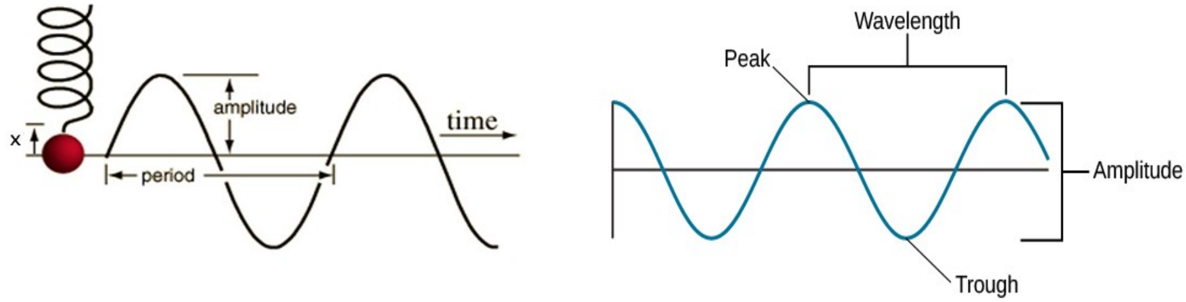
Prelab: Wave Spectra

Everyday thing: A rainbow, a symphony.

It is physics (and mathematics): Every wave is made up of "elementary waves" of different wave lengths.

Reminder: Elementary Waves



Last lab, we studied what we now call an "elementary wave": it is pattern that

- repeats in time with a certain **period** T, or, equivalently, with a **frequency** $f = 1/T$,
- and also repeats in **space** with a certain **wavelength** λ ("lambda").

The wave propagates (=moves forward) with a certain **speed of propagation** c. Frequency, wavelength and speed of propagation are related then through:

$$c = f\lambda$$

Audio spectra

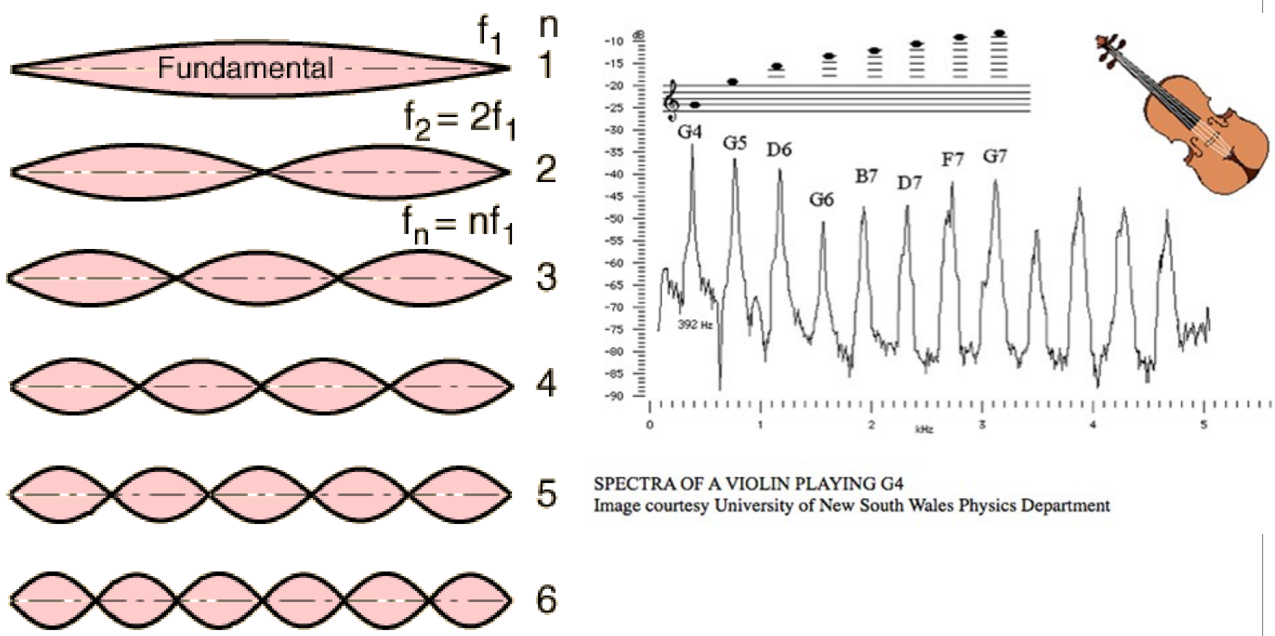
Every wave is made up of elementary waves of different wave lengths.

Let's first consider **sound** as an example: the elementary wave of sound is a so-called sine wave. The frequency of that wave is the **pitch** of the tone, and in a way a sine wave is the "purest" form of that pitch.

--> Generate a couple of sine waves here (play around with the frequency):
http://www.szynalski.com/tone-generator/

Every sound that you can hear is a multitude of these waves hitting your ear at the same time. For instance, if you play two different notes on an instrument at the same time, the sound that you hear is made up of the wavelengths for the first tone plus the wavelengths of the second tone.

So why do different instruments (say, a flute and a violin) sound different even when they play the same note? The answer to this lies in the **standing waves** you were studying last lab: remember that if we constrain our medium at one or both ends (by, say, mounting a string on both ends), we basically allow only certain wave lengths to be present (see plot next page). For a string, the wave must be zero at both ends, so we only allow 1/2 wave length, 1 wavelength, 3/2 wavelengths, and so on.



