World of Light - Problem Set #1

Assigned March 30, due at start of class on ***Wed. April 3***.

Reading

Light Science chapter 2.

Topics and equations

This problem set reviews the following topics: wave terminology, types of waves, the electromagnetic spectrum, velocity, frequency, refractive index, and dispersion. It requires the use of the following constants and equations:

speed of light in vacuum = $c = 3\times10^8$ m/s
acceleration due to gravity = $g = 10$ m/s^2
speed of sound in air = 350 m/s

$$v = \frac{d}{t} \qquad v = \lambda f \qquad v = \sqrt{\frac{\lambda g}{2\pi}} \qquad v = \sqrt{gh} \qquad v = \frac{c}{n}$$

When a problem asks for comparison, use the following answers: "much greater" if it is more than 10x larger, "greater" if it is less than 10x larger, "similar" if the numbers are within about a factor of two, "less" if it is less than 10x smaller, and "much less" if it is more than 10x smaller.

Problems

Grading scale: basically right = 1 point, basically wrong = 0 points, some right and some wrong = 0.5 points; no finer gradations.

1. (a) Draw a picture of a wave. Label: the crests, the troughs, a wavelength, the amplitude. (b) List 2 types of transverse waves. (c) Give an example of a longitudinal wave.

2. This problem reviews the metric system, and helps develop a sense of scale for light waves. (a) What is the wavelength of green light in nm? How does it compare to the size of the following: (b) a bacterium, which is ~2 μm long, (c) a water molecule, which is ~0.2 nm in diameter, (d) a small protein, which is ~2 nm in diameter, (e) a ribosome, which is a very large protein complex and ~20 nm in diameter, (f) a cloud droplet, of which ~20 μm is a typical size, (g) a raindrop, of which ~2 mm is typical, (h) a soap bubble thickness, of which ~500 nm is typical?

3. For the following *electromagnetic* waves, list the type of wave that this is (e.g. visible, infrared, etc.) and compute its frequency or wavelength (whichever is not given). (a) laser pointer: 635 nm, (b) dentist's office: 0.3 nm, (c) carbon dioxide vibration: 15 μm, (d) hydrogen atom: 122 nm, (e) KUOW: 94.9 MHz, (f) oven: 2450 MHz.

4. Lightning strikes the ground five kilometers away. (a) How long does it take the light to reach us? (b) How long does it take the sound (thunder) to reach us?

5. A modern computer central processing unit chip (CPU) runs with a clock speed of 2.7 GHz. (a) How many seconds long is one clock cycle? (b) Electrical signals travel at the speed of light. How far can an electrical signal travel in one clock cycle? (c) Wires between the CPU's control unit and its cache memory (both on this chip), are about 2 cm long. How does this compare to how far an electrical signal can travel in one clock cycle?

6. Bats use echolocation to find their prey, meaning that a bat emits a click and then waits for the sound to bounce off the prey and return to the bat. By timing the returned sound, the bat can figure out how far its prey is. (a) Suppose a moth is 2 m from the bat; how much time is there between when the bat clicks and then hears the echo? (b) A typical bat sound frequency is 50 kHz (1 Hz = 1 cycle per second; by comparison, the highest note on a piano is only 4.2 kHz). What is the wavelength of a bat click, expressed in mm? How does this compare to the size of a moth (much smaller, smaller, similar, larger, or much larger)?

7. Boats generally have a hard time travelling faster than their hull speed, which is the speed of a water wave that has the same wavelength as the boat length. (a) What is the hull speed for a 5 meter canoe in deep water? (b) What about for a 100 meter long ship? (c) What about for a 10 cm long duck? (d) What about for a 5 meter canoe in 10 cm deep water?

8. The 2011 Japan tsunami was triggered by an earthquake 70 km offshore. The earthquake travels through the earth as a sound wave; the speed of sound in rock is about 6 km/s. (a) How long after the earthquake happened was the earthquake felt in Japan? (b) The frequency of this sound wave is about 1 Hz, what was the wavelength? (c) The wavelength of the tsunami is hundreds of miles; the ocean is about 100 m deep in that region. What was the tsunami wave speed? (d) How long did it take the tsunami to reach Japan?

9. (a) How far does light travel in 1 year (1 year = 3.16×10^7 s)? (b) The closest star to Earth is Proxima Centuri, which is 4.24 light-years away. How far is this in kilometers? (c) The Voyager 1 spacecraft is flying away from the sun at about 17 km/s. How many years would it take for it to get to Proxima Centuri? (d) Do you think people will ever travel to other stars?

10. (a) What is the speed of light in water, where the refractive index is 1.33? (b) What is the speed of light in glass, where the refractive index is 1.5? (c) Infrared light travels at 7.5×10^7 m/s in Germanium; what is the refractive index?