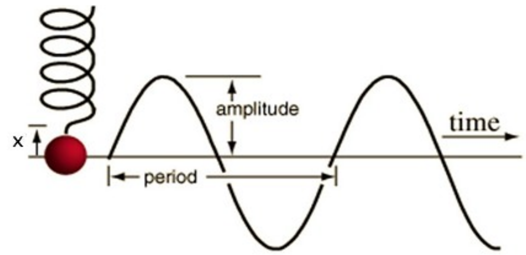
Prelab: Waves

Everyday thing: A wine glass making a particular note when you hit it, musical instruments play different notes depending on how you change the geometry of the string or pipe you blow into.

It is physics: Wherever there are waves, there is resonance and standing waves. The physics of waves are fundamental to all periodic motion.

Reminder: periodic motion



An object is in a periodic motion if the potion repeats after a certain time, called the **period** *T* (its SI unit is obviously the unit of time, s). The maximum displacement from the resting position of that object is called the **amplitude** A (it's unit depends on what it is that is moving, it might be current or voltage or distance). Here is how such a motion looks over time:

The **frequency** *f* is given as the number of oscillations per time:

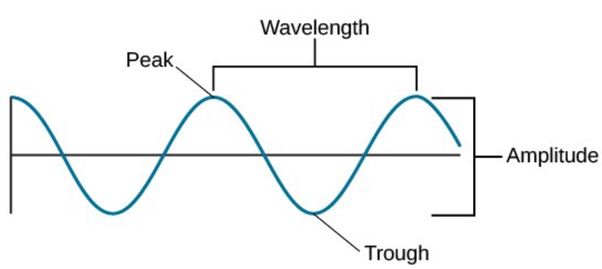
$$\text{frequency} = \frac{1}{\text{period}}$$

$$f = \frac{1}{T}$$

Its SI unit is the **Hertz** (**Hz**) which is the same as 1/s. So if something repeats twice a second, its period is 0.5 second and its frequency is 2 Hz.

Waves

Think of a quiet lake in which you drop a stone: the water molecules on the surface perform a periodic motion (up and down), but they also have a direction (outward from the point where you dropped the stone). We say the water waves propagate (move) at a certain **speed of propagation** *c*. For sound waves in air, we call that speed the **speed of sound**, for light waves we call it the **speed of light**, and so on.



We also see that not only do the waves go up and down as time goes by, we see them forming throughs and peaks at any given point in time. This looks something like the picture on the right. Notice that is similar to the picture above: however, the above picture shows the motion of a single point in **time**, whereas the picture on the right shows a snapshot of the wave when we look at it sideways (in **space**).

The distance between two peaks of a wave is called the **wavelength** λ ("lambda"). It's unit is a distance, and thus **meters** (**m**). It turns out there is a simple formula that relates speed, wavelength and frequency:

$$\text{speed of propagation} = (\text{wavelength}) \times (\text{frequency})$$

$$c = f\lambda$$

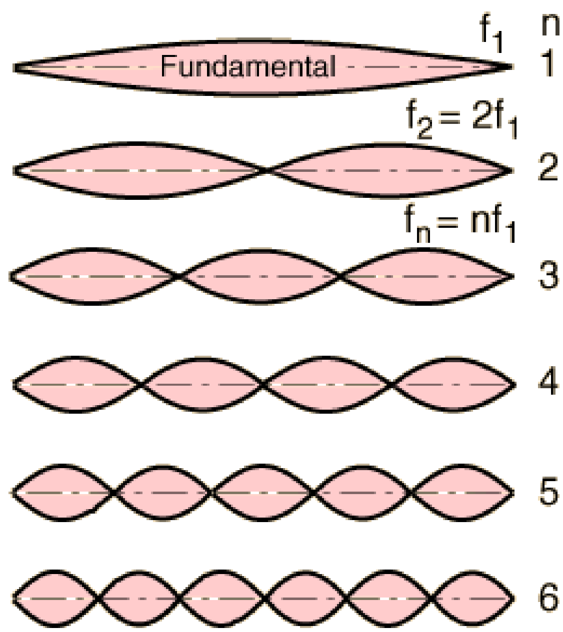
Start the following simulation:
https://phet.colorado.edu/sims/html/wave-on-a-string/latest/wave-on-a-string_en.html

Set to "Oscillate". First, follow a single green bead to figure out the period. Then, pause the simulation, and look at the distance between troughs to figure out the wavelength.

