String theory

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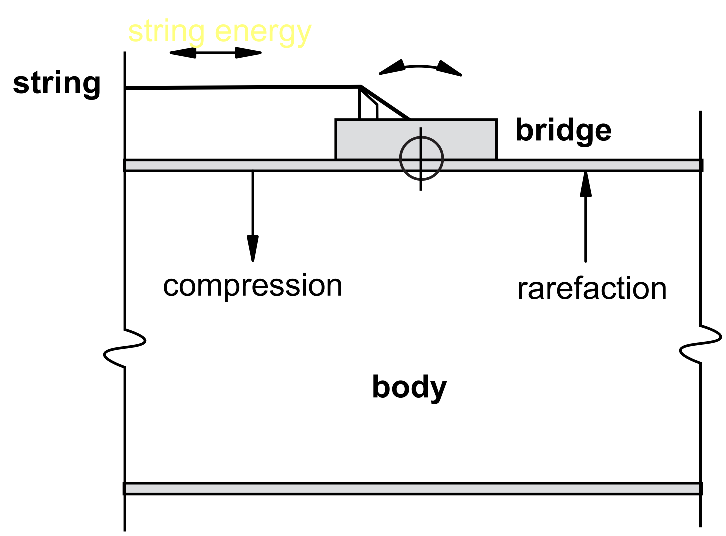
String Theory in this discussion deals with the principles and characteristics of strings as opposed to playing them. It's not about attempts to reconcile quantum mechanics.

How Strings Generate Sound

People who play ukuleles have an intuitive idea of how strings produce sounds and can figure out how to change those sounds in subtle and not so subtle ways. The question is: how does the energy of a plucked string actually create sound in a ukulele.

A ukulele is a fixed bridge instrument in contrast to a movable bridge instrument like a violin. The two translate string energy into sound, but do it in slightly different ways. Here, we will focus on the ukulele and how it works. It all begins with setting a series of actions and reactions in motion by plucking or a string.

When a string is energized, it causes the bridge to torque back and forth on an axis where it connects to the sound board. This in turn causes the sound board to move up and down, alternating from the area in front of the bridge to that in back of the bridge. This, in effect, makes the sound board into an air pump that constantly changes the air pressure inside the body with each cycle (this is called compression and rarefaction). The cycling of the air pressure in the body produces sound waves relative to the pitch of the string, And you hear a musical note.



The energy from the string causes the bridge to rock and alternately cause compression and rarefaction in front of and behind the bridge

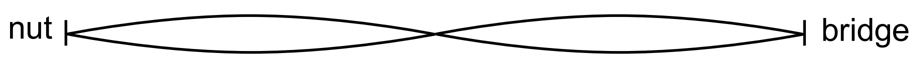
However there is much more going on than that. The strings vibrate in specific patterns and have special characteristics that, if you understand them, can make you a better player.

How Strings Vibrate

The frequency at which a string vibrates, and the resulting air pulses in a ukulele are defined by "Hertz". One hertz (or Hz) = 1 pulse. When a string vibrates as a whole it is called a fundamental, and a string vibrating at 440Hz is the fundamental for an A4 note.

Pattern of a string vibrating as 1st fundamental

The string can also be made to vibrate in two equal segments, producing vibrations twice as fast as the fundamental (A5 or 880 Hz). This is done by briefly touching the string at the 12th fret as it is being plucked. This is the 2nd Fundamental.



Pattern of a string vibrating as 2nd fundamental

It can also be forced to vibrate three equal segments by touching the string near the 7th fret as it is being plucked (the 7th fret is near 1/3 the length of the string).

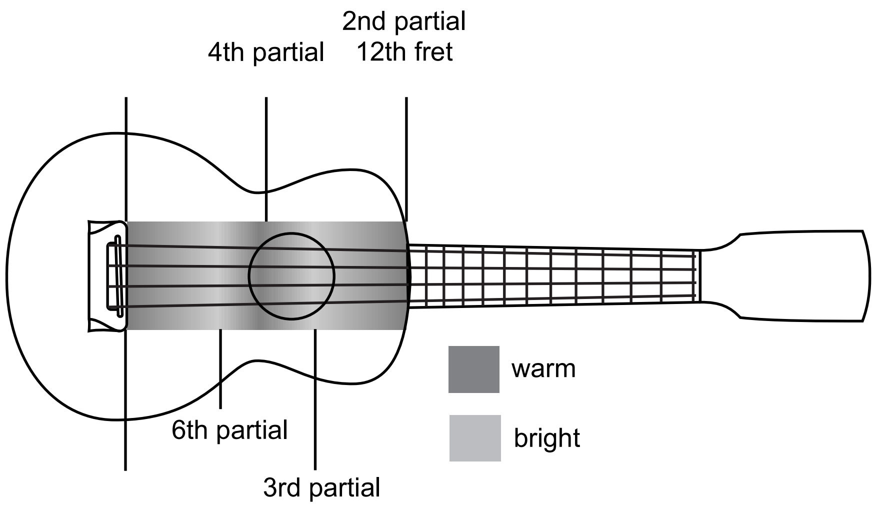
Pattern of a string vibrating as 3rd fundamental

It can also be forced to vibrate four equal segments by touching the string near the fifth fret as it is being plucked (the 5th fret is near 1/4 the length of the string).

Pattern of a string vibrating as 4th fundamental

(Notice too, how the amplitude of the string diminishes as the number of partials multiply).

Additionally, it can vibrate in 4ths, 6ths, 8ths, and so on. A single partial will also contain as many as 16 - 18 discreet audible partials that define the strings timbre, or color. They are called the harmonic series. Even number partials are warmer than odd number partials, so if you pluck a string at the 2nd or 4th partial, it will sound warmer than if you pluck it at the 3rd or 6th partial.

