Acoustic Instruments

Strings, Woodwind, Brass, Piano and Percussion

Dr. Susan Burrows

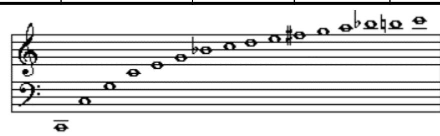
String Instruments

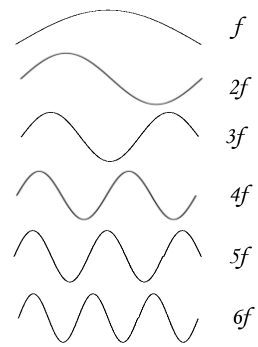
Tenor viol, banjo, guitar

mandolin

Harmonic Series

		frequency	ratio	interval
fundamental	fundamental	*f*		
1st overtone	2nd harmonic	*2f*	2	Octave
2nd overtone	3rd harmonic	*3f*	3/2	Perfect fifth
3rd overtone	4th harmonic	*4f*	4/3	Perfect fourth
4th overtone	5th harmonic	*5f*	5/4	Major third
5th overtone	6th harmonic	*6f*	6/5	Minor third
6th overtone	7th harmonic	*7f*	7/6	Subminor third
7th overtone	8th harmonic	*8f*	8/7	Supermajor second
8th overtone	9th harmonic	*9f*	9/8	Major tone
9th overtone	10th harmonic	*10f*	9/10	Minor tone





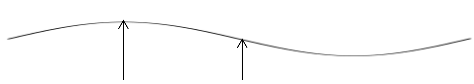
Vibrations in Strings

Tuning:

$$\text{Frequency of string} = \frac{0.5}{\text{length}}\sqrt{\frac{\text{tension on string}}{\text{line density}}}$$

Loudness:

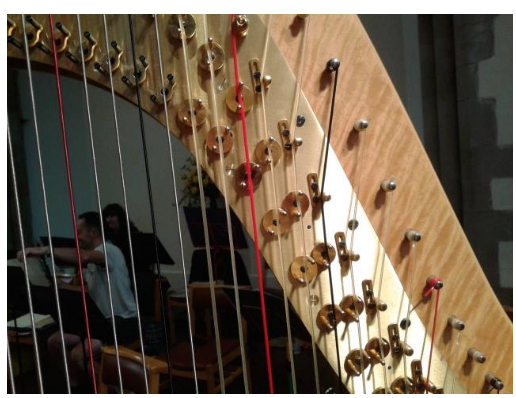
Kinetic energy = ½ mass x velocity^2



Gayageum, or Kayagum

Image from IB musical investigation website

Pedal Harp vs lever Harp



Pitch is determined by length of string:
Length changed either by set of pedals or individual levers

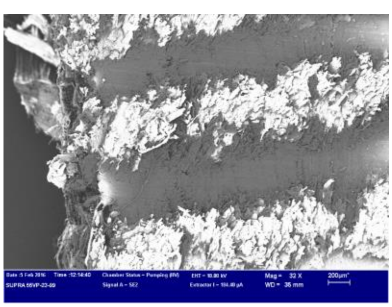
How does a violin work?

- Four strings, vibrated by bow, or plucking
- Bridge to transmit energy from string to violin body. Increasing the mass by adding a mute reduces efficiency of transmission
- Soundpost to connect front ‘plate’ to back ‘plate’. It also adds strength
- Bow works on a ‘stick-slip’ principle.