Standing waves

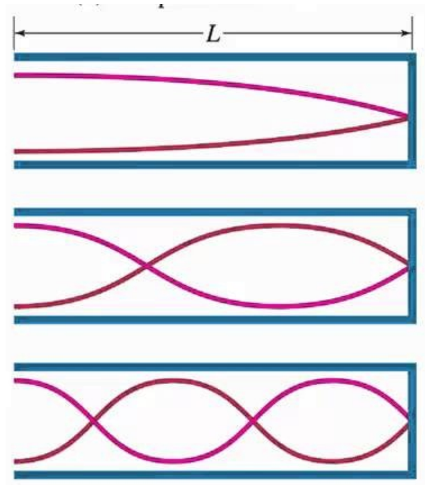
We have already seen many examples of standing waves. These are resonant systems that are somehow constrained at two ends. For example, the guitar string is tied at both ends so that the ends cannot move. The flaming gas pipe has a hard plug at one producing a maximum pressure and no longitudinal movement of the gas atoms and one end open producing a minimum of pressure. These are the two basic situations: the two ends have the same conditions and the each end has an opposite condition.

Think about fitting part of a sine wave along the guitar string of length L. The smallest part of a wave that is the same at both ends is exactly have a full cycle. Then a full cycle, one-and-a-half cycles, two cycles, etc. The half cycle would correspond to a wavelength – the distance for a full cycle – of $\lambda = 2L$ as shown in the figure. This is the **fundamental**.



The **first overtone** corresponds to a full cycle fitting into the length L: $\lambda=L$. The second overtone $3/2\lambda=L$, etc. In general we can write $\lambda=2L/n$, where n=1,2,3,etc. The fundamental has n=1, the first overtone n=2, etc. Also note that n corresponds to the number of maxima of the amplitude. For the fundamental there is one maximum, for the first overtone two maxima, etc. Alternatively one could count the nodes, where the amplitude is zero: the fundamental has zero nodes, the first overtone has one node, etc.

For the case of opposite conditions at the boundaries, the flaming gas pipe demo or the plunger you will use in lab, the situation is a little different. There the standing wave turns out to have a maximum at the opening, so it's like the string set-up "cut in half".



The smallest part of a full cycle that can fit is 1/4 of a cycle, i.e. L=1/4λ or λ=4L – the **fundamental**.

The overtones correspond to shorter wavelengths L=3/4 λ, 5/4 λ , etc.

Resonance

Watch this:
https://www.youtube.com/watch?v=nFzu6CNtqec

As you know, many systems vibrate or oscillate because there are forces that push the system or elements of the system toward equilibrium. For example, a simple pendulum or person on a swing has an equilibrium position, which is the bottom of the swing. If you push the object away from this position, the combined forces of gravity and the pendulum string pull it back – but once it is moving, it moves past the equilibrium and the net force reverses direction. Back and forth you go, slowing down of course due to friction, but basically you are oscillating at a special frequency. This is called the natural frequency of the system. There are many other examples: a mass on a spring (remember), a guitar string, atoms in a solid rod or a wine glass, gas in a tube or syringe, the water on the surface of a pond, etc. All of these have natural frequencies – the frequencies of oscillation or vibration once it is disturbed from equilibrium.

In many cases we put energy into a system in a periodic way. The most familiar may be pumping yourself or pushing someone on a swing. When you add energy at just the right frequency, the amplitude of the swings gets larger reaching a maximum when the energy added each cycle is equal to the energy lost to friction. If you add energy at the wrong frequency (this is hard to do on a swing) the results are not pretty – and you certainly cannot reach the maximum amplitude.

Start the following simulation:
https://phet.colorado.edu/sims/html/wave-on-a-string/latest/wave-on-a-string_en.html

Set to "Oscillate", set "damping" to second-lowest setting. Add a reference line. Compare amplitudes for frequency 0.41 Hz and 0.60 Hz.