Sound Physics: The Piano

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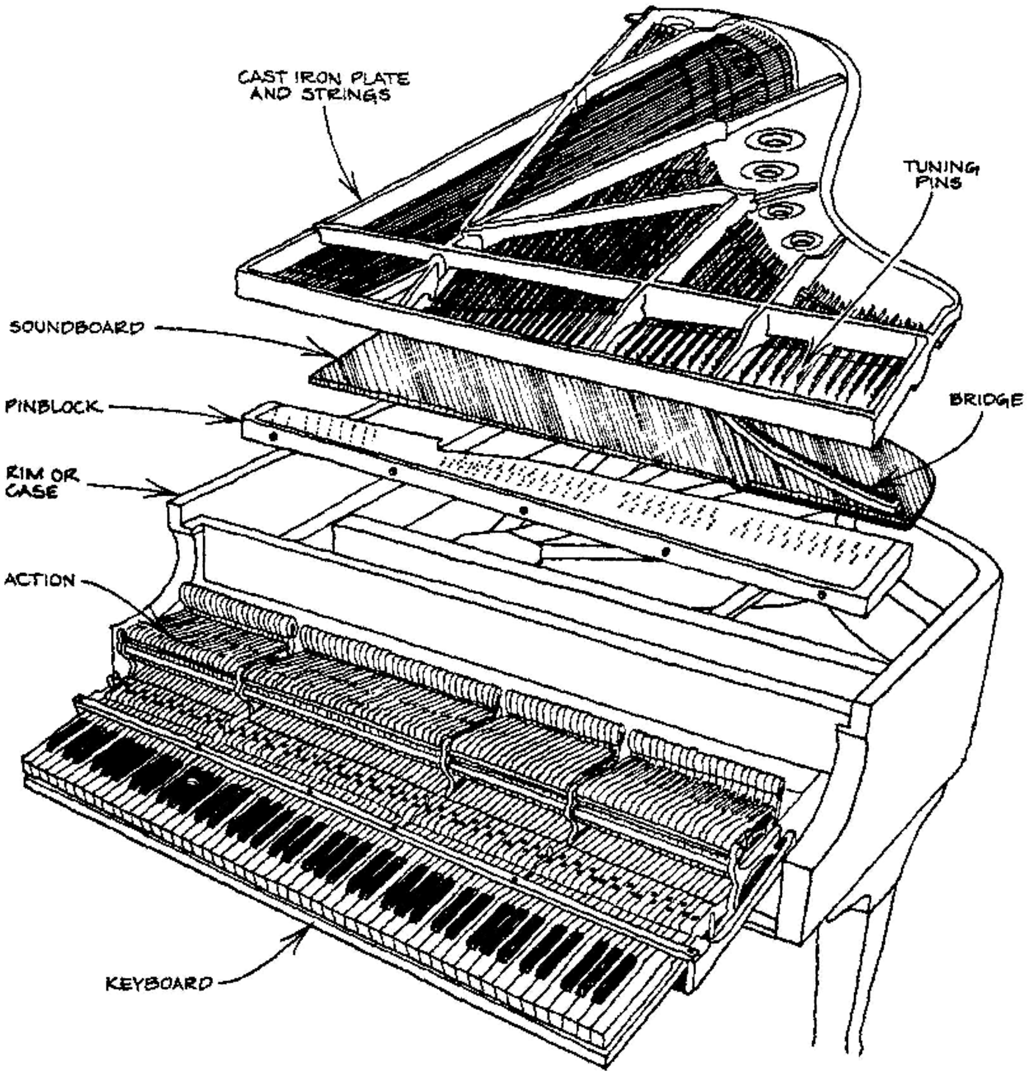
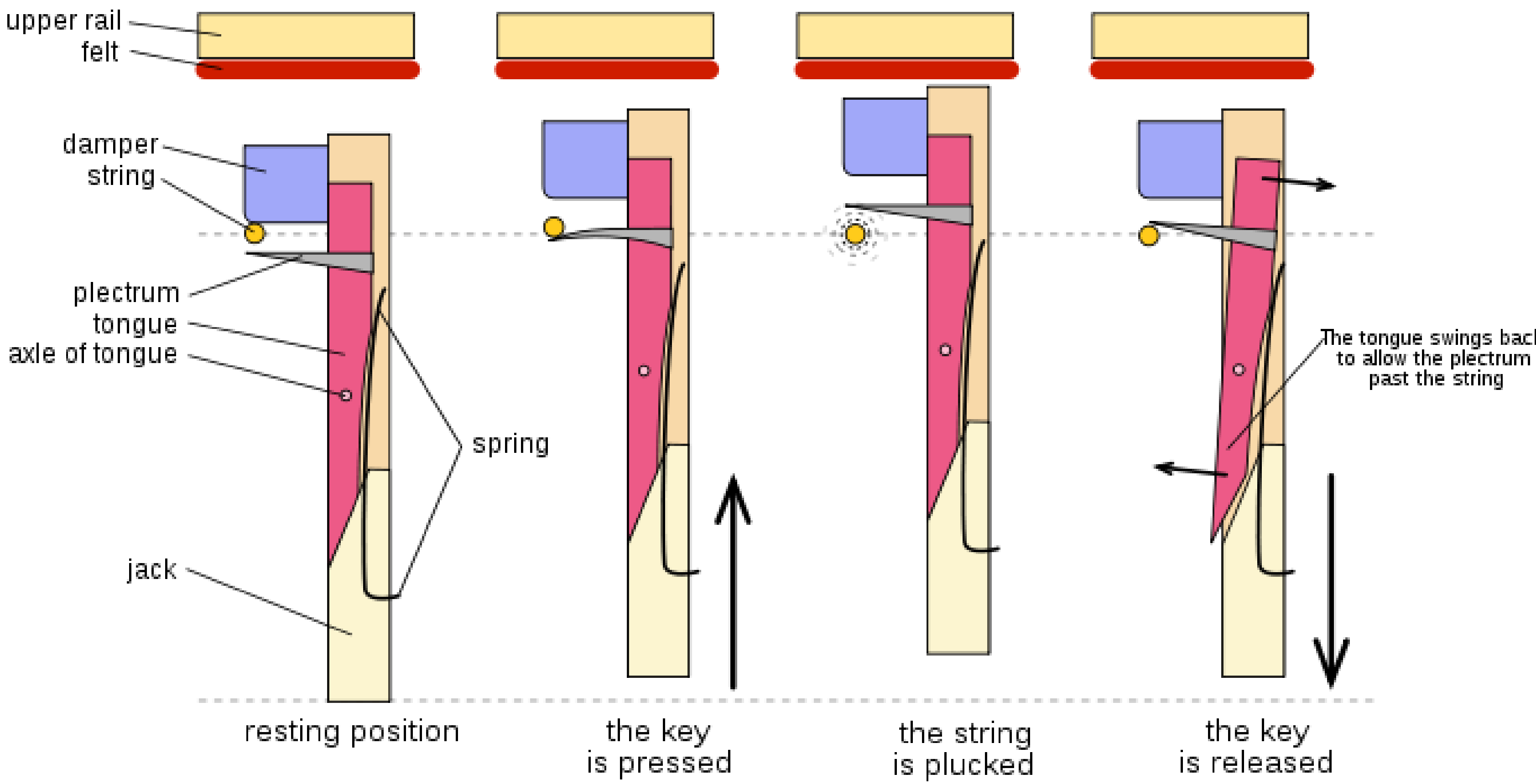