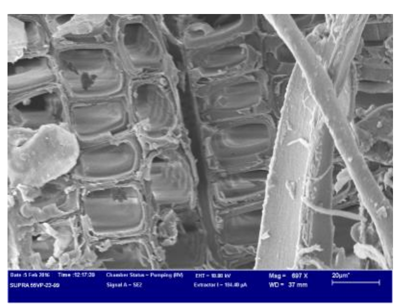
Jacob Stainer (copy) 1650s

Materials in Music - Wood

Wood has porous structure; resonance will vary across or down the grain

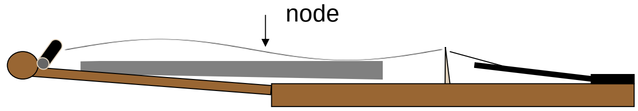


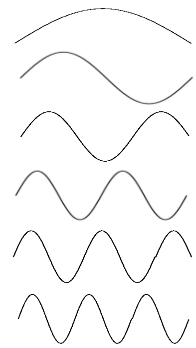
Spruce, mag x 32



Spruce, mag x 697

Harmonics on a violin

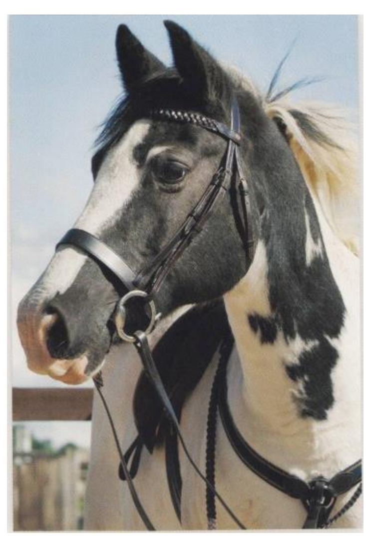




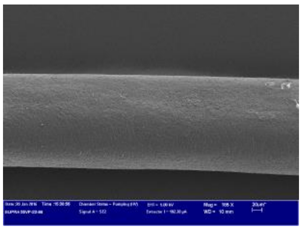
Harmonics can be natural (open string) or artificial (stopped string)

Harmonic modes

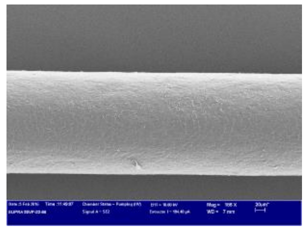
Zach and the Art of Bow hair Maintenance



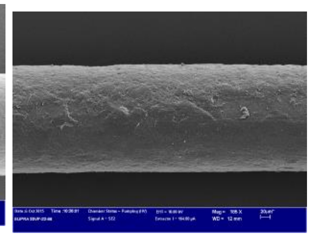
Bowhair – keratin, a fibrous protein with scale structure



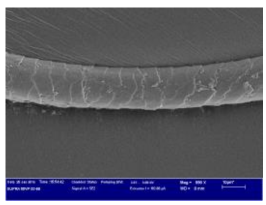
Zach, mag x 185



‘new’ bow hair, mag x 186

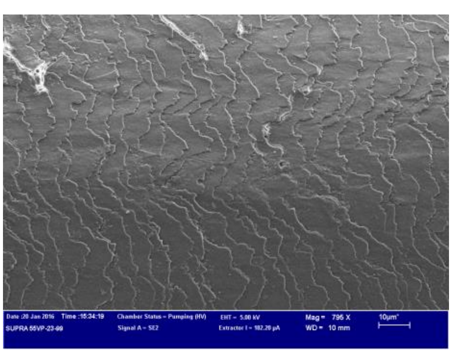


‘used’ bow hair, mag x 185

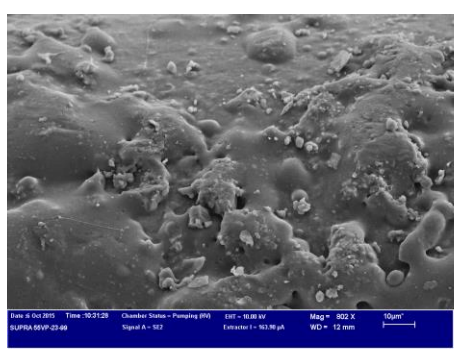


Wool, mag x 998

Bows and Rosin



Zach, mag x 795



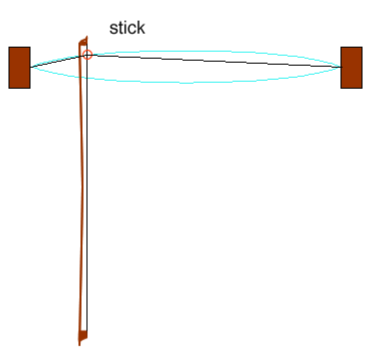
‘used’ bow hair, mag x 802

Bows and Rosin

Rosin: resin tapped from pine trees + secret mixture – increases friction on the bow hair to provide grip