Left: Standing waves on a string: fundamental (1) and overtones (2,3,...). Right: Intensity of different waves (spectrum) of a violin playing a G: the fundamental is G, 1st overtone is a G, one octave higher, the 2nd overtone is D one octave and perfect fifth higher, etc.

The dominant one of those is usually the one with the lowest frequency, called the **fundamental**. However, we don't just excite that frequency, we excite that frequency plus the other allowed frequencies, called **overtones**. Different instrument excite these overtones in different strengths and thus sound differently.

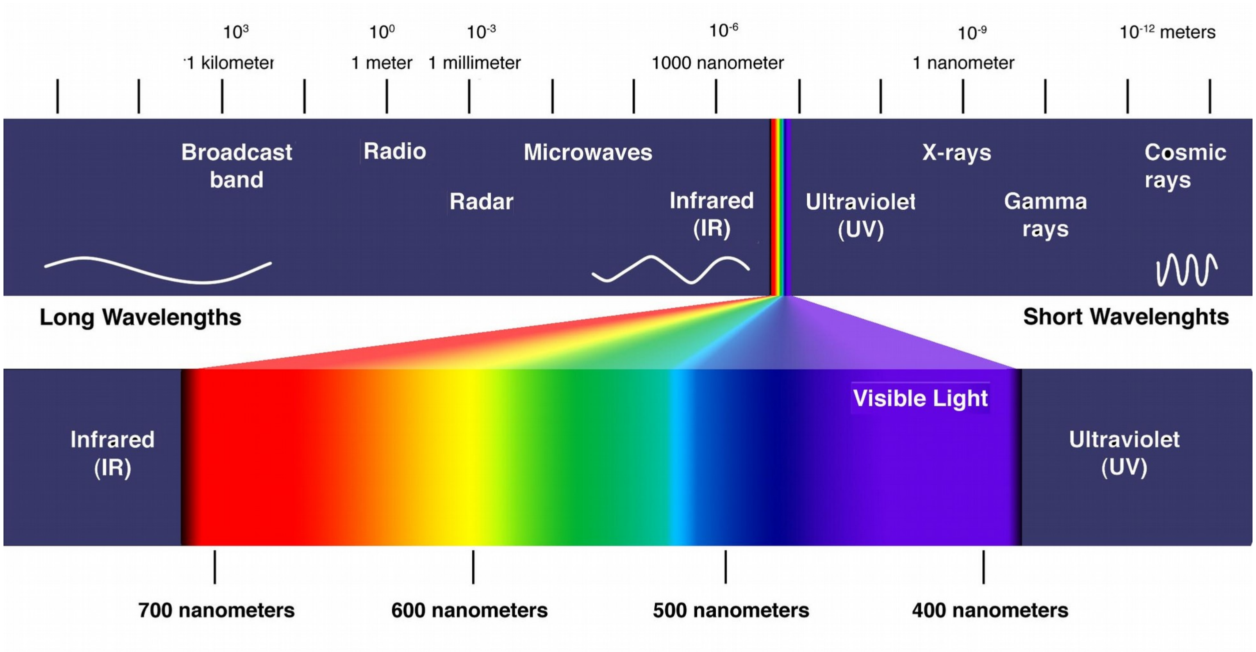
There is a nice way to visualize the strengths of tones of different frequencies in a sound, called a **spectrum**: it is a graph with the frequency on the *x*-axis, and the amplitude of the elementary wave of that frequency on the *y*-axis. If one frequency is strong, one usually sees a spike at that frequency. For a violin, we see that spectrum on the top: the first spike is at 400 Hz, which is the fundamental. But the violin also has a rich set of overtones, which are the spikes at 800 Hz, 1200 Hz, 1600 Hz and so on. This is what you hear and what makes the violin sound.

--> Watch: https://www.youtube.com/watch?v=VRAXK4QKJ1Q

--> Download the "FFT spectrum analyzer" (Android) or "Audio Spectrum Analyzer" (iPhone) app. Open and play with it.

Light spectra

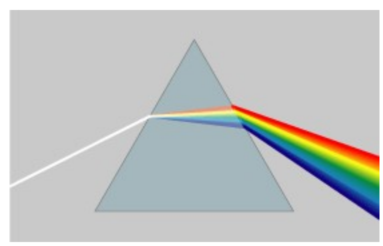
The same as with sound is going on with **light**: light is a wave, and the elementary wave of light is called **monochromatic light**. The frequency of that light we perceive as **color**.



So sound is to pitch as light is to **color**! The wavelength of visible light is very short: the wave length of red light is abut 700 nm (0.0000007 meters) and the wave length of violet light is about 350 nm.

The same thing as for sound also applies to light: we can mix light of different colors to get a new color. In the same way, any light can be decomposed in its colors.

Dispersion



Let us remind ourselves how the **speed of propagation** c is related to frequency f and wavelength lambda: $c = f\lambda$. Now it turns out that for many kinds of waves, waves of different wave lengths move at **different** speeds.

- Sound waves of higher frequencies (higher pitch) usually move faster than sound waves of lower frequencies
- Light light of higher wavelength (more red) usually move "faster" than light waves of lower wavelengths (more blue).

To which extent this is true depends on the medium in which the waves move.

We can make use of this fact to separate waves into their frequencies: for light, one can use a prism. Raindrops naturally act as such a prims to produce a rainbow. For sound, one can use a slinky (see lab).

--> Play around with this sim:

https://phet.colorado.edu/sims/html/bending-light/latest/bending-light_en.html