12.4: In Summary

1. A traveling wave in an elastic medium is a collective disturbance of the particles in the medium (a displacement, or change in pressure or density) that carries energy and momentum from one point of the medium to another, over a distance that is typically much larger than the displacement of the individual particles making up the wave.
2. In a longitudinal wave, the displacement of the particles is along the line of motion of the wave; in a transverse wave, it is perpendicular to the wave's motion.
3. An important kind of waves are periodic waves, in which the disturbance repeats itself at each point in the medium with a period T. Sinusoidal, periodic waves are called harmonic waves. Their spatial period is called the wavelength λ. If the speed of the wave is c, one has $c = f\lambda$, where $f = 1/T$ is the wave frequency.
4. The time-averaged energy density in a harmonic wave (sum of kinetic and elastic potential energy per unit volume) is $E/V = \rho_0\omega^2\xi_0^2/2$, where ρ_0 is the medium's density, and ξ_0 the amplitude of the displacement oscillations. The time average momentum density is E/cV. The *intensity* of the wave (energy carried per unit time per unit area) is cE/V.
5. Sound is a longitudinal compression-and-rarefaction wave in an elastic medium. It can be described in terms of displacement, pressure or density. The pressure or density disturbance is maximal where the displacement is zero, and vice-versa.
6. The speed of sound in a solid with Young modulus Y is $c = \sqrt{Y/\rho_0}$; in a fluid with bulk modulus B, it is $c = \sqrt{B/\rho_0}$. In an ideal gas, this depends only on the ratio of specific heats, the molar mass, and the temperature.
7. Transverse waves on a string with mass per unit length μ and under a tension F^t travel with a speed $c = \sqrt{F^t/\mu}$.
8. When a wave reaches the boundary between two media, it is typically partly reflected and partly transmitted. The incident, reflected and transmitted waves all have the same frequency. The transmitted wave has a wavelength c_2/f, where c_2 is the wave speed in the second medium.
9. The quantity that determines how much of the energy is reflected or transmitted is the *mechanical impedance*, defined for each medium as $Z = c\rho_0$. If $Z_1 = Z_2$ there is no reflected wave. If $Z_1 < Z_2$, the reflected wave is inverted (flipped upside-down) relative to the incident wave. If $Z_1 > Z_2$, it is upright.
10. Standing waves arise in a medium that is confined to a region of space, and are the normal (or "natural") modes of vibration of the system. In a standing wave, each particle of the medium oscillates with an amplitude that is a fixed function of the particle's position (a sinusoidal function in one dimension). This amplitude is zero at points called *nodes*.
11. In one dimension, all the standing wave frequencies are multiples of a fundamental frequency $f_1 = c/2L$, where L is the length of the medium (as long as the boundary conditions at both ends of the medium are identical). These are the *resonant* frequencies of the system: if disturbed, it will naturally oscillate in a superposition of these frequencies, and if driven at one of these frequencies, one will obtain a large response.