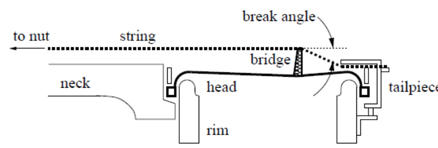
Stick-slip bowing

Friction from rosin causes string and bowhair to stick together.
Motion causes slippage – a stick – slip – stick – slip action



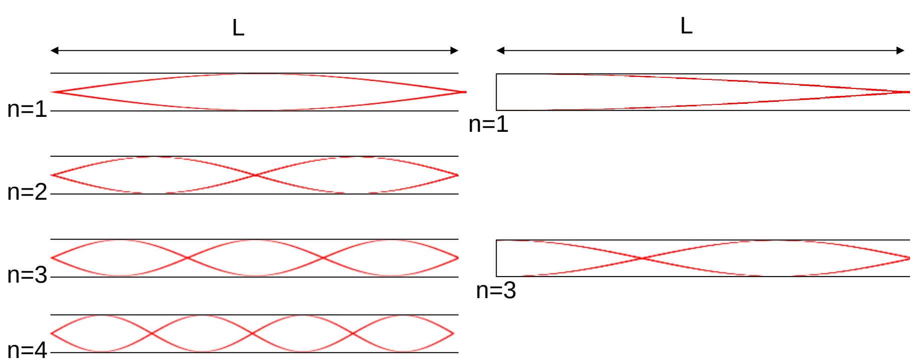
http://newt.phys.unsw.edu.au/jw/Bows.html

Bluegrass Banjo – a non-bowed instrument



Distinctive ‘twang’ is produced by vibration of both string and membrane.

Resonance in pipes



$L = n\lambda/2$, n = 1, 2, 3, 4, 5,….

$L = n\lambda/4$, n = 1, 3, 5, 7, 9,….

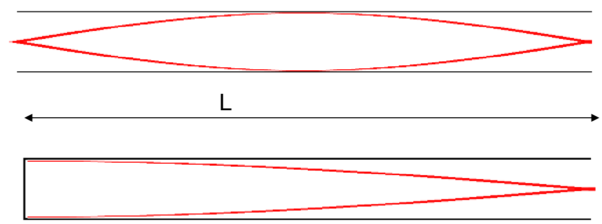
Harmonic series for open pipes

Harmonic series for closed pipes

Acoustic Impedance

$$\text{Acoustic impedance} = \left(\frac{\text{pressure x density}}{\text{area}}\right)$$

Open ended pipes



Closed pipes

Not ideal - end corrections are required.
The effective acoustic length = L + 1/6 radius of open end

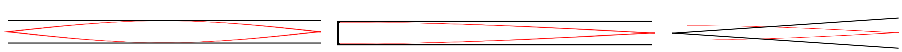
Flutes, Clarinets and Oboes:

