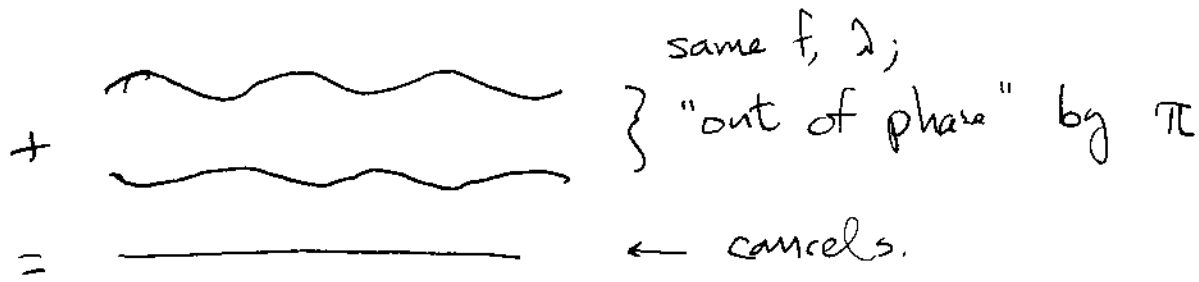
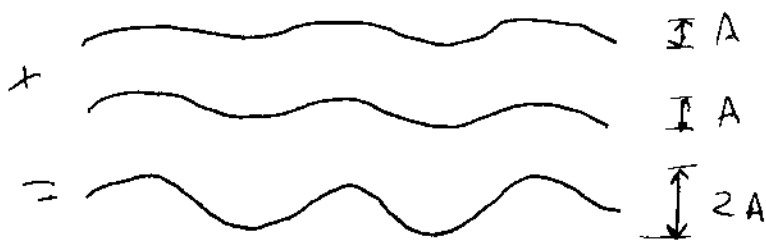


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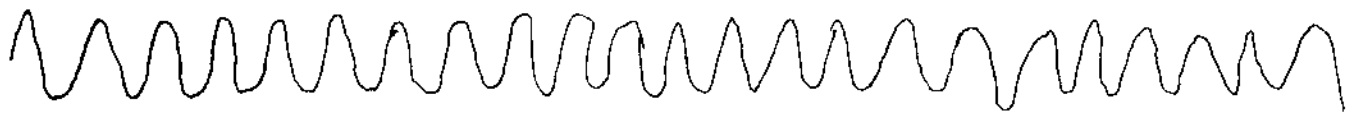
Finishing up sound: Recall the superposition principle:



"In phase", the waves add:



What if f are slightly different?



↑ in phase ↑ out ↑ in ↑ out

→ alternating addition, cancellation: "beat" pattern!

The amplitude Y of the pressure wave controls the loudness of the sound. Big $Y \Rightarrow$ big pressure oscillation \Rightarrow big wag of eardrum \Rightarrow loud sound.

The frequency is the "pitch" of the tone. Hi $f \Rightarrow$ hi notes (soprano) Lo $f \Rightarrow$ lo notes (basso). More on frequency and music below.

Frequency range of human hearing: $f = 20 \text{ Hz} \rightarrow 20 \text{ kHz}$. [frequency f is usually measured in hertz (Hz), cycles per second] The upper end degrades as we age. At age 65, most humans cannot hear above 10 kHz. Dogs can hear up to 35 kHz (ultrasonic).

As with most waves, the speed of sound in air depends on the properties of the medium = air (temperature, mass of molecules, etc) NOT on the properties of the sound wave.

$v_{\text{sound}} = 343 \text{ m/s}$ (this varies by about $\pm 10 \text{ m/s}$, depending on the temperature)

Sounds travels about 1 mile in 5 seconds.. If you see a flash of lighting and then start counting seconds (1-1 thousand, 2-1 thousand, 3-1 thousand...) until you hear the thunder, you can estimate how many miles away the lighting is. The speed of light is very, very fast (light speed $c = 3 \times 10^8 \text{ m/s}$) so the light arrives almost instantly, while the sound wave takes a while to catch up.

Example: What is the wavelength range of human hearing?

$$v = \lambda f \Rightarrow \lambda = \frac{v}{f} = \frac{343 \text{ m/s}}{20 \text{ s}^{-1}} \rightarrow \frac{343 \text{ m/s}}{20000 \text{ s}^{-1}} = 17 \text{ m} \rightarrow 0.017 \text{ m (17 cm)}$$

Music

The frequency is the "pitch" of the tone.

"middle C" = 262 Hz, = 294 Hz, E = 330 Hz, etc. Each "octave" on the musical scale is a factor of 2 change in frequency, for instance, "C above middle C" = $2 \times 262 = 524 \text{ Hz}$

A single frequency sound wave (a pure tone) is an irritating sound to most people. A pleasant musical note is usually a *mixture* of frequencies = lowest or *fundamental* frequency + integer multiples of the fundamental or *overtones*

$$\begin{aligned} f_1 &= \text{fundamental} = 1^{\text{st}} \text{ harmonic} \\ f_2 &= 2 \cdot f_1 = 1^{\text{st}} \text{ overtone} = 2^{\text{nd}} \text{ harmonic} \\ f_3 &= 3 \cdot f_1 = 2^{\text{nd}} \text{ overtone} = 3^{\text{rd}} \text{ harmonic} \\ f_n &= n \cdot f_1 = (n-1) \text{ overtone} = n^{\text{th}} \text{ harmonic} \end{aligned}$$

How to musical instruments manage to produce this nice mixture: $f_1, 2f_1, 3f_1$, etc ??

If a string of length L has its ends fixed, as in a stringed instrument, then only standing waves at certain *resonant* frequencies are possible: