Notes for Lecture 9

Light

9.1 Law of reflection, law or refraction

As we start Chapter T32 and first consider a plane mirror, we use the law of reflection $\theta_i = \theta_f$.

You are quite encouraged to prove this law of reflection using Fermat's principle, as discussed on line as an extra credit question. Other ways include the momentum conservation and the following.

Proving the law of reflection

Note that the law of reflection ($\theta_i = \theta_f$) can be proven by using the "time-reversal symmetry principle." According to this principle, if a physical process is possible, then another physical process which corresponds to the version of the first physical process, but played in reverse, just as you would play a movie backwards, is also a possible physical process, *if* no damping/heat-involving mechanism is considered. This symmetry principle holds for most microscopic laws.

9.2 Index of refraction

Due to the interaction of light and matter (electrons, mostly, and also other particles such as protons), light slows down in matter. This is summarized by

$$n \geq 1 \qquad \text{index of refraction} \tag{9.1}$$

$$v = \frac{c}{n} \qquad \text{speed of light in a medium} \tag{9.2}$$

$$\lambda = \frac{\lambda_v}{n} \tag{9.3}$$

where in the last equation, λ is the wave length in medium, while λ_v is the wave length in vacuum. As usual, here we are concerned with v of a travelling wave, not a standing wave ($v = 0$). This last equation above ensures that the frequency of a given monochromatic light wave never changes (LN 6). Inside the medium, the frequency must be given by $f = v/\lambda$, and this matches the frequency in vacuum c/λ_v. Lastly, c is the speed of light in vacuum = 3.00×10^8 m/s, one of the most important constants of Nature.

Note that in some special frequency regime, some artificial materials give a negative index of refraction $n < 0$. They are interesting research materials, not considered in this course.

9.3 Snell's law

This law can be derived in a variety of ways, using Fermat's principle (feel free to do it on the forum), momentum conservation (as you can easily do *if* you know a bit of modern physics and make use of the above definition of the index of refraction; I am not requiring you to do this, yet, naturally), the Huygens/Feynman view of how light propagates (each point of a wave front is itself a new source of wave, and all of those waves interfere!), or simply by using the boundary condition that D must be continuous at the medium boundary (cf., LN 6). However, in this course, it is more important to know how to *use* Snell's law, than to know how to derive it. The law is given by

$$k_1 \sin\theta_1 = k_2 \sin\theta_2, \tag{9.4}$$

$$n_1 \sin\theta_1 = n_2 \sin\theta_2. \qquad \text{See Figure T32-21 for the defintion of symbols.} \tag{9.5}$$

The first form, in terms of wave vectors, is valid for any wave, while the second form is specialized for light.