1.5 Physical Science: Harmonics Everywhere

Physical science is about as rock-solid of a theory of the world as anything. This is a good place to start. Catherine Schmidt-Jones [Schmidt-waves]:

For the purposes of understanding music theory, however, the important thing about standing waves in winds is this: the harmonic series they produce is essentially the same as the harmonic series on a string. In other words, the second harmonic is still half the length of the fundamental, the third harmonic is one third the length, and so on.

We can either compute or observe (using, say, high-speed cameras) the properties of the stable vibrations that occur when a string or or a column of air is excited:

1. There is one frequency (the "fundamental") at which the string or air will vibrate;
2. there are also other vibrations (the "harmonics" or "overtones") having higher frequencies that are multiples of 2, 3, 4, 5, 6, 7 etc. times the fundamental at which the string or air will also vibrate.

These harmonics can be demonstrated by two people hold a long jump-rope: (1) If they swing the rope slowly, the whole rope makes a single wave. (2) However if they go twice as fast and out of phase (one goes up while the other goes down) then half of the rope will be up and the other half down and the positions of up and down will switch twice as fast; further the very middle of the rope will not move at all (a "node"). (3) A similar effect happens with three waves if they go even faster. For a picture, see [Schmidt-waves, Figure 2]. When a string is plucked, *all of these waves are happening at the same time*. That is, plucking generates all waves, but only those the frequency of which divides the length of the string will bounce back and forth and re-enforce each other and persist; other frequencies will die out. From [Schmidt-waves]:

In order to get the necessary constant reinforcement, the container has to be the perfect size (length) for a certain wavelength, so that waves bouncing back or being produced at each end reinforce each other, instead of interfering with each other and cancelling each other out. And it really helps to keep the container very narrow, so that you don't have to worry about waves bouncing off the sides and complicating things. So you have a bunch of regularly-spaced waves that are trapped, bouncing back and forth in a container that fits their wavelength perfectly. If you could watch these waves, it would not even look as if they are traveling back and forth. Instead, waves would seem to be appearing and disappearing regularly at exactly the same spots, so these trapped waves are called standing waves.

We will call each single sine-wave at a single frequency a "tone", whereas the collection of frequencies that occur together due to a single physical process (such as a vocal utterance or the striking of a piano key) we will call a "note". (A tone can be expressed simply as (1) a wave "frequency" in Hertz (Hz), the number of cycles per second, (2) a wave "amplitude", the wave peak height, and (3) a wave "phase", where the wave is in its cycle compared to other waves; we won't discuss amplitude and phase much.)

This sequence of tones forming a note is called the "Harmonic Series" [har] or "Overtone Series" of the fundamental. Herein we speak of "the (ideal) Harmonic Series" when we mean an abstract computational ideal and speak of "an overtone series" when we mean what is actually produced in reality by a particular actual instrument (which may be quite different from the ideal); note that others quoted here may not follow this same convention. (Further, throughout

Comment [1]: This is something we learned in physics with those tuning rods.

Comment [2]: In solfege, this is the Mi to the Do.

Comment [3]: Higher frequencies usually sound higher in pitch as well.

Comment [4]: Which allows the ringing sound?

Comment [5]: This is how sound is interpreted in our brain as well as the sound waves bounce back from our ear drums.

Comment [6]: I saw this on Audacity when it came to controlling the volume. I did not know that Hz and volume were related.

we pluralize "series" as "series-es" because in a technical discussion it is very important to avoid the ambiguity between a single series of multiple tones and multiple series-es of multiple tones.)

There are two conventions for numbering overtones/harmonics; we use the convention where the fundamental or "Root" tone is called "harmonic 1", the tone vibrating twice as fast is called "harmonic 2", the tone vibrating three times as fast is called "harmonic 3", etc.

Comment [7]: So this is how a chord is made.