Lecture 2.8

Sound, Doppler Effect, Hearing

Foundation Physics
Travelling Waves

Simple wave or traveling wave, also sometimes called progressive wave, is a disturbance that varies both with time $t$ and distance $z$ in the following way:

$$y(z,t) = A(z,t) \cdot \sin(kz - \omega t + \phi)$$

where $A(z,t)$ is the amplitude envelope of the wave, $k$ is the wave number and $\phi$ is the phase.
The angular frequency is related to the frequency, $f$, by

$$f = \frac{\omega}{2 \cdot \pi}$$

The phase velocity $v_p$ of this wave is given by

$$v_p = \frac{\omega}{k} = \lambda \cdot f$$

where $\lambda$ is the wavelength of the wave.
Ultrasound has a speed of 1500 m/sec in tissue. (a) Calculate the smallest detail visible with 2.0-MHz ultrasound. (b) To what depth can the sound probe effectively? (c) How long does it take the echo to return to the probe from a depth of 0.10 m?
Phase shift

If we excite micro-cantilevers the mechanical response has a phase shift.

If there is no displacement at time $t = 0$, the phase shift is given by:

$$\phi = \frac{\pi}{2}$$
Constructive interference

A small phase shift $\varphi_0$ (or also $\varphi_0 = 0$) leads to constructive interference (snapshot at time $t=0$)

$$y(x) = y_1(x) + y_2(x)$$

Blue (interfering wave response)
If the phase shift is close to $\pi$, then destructive interference is taking place.
A wave which interacts with an obstacle, can propagate in different directions behind the obstacle. Example: water waves behind an opening in a wall.

The development of diffraction can be explained by the principle of Huygens (Ch. Huygens, 1629-1695).

A wave propagates, in each of its point we have a source of sphere shaped elemental wave. The envelope of all the elemental waves results in the wave at a later time point.
Propagation of a plane wave

Wave front at time $t$

Wave front at time $t + \Delta t$

Wave front at time $t + 3\Delta t$

obstacle
Standing waves are defined by fixed points of **no** deflection (**nodes**) and points with maximum deflection.

Example of a string with a first frequency or an upper (higher harmonic) frequency.
The Doppler effect, in principle it’s a frequency shift, caused by the relative motion of the source with respect to the observer. Approaching (the sound appears higher), travelling away (sound is perceived lower).
Doppler effect

\[ f_{obs} = \left( \frac{V_w}{V_w \pm V_{source}} \right) \cdot f_{source} \]
Red shift in optics

light/sound wave frequency

observer

object

original spectrum

shifted spectrum
- Repetition
- SI units
- Problems