Waves

- **Basic idea:** A wave is a propagation of something happening – the spring moving, the air vibrating, the water rising, etc.
- **Basic idea:** Pulses passing each other add by superposition (adding displacements that would have happened with each wave separately point by point.) Effects can add or cancel.
- **Basic idea:** A wave pulse reflects at a fixed boundary, and comes back upside down, just as if an equal and opposite pulse were coming from the other direction; in both cases, the point on the fixed boundary doesn’t move.
- **Result:** \( v_{\text{wave}} \), the wave pulse travel speed (or wave speed for a periodic wave) depends on the properties of the medium – the “reaction time” it takes one part of the medium to react to what happened to the adjacent part. Higher spring tension makes a faster reaction, higher mass of the string per unit of length makes a slower reaction.
- **Result:** \( v_{\text{wave}} \) does NOT depend on properties of the pulse like amplitude or pulse width.
- **Result:** The relationship between the pulse length, the wave speed and the time it takes to make the pulse is \( l = v_{\text{wave}} t \). (That is, if you flick your hand up and down, \( t \) is the amount of time your hand is in motion making the flick, and \( l \) is the length of the pulse you produce.)
- **Result:** A sinusoidal oscillation produces a sinusoidal wave, which we use for basic definitions.
- **Definitions:** Amplitude is the maximum height of the wave; wavelength \( \lambda \) is the length of the wave produced by one cycle of oscillation. Period \( T \) is the time for one cycle; frequency \( f \) is the number of cycles per second.
- **Result:** \( \lambda = v_{\text{wave}} T \), for the same reasons as \( l = v_{\text{wave}} t \). \( \lambda = v_{\text{wave}} T \) is equivalent to \( \lambda = \frac{v_{\text{wave}}}{f} \), since the frequency \( f \) is the number of flicks per unit time or \( 1/T \).
- **Result:** The frequency of sound determines the pitch; the amplitude the volume.
- **Result and more definitions:** The basic idea of superposition, plus the idea of sinusoidal waves, means that sinusoidal waves of the same amplitude, wavelength, and frequency that are moving in opposite directions interfere to make standing waves, in which the medium oscillates without any apparent motion forward or backward (As illustrated, e.g., here: [http://www.phy.hk/wiki/englishhtm/TwaveStatA.htm](http://www.phy.hk/wiki/englishhtm/TwaveStatA.htm)). Spots on the medium that don’t move at all are called nodes; spots that move the most are called antinodes. But the frequency of oscillation is still given by \( f = v/\lambda \).
- **Result:** The frequency of a wave doesn’t not change as it passes from one medium to another.
- **Result:** The fixed ends of a string must be nodes for any standing wave to fit on the string. (The not-fixed ends of that aluminum rod had to be anti-nodes, for a wave to fit on it.) The frequencies at which standing waves oscillate on a string or rod or tube depend on the wave speed and the wavelengths that can fit.
• **Result and definitions:** Two sources of waves — whatever kind of waves! — can interfere constructively (waves at a given point add in amplitude, building on each other’s effect) or destructively (waves at a given point cancel each other’s effect).

• **Result:** Constructive interference points are louder, brighter, etc and the displacement at those points oscillates between big peaks and big troughs. Destructive interference points are softer, dimmer, etc. and ideally no disturbance at all is happening there.

• **Result:** Turning on a second speaker — adding a second source of sound — can actually make for less sound at points of destructive interference, if the effect of that second speaker is opposite the effect of the first.

• **Result:** Adding a second source of light can do the same, again if the source has the same amplitude and frequency as the first — in some spots, the effect can cancel. That this can happen is very convincing evidence that light isn’t made up of “corpuscles” as Newton thought, but of waves.

• **Result:** We can represent the wave peaks and troughs of two sources oscillating in sync with each other using diagrams showing the peaks of waves. There’s constructive interference when peaks of waves from one source match with peaks from the other, or troughs line up with troughs; there’s destructive interference when peaks of one source line up with troughs of the other. That means there’s constructive interference at a point A if distances from A to each of the sources are the same or differ by a whole number of wavelengths. If they differ by a half a wavelength (or n + λ/2), then the two waves will be exactly opposite and that’s destructive interference. We used trigonometry to find that the difference in path length between the two sources is dsin θ, so destructive interference happens at angles when \( dsin \theta = (n + \lambda/2) \).

• **Result:** When a source is moving toward you, the frequency of waves from it is higher; when a source is moving away from you, the frequency is lower — this is called the Doppler effect, and it explains the drop in pitch you hear when something comes toward you and then moves away.

### Light as waves

• **Basic idea:** Light rays from the particle model correspond to the lines perpendicular to wavefronts. The wavefronts are the lines along which the peaks of the wave are at any moment (the lines you saw in the ripple tank. See the lines in drawings below. The blue lines are the wavefronts and the green lines correspond to the light rays in the particle model.

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Waves traveling in one direction, like a flashlight or laser rays

Waves traveling out in all directions from a single point, like a point source or light scattering when it hits a non-mirror.
• **Basic idea:** If light is a wave, then its speed changes from one medium to another. Refraction is now understood as resulting from the wave speed slowing down, as it passes from one medium to another: The speed of waves of light is \( v_{\text{wave}} = \frac{c}{n} \) (\( n = \) index of refraction.) Experiments that show light moves more slowing in glass, e.g., than in air are further evidence that light is made up of waves rather than corpuscles.

• **Results:** That’s how the wave model explains Snell’s Law, \( n_1 \sin \theta_1 = n_2 \sin \theta_2 \). And the wave model similarly explains total internal reflection – when light (or other waves!) move from a slower medium to a faster medium at a large enough angle, there’s no solution for the angle on the other side.

(I don’t plan to write exam questions on this stuff...)

• **Basic idea:** Light is an “electromagnetic wave” — a wave of oscillating electric and magnetic fields. The spectrum of light includes radio waves, visible light, x-rays… all depending on the frequency.

• **Basic idea:** The speed of light in a vacuum is \( 3 \times 10^8 \) m/s.

• Experiments show that the energy of light come in little bundles—for light at a certain frequency, there’s a minimum “quantum” of light energy—you never get half a quantum. That makes light start to seem more particle-like. **And**, maybe even more strange, “particles” like electrons can show interference patterns! And so can neutrons, and even atoms. So these things we’re used to thinking of as particles can also seem more wave-like. The higher the energies, in general, light and everything else tends to seem more like particles; the lower the energies, light and everything else tends to seem more like waves.

• **Definitions:** Very high energy light is called “gamma radiation.” Beta “rays” are another form – they are electrons, and they have a negative charge. Alpha radiation is helium nuclei. The danger from radiation comes from the particle (gamma, beta or alpha) hitting things in your body. There’s two things to think about: the amount of energy the particle has (more is more dangerous) and how likely the particle is to hit something. Alpha particles are very likely to hit something, which is a good thing if they’re coming from outside your body: They aren’t likely to get in. An alpha particle will generally lose all of its energy to the air, or if you’re holding it to the outer layers of your skin. If they’re inside your body, that’s bad! Beta particles are generally the worst, because they’ll penetrate your body and hit something while inside. Gamma rays would be bad if they hit something, but at the highest energies they’re not very likely to!