Open pipe, Closed pipe, Closed cone

Flute

Clarinet

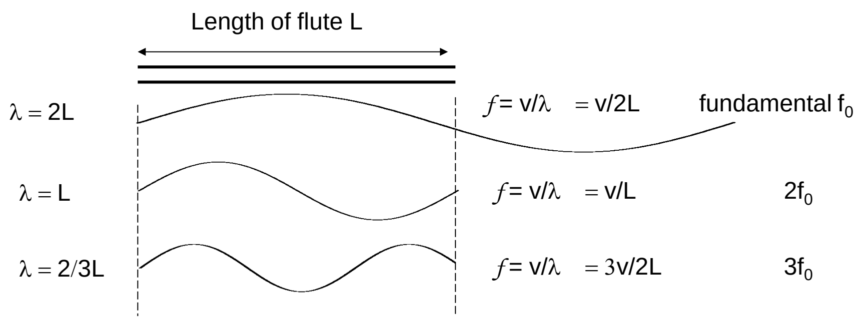
Oboe
Saxaphone
bassoon



For a cone, wavefront is spread out over an increasing area

For a flute and clarinet of the same length, the flute produces a wavelength twice as long as the 'pipe', and the clarinet produces a wavelength four times as long; the frequency produced by the flute is double that of the clarinet, and the lowest note it can play is one octave higher . The oboe has similar characteristics to the flute.

Pitch



v Speed of sound in air = ~350ms^{-1}

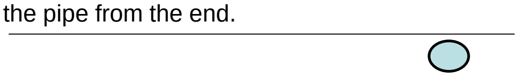
L Length of flute = ~ 0.66m

Therefore frequency of fundamental = 265Hz. Equivalent to C4

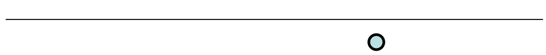
(clarinet =~0.60m D3 146Hz)

Holes in Pipes

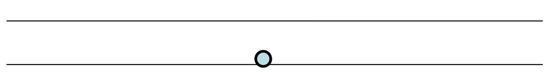
- Both size and position of hole will affect the pitch; a fingerhole will introduce a pressure node further up the pipe from the end.



A large hole will effectively shorten the length of the pipe (tone hole)

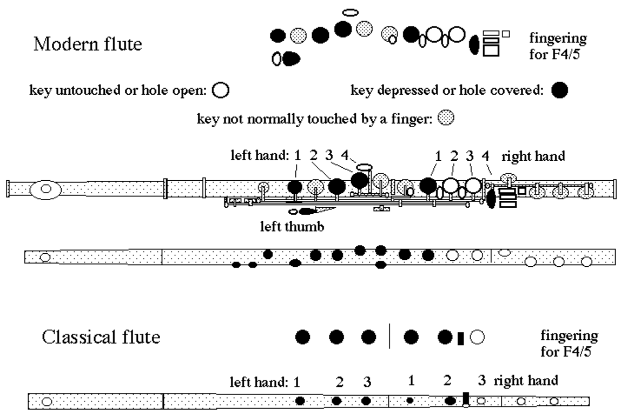


A small hole will also act to change the acoustic impedance; a pressure node will not always form under the hole.



A small hole at the halfway point will damp certain harmonic modes (register holes).

Tone holes and register holes



Acoustics of baroque, classical and modern flutes Joe Wolfe, John Smith, John Tann and Neville H. Fletcher

Reeds and the Bernoulli effect

"Bernoulli effect" is the lowering of fluid pressure in regions where the flow velocity is increased

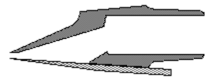
$$p + \frac{1}{2} \rho v^2 + \rho g h = \text{constant}$$

Where p = pressure
ρ = density
v = velocity
g = gravitational constant
h = elevation

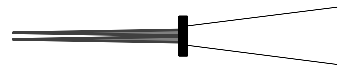
A reed will bend in response to air flow velocity
A soft reed (oboe, clarinet) will vibrate at a frequency of external pressure fluctuations
A hard reed (harmonica, organ pipes) has a vibration frequency determined by its stiffness and dimensions

