

## Chapter 33

# The Nature and Propagation of Light

### 33.1 Light Wave Terminology and Basics

8/10:

- **Geometric optics:** The study of situations in which EM radiation interacts with objects (possibly with holes) such that  $\lambda \ll$  size of obstacles, holes.
- **Physical optics:** The study of situations in which EM radiation interacts with objects (possibly with holes) such that  $\lambda \approx$  size of obstacles, holes.
- **Ray:** An imaginary line, perpendicular to the wave fronts, that indicates the direction of propagation.
- Any time a wave hits a medium, you get reflection and transmission.
- **Huygens principle:** All points on a wavefront act as point sources of spherical wavelets. After a time  $\Delta t$ , the new position of the wavefronts is the surface of tangency of the wavelets.

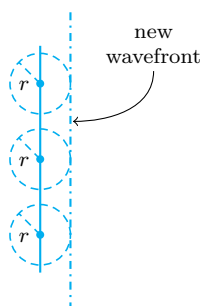


Figure 33.1: Huygens principle.

- The radius  $r$  of the wavelets, in terms of the time  $\Delta t$  from their creation, is  $r = c\Delta t$ .
- Light rays hitting a surface (see Figure 33.2).
  - Since the triangles containing the **angle of incidence** and the **angle of reflection** ( $\triangle ACD$  and  $\triangle ABD$ , respectively) share  $\overline{AD}$ ,  $r$ , and a right angle (see Figure 33.2c), we have that they are identical.
  - Thus,  $\theta_1 = \theta_2$ .
  - Since light rays have a constant phase offset (specifically,  $90^\circ$ ) from light waves, it follows that light rays also reflect off of surfaces with their original angle of incidence.
- **Angle of incidence:** The angle with which wavefronts hit a surface, or the angle a light ray makes with a normal to a surface.

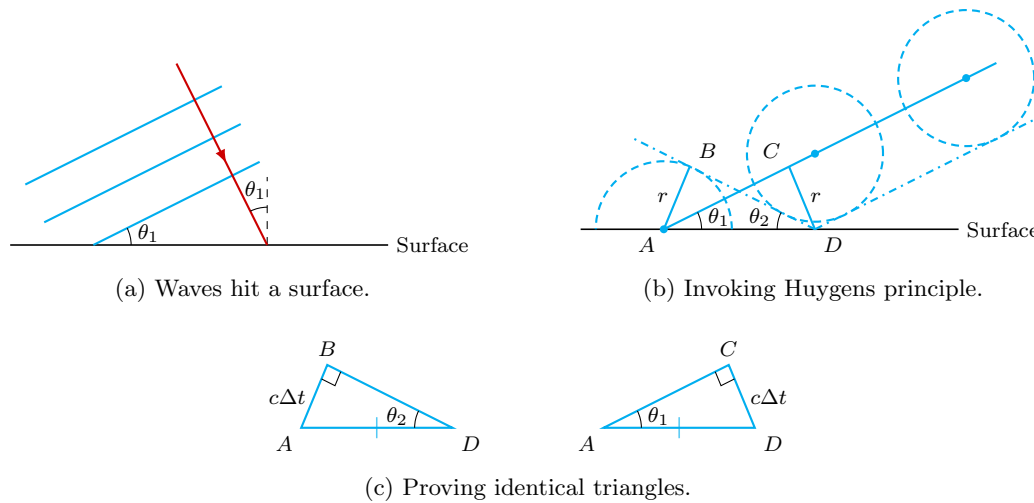


Figure 33.2: Properties of reflecting waves.

- The quantity  $\theta_1$  in Figure 33.2.
- **Angle of reflection:** The angle with which the reflected wavefront intersects with a surface.
  - The quantity  $\theta_2$  in Figure 33.2b.
- **Law of reflection:** The principle that  $\theta_1 = \theta_2$ .

## 33.2 Reflection

- Corner reflector:

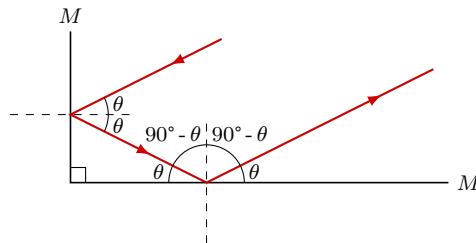


Figure 33.3: Corner reflector.

