmonic due to the complexities of the material and shape of the instrument
- Excitations can include:
  - Bending modes, characteristic of bars and tubes
  - Radial modes, characteristic of bells and glasses