Waves carry energy
(Move masses as they travel)

- Light waves carry energy from sun to us
- Earthquake waves can destroy buildings
- Sound waves can burst eardrums

\[ M = \text{mass, length} \]
\[ \text{Mass} = \mu \text{dx} \]

Consider Harmonic Wave - mass moves in SHM
has energy
\[ E = \frac{1}{2} k x^2 \quad \text{where} \quad x = A \]
\[ k = m \omega^2 \]

Energy per unit time at a point
\[ dE = \frac{1}{2} \mu (dx)^2 \omega^2 \quad \text{d}x \]
\[ \frac{dE}{dt} = \frac{1}{2} \mu \omega^2 A^2 v \quad \text{Rate of energy transfer} \]

More generally
\[ \frac{dE}{dt} \times A^2 v \quad \text{Watts} \]

Will see much more of this next semester
Intensity of wave = \( \text{Power} \div \text{Area} = \text{Watts} \div \text{m}^2 \)

energy transported by wave per unit time across a unit area \( A \) in direction of flow

Intensity of sound = 1.3 \( \text{W} \div \text{m}^2 \)

Usage ...

Reference intensity to some common reference

\[ \beta \text{ (decibel)} = 10 \log \left( \frac{I}{I_0} \right) \text{ dB} \]

Threshold of hearing \( \beta = 0 \text{ dB} \)
Whisper \( \sim 20 \text{ dB} \)
Street traffic \( \sim 70 \text{ dB} \)
Speech @ 30 m \( = 100 \text{ dB} \)
Rock Concert above threshold \( \sim 120 \text{ dB} \)
Jet engine at 30 m \( \sim 140 \text{ dB} \)

**Example**

Stereo advantage

flat response \( = 3 \text{ dB} \) from 30 Hz to 18,000 Hz

What does this mean in terms of intensity variation?

Average intensity \( I_1 \), without variation

\[ I = I_1 + 3 \text{ dB} \]

\[ \beta - \beta_1 = 10 \log \left( \frac{I}{I_0} \right) - 10 \log \left( \frac{I_1}{I_0} \right) \]

\[ 3 \text{ dB} = 10 \log \left( \frac{I}{I_1} \right) \Rightarrow \frac{I}{I_1} = 2.0 \text{ Variation in intensity is a factor of two} \]
Interference of Waves

At $\rightarrow$ when waves interact.

You talk about Superposition of waves when you talk about beats.

Now look at waves of same frequency from different sources, say two speakers hooked to a stereo.

Sound is longitudinal of course, but easier to see with transverse waves like ripples in water.

Now call path difference $\Delta \varphi$.

So $\Delta \varphi$ is the difference in the distance the two waves have traveled $\Delta \varphi = \varphi_2 - \varphi_1$. 
Now, it's off by 1.

Some this, try add \( \rightarrow \) bigger wave.

\[ \Delta r = r_2 - r_1 = n\lambda \quad n = 0, 1, 2, \ldots \]  

**Constructive Interference**

Now \( \rightarrow \) off by \( \frac{\lambda}{2} \).

When you add these points \( \rightarrow \) one \( \theta \) one \( \Theta \).

We set zero at all points.

**Destructive Interference**

\( \rightarrow \) off by \( \frac{3\lambda}{2} \), \( \frac{5\lambda}{2} \) \( \rightarrow \) \( \Delta r = \frac{n\lambda}{2} \), \( n = 1, 3, 5, \ldots \).  

What is different between this and steady waves?

Standing wave \( \rightarrow \) no energy. How in either direction.

Traveling wave \( \rightarrow \) no net energy flow.
Doppler shift of Sound frequency

\[ \lambda = \text{Distance between wave crests} \]

Suppose Source Moves! \( \pm v_w \)

Velocity of wave in Medium NOT affected by Source movement.

\[ V_{\text{source}} \]

\[ d = V_{\text{source}} \cdot T \]

\[ T = \frac{1}{f} \]

\[ V_{\text{wave}} = \lambda f \]

\[ \lambda = d + \lambda' \]

\[ \lambda_0 = d \lambda - d = \lambda - \frac{V_s}{v_w} \]

\[ \lambda' = \lambda \left( 1 - \frac{v_s}{v_w} \right) \]

or \[ \Delta \lambda = \frac{\lambda v_s}{v_w} \]

What is usually "heard" or measured is frequency

\[ f' = \frac{V_w}{\lambda'} = \frac{V_w}{\lambda \left( 1 - \frac{v_s}{v_w} \right)} = \frac{f}{\left( 1 - \frac{v_s}{v_w} \right)} / \]

\[ f' > f \]
Can derive for source moving away from observer

\[ f' = \frac{f}{1 + \frac{v_s}{v_w}} \]

known as Doppler shift of frequency
- Train whistle
- Demos
- Similar thing for light \( \rightarrow \) receding galaxies