- The law of reflection implies that the ray entering at an angle  $\theta$  will exit at the same angle, just displaced a bit.
- If you don't want radar to detect planes:
  - Eliminate right angles (they're corner reflectors).
  - Make the surface something that absorbs radiation (hi tech ceramic).
- Mirrors create images; tie to projective geometry.
  - Seeing an object in the mirror is equivalent to seeing it as far behind the mirror as the thing is in front of the mirror.
  - This is **ray tracing**!

- **Virtual image:** An image that is created by light rays that don't really exist, i.e., projected light rays.
- Mirrors don't reverse left and right; they reverse front and back.

### 33.3 Refraction

- Light waves and glass.
  - Light waves enter glass, shake the atoms therein, and then those atoms emit their own light.
  - However, the light emitted by the atoms goes in all directions.
  - When you sum up all the secondary sources in a horrible integral, you end up with an effective wave propagating to the right, but at a speed less than the speed of light.
- **Index of refraction:** The quotient of the speed of light in a vacuum and the speed of light in a particular medium. *Denoted by  $n$ .*

$$n = \frac{c}{v}$$

- Since light can never travel faster than the speed of light,  $n \geq 1$ .
- Some common  $n$  values:
  - $n_{\text{water}} \approx 1.33$ .
  - $n_{\text{glass}} \approx 1.5$ .
  - $n_{\text{diamond}} \approx 2.5$ .
  - $n_{\text{air}} \approx 1.003 \approx 1$ .
- In materials,  $v$  changes and  $f$  remains constant, so  $\lambda$  changes.
  - $c = f\lambda$  and  $v = f\lambda'$  imply that

$$\lambda' = \lambda \cdot \frac{v}{c} = \frac{\lambda}{n}$$

- In a surface, the wavefront gets bent.

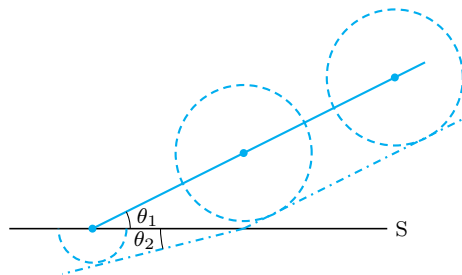


Figure 33.4: Properties of refracting waves.

- Similarly, the ray gets bent.
- When looking from air into a different surface,  $\theta_2 < \theta_1$ .
- Explains why when you reach for something in water, it appears closer and in a different spot — you're reaching for the virtual image!
- **Angle of refraction:** The angle with which the refracted wavefront intersects with a surface.
  - The quantity  $\theta_2$  in Figure 33.4.
- **Snell's law:** The formula  $n_1 \sin \theta_1 = n_2 \sin \theta_2$ . *Also known as law of refraction.*

- **Critical angle:** The angle of incidence such that light will be refracted at  $90^\circ$ .
  - If  $\theta_{\text{inc}} > \theta_{\text{crit}}$ , you only get reflection!
  - From Snell's Law,
$$\theta_{\text{crit}} = \sin^{-1}(n_2/n_1)$$
- **Total Internal Reflection:** Conditions such that all light is reflected and none is refracted. *Also known as TIR.*
  - Only a possibility when the light wave is moving to a medium with a lower index of refraction.
- If you have a glass rod and you put light in at one end at an angle greater than the critical angle, it will be trapped and can only come out at the other end.
  - Total internal reflection allows us to redirect light however we want.
  - Light “flowing” through this construction is analogous to water flowing through a pipe.
  - As long as the angle we bend the light pipe at isn't too sharp, it will stay trapped in the light pipe.
  - In a well-designed light pipe, you will lose very little intensity.
  - This is the principal behind fiber optics.
  - You lose current in a wire due to resistance, but you don't lose much intensity in a light pipe.

### 33.4 Office Hours (Pandey)

- 8/11:
- Can you explain the upwards and downwards displacement currents in Figure 32.3?
    - Not really.