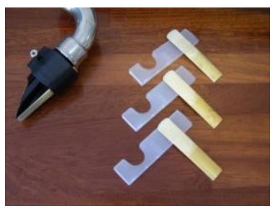
Reeds

Clarinet reed



Bassoon, oboes have double reeds





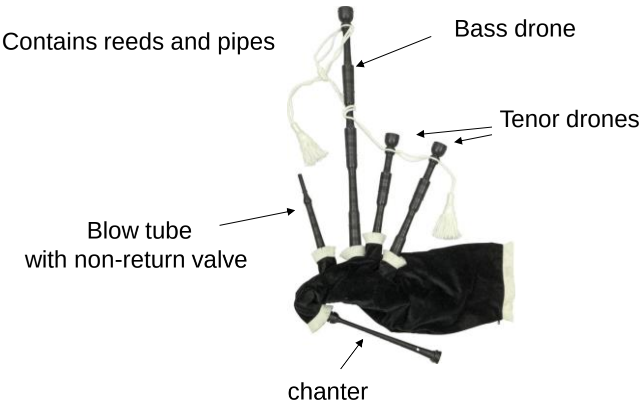
The reed controls the flow of air into the instrument. It has its own resonant frequency which can manifest itself as a squeak, especially if not damped.

Harmonica

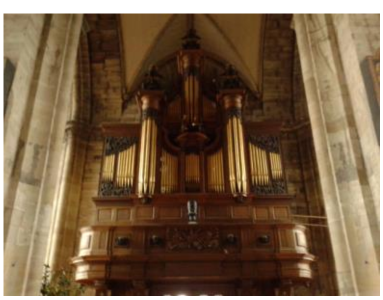
Contains a set of reeds of different lengths; each reed will produce a different note, with the sounds being determined by the case of the instrument, and the positioning of the reeds.
The ‘comb’ contains holes through which air is blown across the reeds.

Great Highland Bagpipe

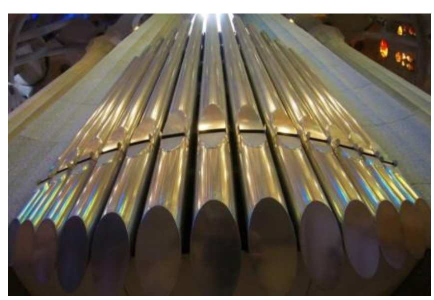
- Contains reeds and pipes



Church organ



St Mary's Church, Warwick

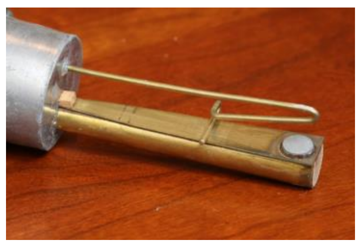


Sagrada Familia, Barcelona

Church organ

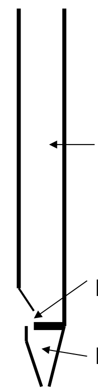
Flue pipes and Reed pipes:
Each pipe corresponds to a single pitch.
Largest cathedral flue pipe is typically 32’

Air is blown across the mouth of the pipe and sets up a standing wave



Reed pipe

Flue pipe



Organ – stops, ranks, manuals

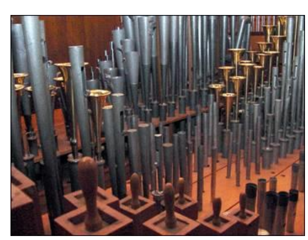
‘Stops’ control which pipes are available to produce a note

‘Ranks’ are rows of similar pipes

‘Keyboards’ (manuals and pedals) control flow of air to pipes

‘Swell’ pedal plays a set of pipes behind shutters

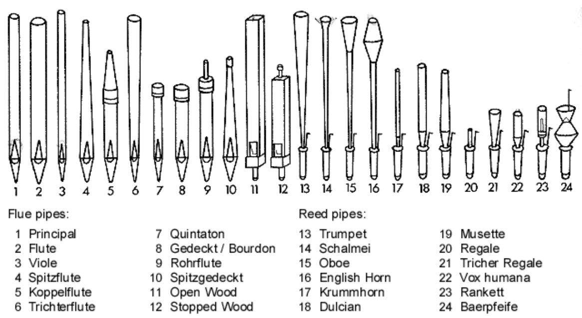
Different shapes of pipes give different timbre, e.g. ‘open diapason’ is a cylindrical pipe

