Homework 20

Waves

The word "wave" is associated with periodicity. As we think of waves on the surface of water we imagine periodic rows of peaks and deeps. As long as both oscillations and waves are periodic, it is natural to assume that they are related to each other. Another observation is that that the waves are running (there is a type of waves which do not – we will discuss them later) – the peaks and deeps are moving. After some time, each peak takes place of the next one. We can say that waves are periodic in space and time. The waves can propagate in an extended (at least in one dimension) object or media such as string, air or surface of water. We can consider the media as a bunch of particles connected with coil springs. As we knock on the surface of a table we apply force to a small fraction of these particles. They start oscillating and excite oscillations of the adjacent particles. These "neighbors", in turn, make their "neighbors" oscillate – so the wave is propagating in a way similar to the way rumors are spreading among people. As long as the particles have nonzero mass, it takes some time to accelerate them, so each next "neighbor" starts oscillating a bit later, so there is a phase shift between adjacent oscillators. As long as the oscillators are identical, the phase shift is constant.

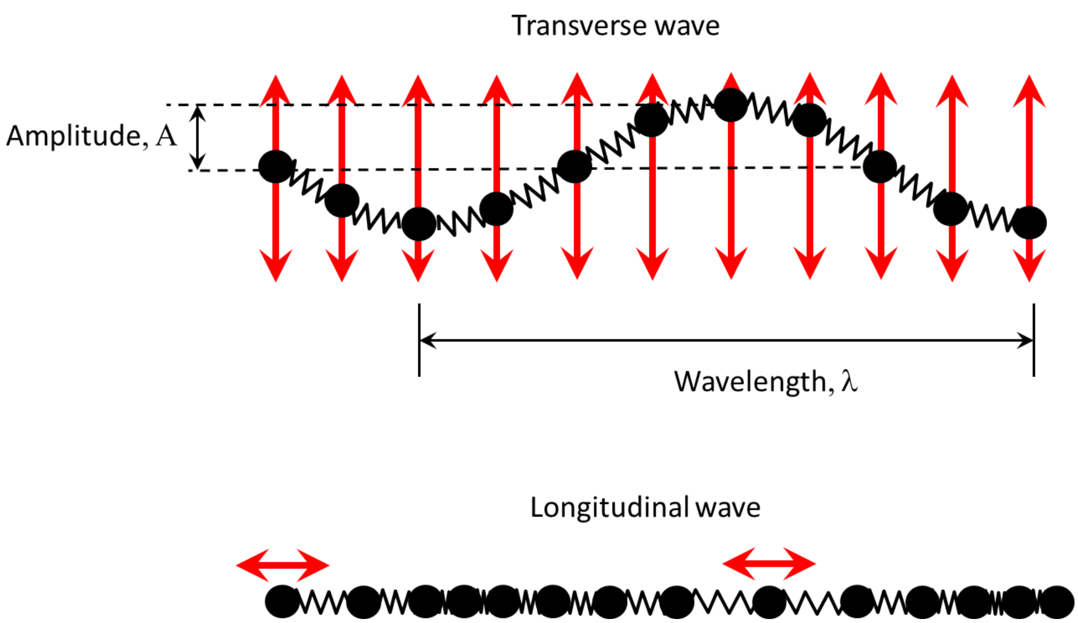

Figure 1.

So the total phase shift between two oscillating particles depends on how many particles in between them and, hence, on the distance between two particles. At a certain distance λ the phase shift becomes 2π, so the particles separated by distance λ oscillate in the same phase. This distance is called ***wavelength*** (Figure 1).

One of the simplest expressions describing wave is:

$$Y = A \cdot \cos(\kappa x - \omega t) \quad (1)$$

Here Y is the parameter, which is oscillating (in Figure 1(top) Y is vertical displacement of the particles, for sound waves Y is the local air density, for light wave Y is electric or magnetic field), **ω** is the circular frequency of the oscillating particles, $\kappa=2\pi/\lambda$ is called wavenumber. Wavenumber is the number of waves within 2π meters. If we fix the time at the moment t_0, the wave will "freeze" and Y will be a simple oscillating function of x with the initial phase $-\omega t_0$. Remember that if we subtract a number from a function's argument, the function just shifts to the right (along X axis) for the same number. As the time goes, the shift is increasing – the wave is moving to the right. If we change the sign before ωt in the expression (1) from plus to minus, we will have the wave running to the left.

If we will observe just one particle which is locates at x_0 expression (1) will describe harmonic oscillation with a circular frequency ω and initial phase $-\kappa x_0$.

Let us calculate the velocity of the wave. To do that, let us concentrate on one oscillating particle. If initially this particle has, say, maximum displacement, then it will return to the same place in a time equal to the period of oscillation ***T***. But this means that during the time ***T*** the wave has moved to the distance which is equal to $\boldsymbol{\lambda}$. So, the velocity of the wave is:

$$v = \frac{\lambda}{T} \quad (2)$$

We can specify two types of waves. If the displacement of the particles is perpendicular to the direction of the wave propagation we have ***transverse*** wave (Figure 1, top). In case the particles are oscillating along the direction of the wave propagation the wave is ***longitudinal*** (Figure 1, bottom).

Problems:

1. During the thunderstorm you hear the thunder 15 s after you see the lightning. How far from you was the lightning? Take the speed of sound in the air is 340m/s

2. A piano can produce sounds in the frequency range from 90 to 9000Hz. Find the sound wavelength range of the piano. Use the data of the problem 1.

3. What kind of waves (transverse of longitudinal) a bird creates with its wings in the air?

4. Find the frequency of tuning fork oscillations if the corresponding sound wave is 24cm long? (the speed of sound is 340m/s)

5. Why does a human have 2 ears?

6. Based on question 5: why does a speaker set for stereo sounds include 2 speakers for high frequency sounds but usually only one speaker for low frequency sounds?