$$\frac{\partial^2 y}{\partial x^2} = \frac{1}{v^2}\frac{\partial^2 y}{\partial t^2}$$

$$y(x,t) = y_m \sin(kx - \omega t + \phi)$$

$$v = \frac{\omega}{k} = \frac{\lambda}{T} = \lambda f$$

$$v \propto \sqrt{\tau / \mu}$$

$$k\lambda = 2\pi$$

$$v = \sqrt{\frac{B}{\rho}}$$

$$\Delta p(x,t) = \Delta p_m \sin(kx - \omega t)$$

$$P_{avg} = \tfrac{1}{2}\mu v \omega^2 y_m^2$$

$$\beta = (10\,dB)\log\frac{I}{I_0}$$

Observer Moving

- Because of relative velocities, if the frequency of sound waves change when the source is moving but the observer is stationary, it is also true that the frequency of sound waves will change if the source is stationary but the observer is moving.

- To think about this, consider a *stationary* source emitting spherical wavefronts having a fixed frequency.

- If the observer is traveling *towards* the source, it will intercept wavefronts (specifically, maxima in displacement) *more often* than if the observer was at rest. This will *increase* the measured *frequency* (since *more* maxima are counted in the same amount of time).

- Conversely, if the observer is moving *away* from the source, it will intercept wavefronts *less* often than if the observer was at rest. This will *decrease* the measured frequency.

- For both cases (source moving and observer at rest, or source at rest and observer moving), we note that if the *source and observer are moving together the frequency increases, when they are moving apart, the frequency decreases*.

•If the observer is at *rest*, the time between successive maxima (T=1/f) is simply λ/v.

•Consider a observer *moving towards* a stationary source with some velocity v_D.

•Now the time between successive maxima (T'=1/f') is $\lambda/(v+v_O)$, or $f'=f(1+v_O/v)$.

•Similarly, if the observer is moving away from a stationary source, the frequency will be shifted *downward* like $f'=f(1-v_O/v)$.

•To summarize, for the source moving, and the detector at rest we find:

$$f' = f\frac{v}{v \pm v_S} = f\frac{1}{1 \pm {v_S}/{v}}$$

and for the source at rest and the detector moving we find:

$$f' = f\frac{v \pm v_O}{v} = f\left(1 \pm {v_O}/{v}\right)$$

where the sign carries the information about whether the observer and source are getting closer together or further apart (closer together means *higher* measured frequency, further apart means *lower* measured frequency).

Doppler effect

- In practice, it is possible to have both the source and observer moving.

- In this case, we must combine the two equations to obtain the general expression:

$$f' = f\,\frac{v \pm v_O}{v \pm v_S} = \frac{1 \pm v_O/v}{1 \pm v_S/v}$$

- The sign (whether plus or minus) can be remembered by recognizing that if the source is moving towards the observer the frequency will increase, and if the observer is moving towards the source, the frequency will increase (or *toward means shift up, away means shift down*).

- We will only consider 1D motion in this course, although these arguments can be extended to looking at cases where the source is moving at an angle to the detector.

Supersonic Speeds

- The expression for the Doppler shift for a moving source *diverges* when $v_S=v$, when the source is moving *at the speed of sound*.
- It is also possible for the source to be moving *faster* than the speed of sound.
- In this case, the wavefronts (corresponding to sound emitted at different times) will *intersect*, leading to very large amplitudes of oscillation.
- Recall that the radius (R) of a spherical wavefront will increase like $R=vt$, where t is the time elapsed since the soundwave was created.
- This wavefront will intercept smaller radius (R') wavefronts created at a *later* time with $R'=vt'$, because the source is traveling *faster* than the wavefronts.

- The wavefronts emitted at different times will *intercept* in a *cone* (called the *Mach cone*) having its axis along the direction of motion of the source.
- The angle this cone makes to the direction of travel (the *Mach cone angle*) is given by:

$$\sin\theta = \frac{vt}{v_S t} = \frac{v}{v_S}$$

where v_S/v is called the *Mach number*.
- A *shock wave* occurs on the surface of the Mach cone where the wavefronts intercept.
- For sound waves traveling in air, this shockwave produces a *sonic boom*.

Digital Recording

•The human ear is capable of distinguishing sounds with frequencies ranging between approximately 20 Hz and 20 kHz.

•Music consists of a combination (superposition) of sound waves having different frequencies and different intensities. The total intensity of the sound is the sum of the intensities at each different frequency.

•Music can be *digitized* by converting the total intensity to a voltage.

•These voltages are typically stored as binary numbers between 0 and 65535.

•The intensity is sampled a 44 kHz, which is a high enough sampling rate to capture the highest frequencies audible to the human ear.

•These voltage readings are stored as “1”’s and “0”’s on an optical disc. A change from a highly reflective region to a low reflection region as the laser moves across the disc is registered as a “1”, if there is no change, it is registered as a “0”.