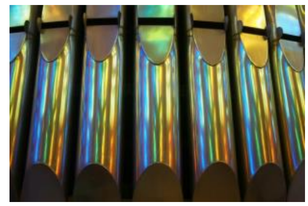


Top image from SalemOregon.com
Bottom image from www. die-orgelseite.de

Materials in Music

lead and tin chosen due to corrosion resistance

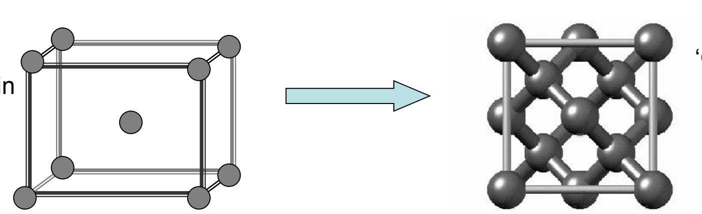




Tin Pest

$\beta - \alpha$ transition occurs at 13.2°C

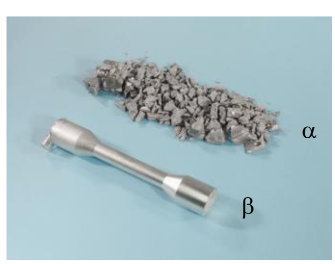
'white' tin
β form



'Grey' tin
α form

Density ρ = 7.365 g/cm^3

ρ = 5.769 g/cm^3



Brass

Bugles, cornets, euphoniums, horns, serpents, sousaphones, trumpets, trombones

Lips generate the note - mouthpiece enables control of vibration
Column of air in tube acts as resonator
The opening, or 'bell' radiates the sound

'Gabinetto Armonico' by Filippo Bonanni 1723

Brass

The range of notes a brass instrument can play is increased by inserting three 'crooks', or extra lengths of tube, which can each be opened with a valve. The first valve will drop the pitch by a semitone, the second by a whole tone and the third by a tone and a half. Any note on the diatonic scale can now be played.

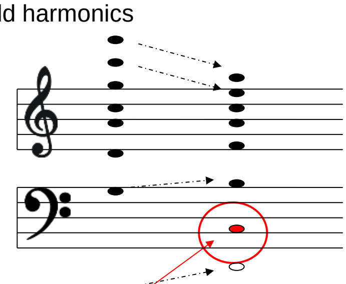
The Bell effect and the mouthpiece – acoustic impedance again……

Shorter wavelengths can travel further down the bell before being ‘reflected’

Harmonics of brass instruments –pedal tone

A closed tube produces only odd harmonics

The mouthpiece flattens the higher harmonics; the bell raises the lower harmonics. This effect gives a more harmonic series, but the fundamental is now usually out of tune, or unplayable



A pedal tone is found at the pitch of the fundamental of the harmonic series

Materials in Music - Brass

Yellow brass	70% copper, 30% zinc – harder material, brighter sound
Rose brass	85% copper, 15% zinc
Red brass	90% copper, 10% zinc

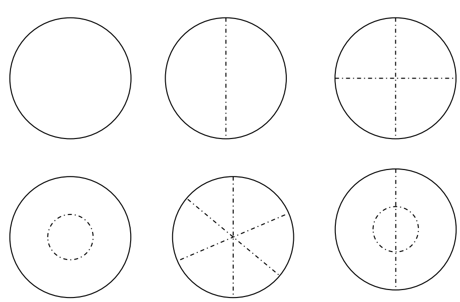
Things to consider for acoustic signature
a) gauge of material
b) Tempering/annealing

Annealing will soften the brass after ‘working’

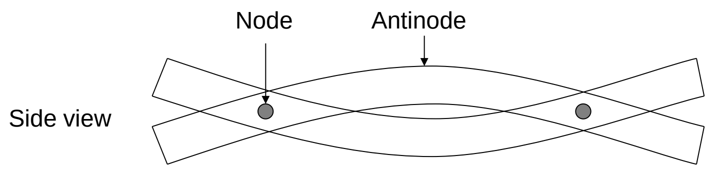
Resonance in membranes - percussion

Membranes contain both radial modes and azimuth modes of resonance due to their two-dimensional nature

timpani



Fixed body resonance – glockenspiel, xylophone



Energy is delivered by striking with a solid object (eg mallet). The length of time T that the head of a mallet is in contact with the body will influence the overtones produced, and frequencies f > 2/T will be damped. Soft mallets will deform more when struck and so will be in contact with the body for a longer time period : there will be fewer higher frequency overtones for a soft mallet than a hard mallet