CAST IRON PLATE AND STRINGS
TUNING PINS
SOUNDBOARD
PINBLOCK
BRIDGE
RIM OR CASE
ACTION
KEYBOARD

Brief History

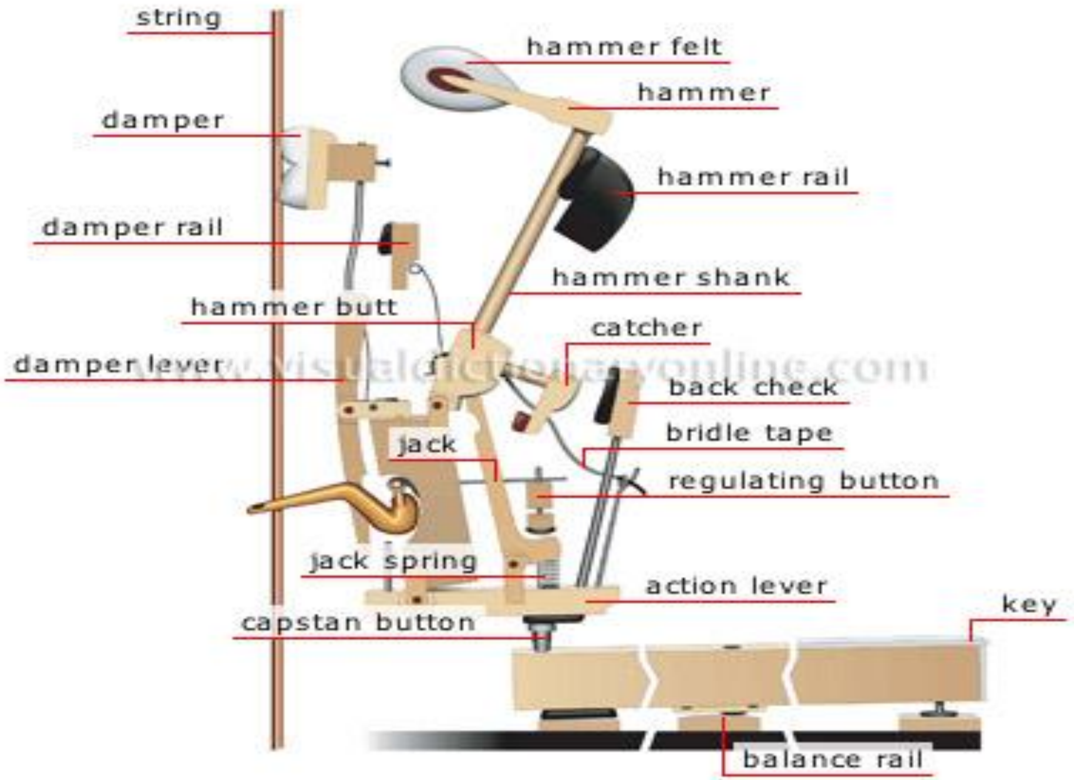
- In the1700s, Bartolomeo Cristofori di Francesco came up with the original concept of striking the strings with a hammer, which produced a much more pronounced and sustained sound.
- Shortly after Cristofori's new concept, the piano "action" was developed, which not only kept the strings damped when not being played, but also kept the hammers from remaining on the strings after striking them.

Harpsichord Action



Piano Action

- Struck vs. Plucked



Frequency Spectra

- *Piano to Forte*– When the pianist makes volume changes the tone becomes louder or softer and brighter in color.
- *Frequency Vibrations and Decay*
- *Modes and Nodes encountered*
- The piano's 88 keys range in frequency from A0 at 27.5 Hz to C8 at 4186 Hz.