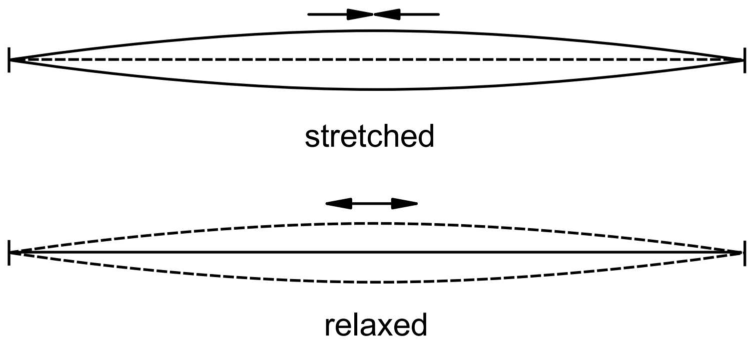


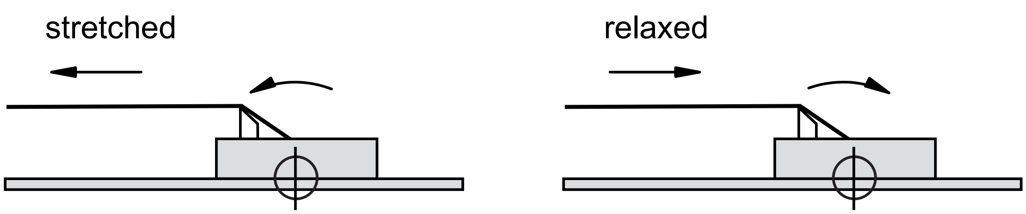
Partials become less audible as their number goes up. So playing at the 3rd partial will bring out more bright tones than playing at the 6th, and playing at the 2nd partial will bring out more warm tones than at the 4th.

Unlike ukuleles, piano strings vary in length from low (long) to high (short). The hammers are positioned to strike each string at 1/7 its length where the partials are balanced, and they all have the same timbre. On 3 pickup electric guitars, the pickups are positioned to take advantage of the partials, and are sometimes placed at an angle to balance the timbre of each string.

Lateral vs. longitudinal vibrations

When a string is plucked it begins vibrating side to side, then around its axis to up and down, then around to side by side again. But a string also moves longitudinally, stretching and relaxing with each cycle. The elasticity of the strings, when energized, is what powers the bridge on a fixed bridge instrument.





The lateral force has much less power than the longitudinal force, but it is what powers the longitudinal force. It does this through a mechanical advantage where the lateral movement of the string is greater than the longitudinal movement. Strings that stretch less than others have more stored energy when tuned to pitch and will produce more volume and sustain. For example: on a ukulele, fluorocarbon strings stretch less than nylon and are somewhat louder and brighter.

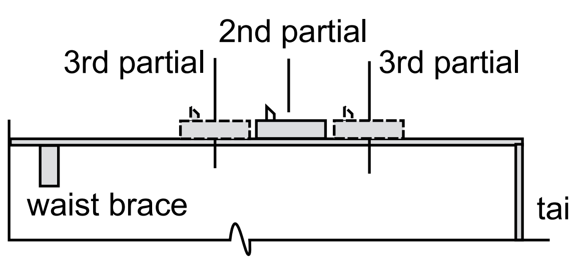
Wood

Some of the power from a plucked string is wasted if the sound board is not of the optimum thickness, and properly braced. If the top and bracing are too thick, they will restrict movement of the bridge, and reduce the volume. A top and bracing that is too light will be less elastic and physically distort more than it should, sometimes causing permanent damage to an instrument. A sound board with optimum thickness and proper bracing will load the top in a state of equilibrium and produce the ideal amount of volume and tone. It will also translate more harmonic partials into sound than an over braced or under braced board.

Wood choice is another factor that will effect the usage of string energy to create sound. Spruce is the most common wood choice for stringed instrument tops because of its high strength to weight ratio. It will absorb less string energy and vibrate more freely than other woods. By contrast, a dense wood like maple will absorb more energy and not translate all the subtle harmonic partials. The result is a muted sound with less character.

Bridge Location

The location of the bridge between the tail and waist brace will effect the tone of an instrument much in the same way odd and even partials effect the tone of the string. If the bridge is placed close to the tail or the waist brace, it will be brighter with less volume (third partial). If it is placed an equal distance between the brace and the tail it will be warmer with more volume (2nd partial).



Bridge position in relation to sound board partials

Intonation, Compensation and Equal Temperament

Intonation is the pitch accuracy of a musical instrument, and it is measured by finding the convergence of the 2nd partial wave form.

With perfect intonation, if we tune a string to pitch at A, 4th octave (440 Hz), we should then be able to play A, 5th octave (880Hz) at the 12th fret in perfect pitch.

In reality, we can't do this because when we press down on the string we create more tension in it and it plays sharp. If the string is made slightly longer, then it will play on pitch when pressed down at the 12th fret and is said to be compensated.

Strings of varying diameter and mass must be compensated individually. Those with greater diameter or mass require more compensation than those with less

Equal temperaments are scales in which the octave is divided into scale steps of equal size. A ukulele has a 12 tone equal temperament scale.

Most all fretted instruments use fixed fret spacing based on a mathematical formula to determine equal temperament. This formula doesn't take into consideration individual characteristics of strings, and it's common for a string to play sharp or flat by a few cents on a given fret because the "one size fits all" temperament formula.

Straight frets can be spaced for only one string to play on pitch on a 12 tet finger board. Ukuleles will play sharp or flat as much as 5 or 6 cents for a given note with straight frets. This guitar is adjusted for every string and has perfect temperament.