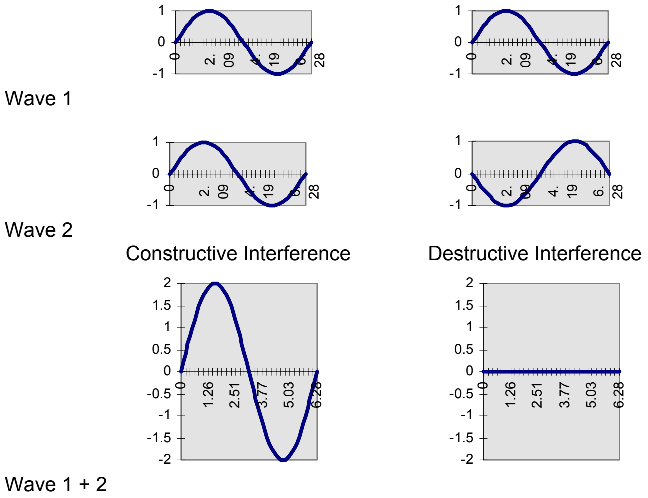
The Lost Lectures

Waves and Sound

- Waves can be single pulses or continuous. A continuous sine wave has a *wavelength*, λ, a *frequency*, f, and a *wave speed*, v. They are all related by $v = f\lambda$.

- In a vibrating string, the string vibrates perpendicular to the wave. This is a *transverse wave*. In a gas, the sound wave exists as a overpressure and underpressure about the base air pressure. The gas molecules compress and expand – this is a *longitudinal wave*. A Slinky™ can do both longitudinal and transverse waves.

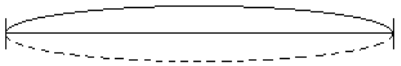
- If you have more than one wave, or if one wave is split into pieces and recombined, then the waves can add together. The two extreme cases are *Constructive Interference*, where the waves are in phase and they add up together, and *Destructive Interference*, where the two waves are exactly 180° out of phase and they cancel each other out.



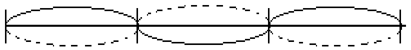
- *Standing waves* are the result of confining a wave to a particular geometry, such that the reflection at the ends create a *resonance* – where we can more directly detect the wave. The wavelength λ (or some multiple of $\lambda / 2$) fits into the dimensions of the object, the length L of a string, for example. *A vibrating string actually looks like the pictures…*

- For standing waves in general, places where the vibrations are maximized are called *anti-nodes*. Places where the vibrations appear to disappear are called *nodes*. Resonance and interference are very important properties in Physics. But do not confuse the amplitude of the vibrating wave with the motion of the wave.

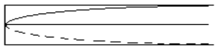
- For standing waves on a string fixed at both ends, one has to have nodes at both ends. That means that the longest wavelength wave that will fit the string has $\lambda / 2 = L$ or $\lambda = 2L$. This longest wave is called the *fundamental*. (The dashed lines represents the reflected wave also just fitting the geometry.)

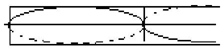


- The next resonance occurs when we fit in another node. For a string fixed at both ends, the *first overtone* occurs when $\lambda = L$. And the *second overtone* has yet another node, for $3/2\ \lambda = L$ or $\lambda = 2/3\ L$.



- For a tube open at one end and closed at the other, the resonance conditions change: you need a node at the closed end and an anti-node at the open end. (This is the same as for a vibrating string fixed at one end and free at another – this is how cowboys do their tricks with a lariat.) The fundamental is then $\lambda / 4 = L$ and the first overtone is $3/4\ \lambda = L$. (If you had a tube open at both ends, you would need anti-nodes at both ends, but the equations would be the same as for a string fixed at both ends.)





- If you play two notes that are very close in frequency (or wavelength), you will get an interference pattern that sometimes is in phase and sometimes out of phase. A sort of *Waa-Waa-Waa-Waa…* change of volume as the two waves alternately constructively and destructively interfere with each other. The frequency of this volume pattern is called the *beat frequency*, and it is equal to Δf, the difference between the two frequencies.

- If you try to move through a media faster than the prevailing waves can, you will get a shock wave. In air this is called a *sonic boom*. In water you get a *wake*. The shock waves spread out at an angle θ behind you, with θ determined by your speed. There are usually two shock waves, one from the front and one from the back – hence if you hear a sonic boom, you hear a double-boom. Should you go faster than the local speed of light in air or water, you will see a blue glow called *Cerenkov radiation*, but it is also the same sort of shock wave.

Changing Temperature and States of Matter in Materials

- There are *3 Classical States of Matter: SOLID, LIQUID and GAS*. In Modern Physics, we can add two more: *CRYOGENIC* (extremely odd behaviors at extremely low temps) and *PLASMA* (very high temperatures where we rip the electrons from the gas molecules or atom and make them into highly charged ions).

- To change the temperature of a material while keeping it in the same state, we need to add (or remove) heat energy Q to the material, which has a *heat capacity, C,* or a *specific heat, c,* (heat capacity per mass) that is based on the material and the state it is currently in. Our equation is $Q = mc\Delta T$. Since we are looking at a change in temperature, you can use either °C or Kelvins for your temperatures.

- A change in state of matter occurs at a single temperature. For example, a melting ice cube appears wet because it consists of water in both solid and liquid forms at 0°C. If the ice cube was at $T < 0°C$, it would not be melting, and if it were at $T > 0°C$, it couldn't be ice (all this at 1 standard atmosphere pressure = 101,300 Pa).

- To change from solid to liquid (or back) we have to add (or subtract) energy based on the *latent heat of fusion,* L_f , of the material. $Q = mL_f$.

- To change from liquid to gas (or back) we have to add (or subtract) energy based on the *latent heat of vaporization,* L_v , of the material. $Q = mL_v$.

Problem: Suppose we wish to turn a 1.00 kg block of ice at T = -20°C into 1.00 kg of steam at T = 100°C.

Step 1: Heat ice from -20° C to 0°C.

$$Q = mc\Delta T = (1.00\ kg)(2090\ J/kg\cdot°C)(+20°C) = 41,800\ J$$

Step 2: Melt ice into water at 0°C.

$$Q = mL_f = (1.00\ kg)(333,000\ J/kg) = 333,000\ J$$

Step 3: Heat water from 0°C to 100°C.

$$Q = mc\Delta T = (1.00\ kg)(4186\ J/kg\cdot°C)(+100°C) = 418,600\ J$$

Step 4: Boil water into steam at 100°.

$$Q = mL_v = (1.00\ kg)(2,260,000\ J/kg) = 2,260,000\ J$$