Unique Oscillations

- Polarization
- Coupled Oscillations

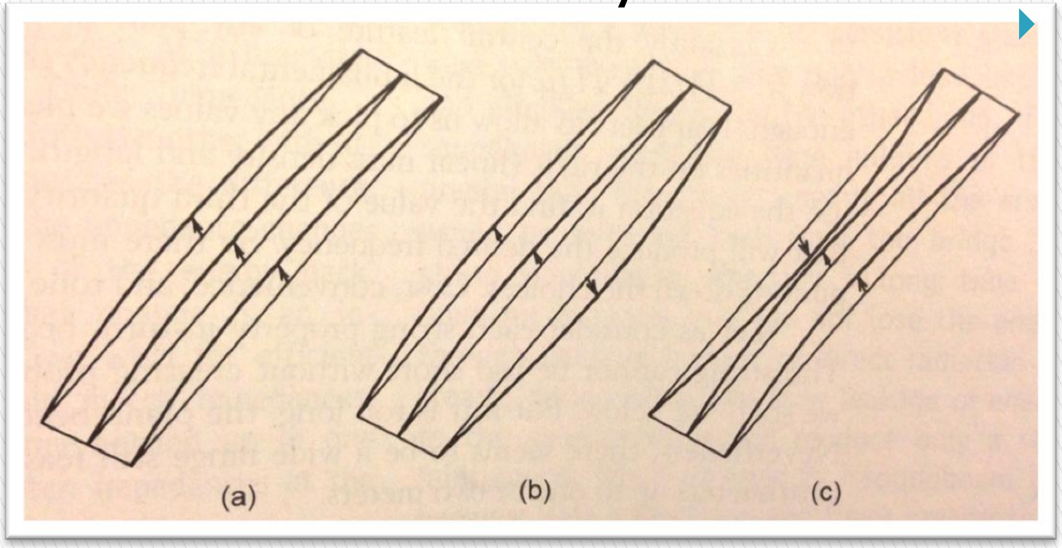
Piano Strings

- Three strings are coupled on the same bridge
- Higher notes only
- Higher strings made of steel
- Lower strings made of steel with copper wrapped around them

Fundamental Modes of Triple Strings

Symmetrical (a)

- All strings move in the same direction
- Moves bridge efficiently, resulting in a shorter decay time



Unsymmetrical (b) (c)

- Two strings pull up just as hard as the third string pulls down creating a zero net force
- Results from a slightly lopsided hammer hitting two only two strings
  - *Una corda* pedal

Piano Scaling

- The way in which string lengths and diameters change from note to note and from octave to octave
- Fundamental frequency of a string
  - $f_1 = (1 / 2L) \sqrt{(T / \mu)}$
- These factors only get the desired frequency, but cost, convenience, and tone quality must also be considered

String Properties

- Length
  - Too short = problems with tone quality
  - Too long = bulky and expensive piano
  - Wide range from a few centimeters to one or two meters

- Tension
  - Cannot exceed the breaking strength of the wire
  - $T < (\pi/4)(d^2)H$
  - Steel has $H \cong 1.5 \times 10^9$ N/m2
  - Smaller tension decreases ability of the string to feed energy to the soundboard
  - Difference in impedances
    - Measure of how much force should be applied to a wave to produce a given amount of motion
    - For the piano, a soundboard impedance only a few thousand times greater than the string impedance is desired

- Diameter
  - Too small = weak sound
  - Too large = not fully flexible
  - Stiffness
    - Higher modes are affected and destroyed by stiffness
    - Causes *inharmonicity*
      - Modest stiffness = enough harmonic for tone to be pleasing and musical
      - Excessive siffness = string behaves like a rod; metallic sound
- Compromise
  - Higher frequencies: decrease string length and diameter to avoid stiffness
  - Lower frequencies: making strings heavier rather than longer
  - Triple stringing the treble to deliver adequate energy to the soundboard

Tuning

- In the middle range, a tuner sets the octaves at 2:1 frequency ratios
- Top octave strings (more stiff) are stretched slightly (C7–C8) to ratios of 2.025:1
- Similar effect for lowest bass notes

Reasons for Stretching Octaves

- Physical
  - Higher note matched precisely with the second mode of the lower note so no beats are produced
  - Higher strings are more stiff, resulting in lower note frequency to be slightly more than twice its fundamental
  - Dependent on piano
    - Large grand piano: little stretching; inharmonicity of bass strings is hardly any greater than the midrange
    - Small spinet: much more stretching; relatively short, stuff bass strings are quite inharmonic
- Psycological
  - Difficult pitch perception in extreme ranges
  - Similar stretched octaves on any piano

Song Elements

- In the key of C
- Hand Mute Technique creates different wave
- Use of all Pedals
- Fluctuating frequencies
- Key changes to show difference in contour, brightness, tone and emotion.