Resonance in Bars

$$f_0 = 1.028\frac{h}{L^2}\sqrt{\frac{Y}{\rho}}$$

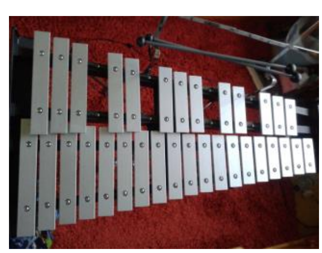
transverse

$$f_0 = \frac{1}{2L}\sqrt{\frac{Y}{\rho}}$$

longitudinal

$$f_0 = \frac{1}{2L}\sqrt{\frac{G}{\rho A}}$$

torsional



The fundamental frequency f_0 is determined according to the length L and thickness h of the bar, and also its material properties (Young's modulus Y, shear modulus G, proportionality factor A, and density ρ)

Modes of a glockenspiel

Three modes of vibration: transverse - dispersive
longitudinal - non-dispersive
torsional - non-dispersive

Dispersion – waves of different wavelength travel at different speeds

$$f_n = 0.113\,\frac{h}{L^2}\sqrt{\frac{Y}{\rho}}\,(2n+1)^2$$ Bar, h = thickness

$$f_n = 0.196\,\frac{a}{L^2}\sqrt{\frac{Y}{\rho}}\,(2n+1)^2$$ Rod, a = radius

$$f_n = 0.196\,\frac{\sqrt{a^2+b^2}}{L^2}\sqrt{\frac{Y}{\rho}}\,(2n+1)^2$$ Tube, a = outer radius, b = inner radius

Transverse modes	1	2	3	4	5
Frequency	1.00	2.76	5.40	8.93	13.34

Inharmonic!!!!

Resonance

"sound produced by a body vibrating in sympathy with a neighbouring source of sound"

Marimba and xylophone – bars are undercut to produce a harmonic sound; pipes of the correct resonant frequency are added underneath to enhance fundamental

Piano Action!

A percussion instrument which uses strings……..

Development of the piano from a plucked to a struck instrument

Clavichord - touch action
Virginal - plucked strings
Spinet - plucked strings
Harpsichord - plucked strings
Pianoforte - hammer action

Piano Construction

Straight-strung upright, 1917
Brinsmead

Cross-strung grand, 1907
Steinway

http://www.piano.christophersmit.com/popUpMotion.html

Forces on a piano

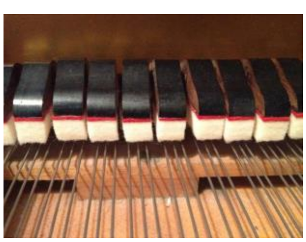
Tension = line density x $\left(\frac{\text{frequency x length}}{0.5}\right)^2$

Line density = mass of 1m length of wire

(= 0.0059 kg/m for 1mm diameter steel piano wire)

Each string is subject to a force equal to ~ 700 – 1000N

Timbre



Two or three pedals to control volume:

- Soft pedal (moves bar with hammers closer to the strings felt bar, or shifts action)
- Practice pedal (felt bar between)
- Sustain pedal (lifts dampers from strings).

Lower notes are louder so fewer strings needed

Kinetic energy = ½ mass x velocity^2

Re-cap

Waves in strings:

$$\text{Frequency of string} = \frac{0.5}{\text{length}}\sqrt{\frac{\text{tension on string}}{\text{line density}}}$$

Harmonic series for open pipes: $L = n\lambda/2$, n = 1, 2, 3, 4, 5,….

Harmonic series for closed pipes: $L = n\lambda/4$, n = 1, 3, 5, 7, 9,….

Frequency = velocity / wavelength $f = v/\lambda$