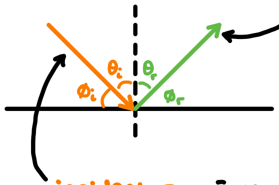
# Specular and diffuse reflection 1

7/29/18

* Reflection
  - Two types:
    ① Specular Reflection



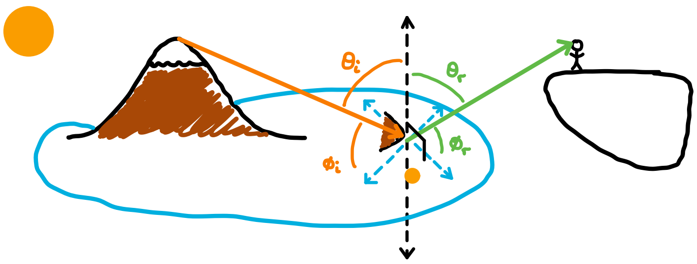

reflective ray = ray that bounces off the reflective surface

incident ray = ray approaching the reflective surface

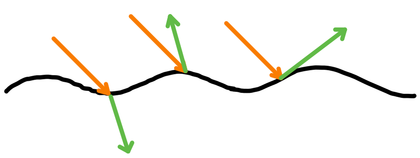
$\theta_i$ = the angle of incidence ; $\theta_i + \phi_i = 90°$

$\theta_r$ = the angle of reflection ; $\theta_r + \phi_r = 90°$

- A defining property of specular reflection: $\theta_i = \theta_r \therefore \phi_i = \phi_r$
- Example: Reflection of a mountain on a lake being observed by an observer standing on a cliff




② Diffuse Reflection
- Involves light reflecting off an unsmoothe surface
  - ~ Examples
    - Light that isn't reflected by the mirror
    - An observer observing light reflected directly by the mountain
- The molecules that comprise an "unsmoothe" surface do various things to light
  - ⇒ Specifically, the reflected ray varies for the same incidence ray
  - ~ e.g.,

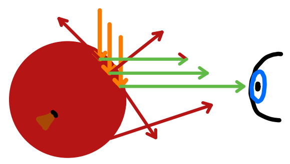


* Importantly, specular reflection "preserves" the image of the light from the incidence ray while diffuse reflection loses this info.
* Aside: white = the entire spectrum of light
  - Anything that is white (e.g., snow or paper) absorbs the entire spectrum of light
  - Anything w/ color (e.g., green leaves on a tree) absorbs every other frequency of light except green and then reflects the green back to the observer

# Specular and diffuse reflection 2

7/29/18

* Example of specular and diffuse reflection occuring simultaneously: Light shining on an apple



- The "shiny" point is where specular reflection occurs
- The rest of the apple is where diffuse reflection occurs

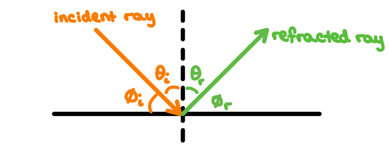
- If we move the apple or the observer moves to another part of the room, the shiny point (i.e., point w/ high specular reflection) on the apple will "move" as well (relative to the observer)
  - Specifically, the region w/ high specular reflection relative to the observer will be located s.t. the angle of incidence is approximately perpendicular to the surface of the reflective surface (i.e., the apple)
- Note: Each point on the apple is associated w/ some amount of specular reflection and some amount of diffuse reflection
  - The diffuse reflections are scattered in many different directions throughout the entire surface
    - => Regardless of where the observer observers the apple, he/she will see a similar image (excluding how the shape of the 2D-projection of the apple changes depending on where you view it from)
  - The size/region where specular reflection occurs will be most pronounced
    - => this is b/c each "pair" of observer-specular reflection points is associated w/ a MUCH narrower "bandwidth" of specular reflective light interacting w/ the observer's eyes

# Refraction and Snell's law

7/30/18

*Last two videos:

- **Specular reflection** = occurs when light bounces off a "smoothe" surface (e.g., a mirror)



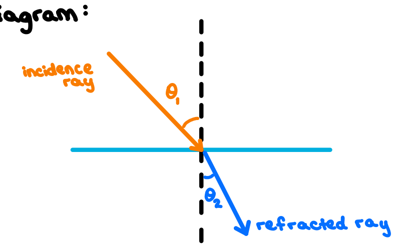

$\theta_i$ = the angle btwn the axis perpendicular to the reflective surface and the incident ray

$\theta_r$ = the angle btwn the axis perpendicular to the reflective surface and the reflective ray

- Defining property of specular reflection: $\theta_i = \theta_r$

*Refraction = occurs when light travels through a medium rather than bouncing off a surface

- **Example:** Consider a scenario where light is emitted onto a glass medium (or, any medium where light travels more slowly) in a room that is a vaccum everywhere else
  - Diagram:

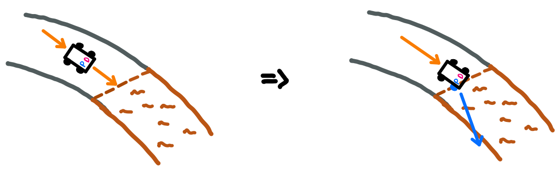



~Here, $\theta_1$ = inciecence angle

$\theta_2$ = refraction angle

*Aside: Depending on the context, there are different ways to "treat" light (e.g., a ray vs. a photon)

- For refraction, it helps to think of light as a car travelling along a newly-paved road that turns into a bumpy dirt road
  - The incidence ray travelling through the vaccum (at max speed, $v_1 = c = 3 \cdot 10^8$ m/s) corresponds w/ the car travelling along the newly-paved road
  - The refractive ray travelling through the glass medium (at a hindered speed, $v_2 < c$) corresponds w/ the car travelling along the bumpy dirt road
- Diagram:



**Note: This is NOT the actual mechanics underlying the bending of light

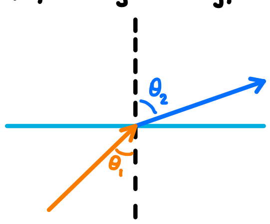
- At the point where the car first encounters the dirt road, the front-passenger tire will be the first to roll over the dirt/bump road

=> at this point, the front passenger tire will slow down relative to the other three wheels

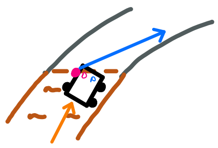
=> driver's side of the car will be travelling w/ a higher velocity relative to the passenger's side until the car has completely crossed over to the other side of the road and the wheels "re-synchronize"

=> during this short period of time, the car will start to turn about the slower (i.e., passenger) side

*we can continue using our car analogy to describe the case where the incidence ray is emitted inside our glass medium (or, more generally, any other medium) and the refractive ray bounces off the glass surface into the vaccum:

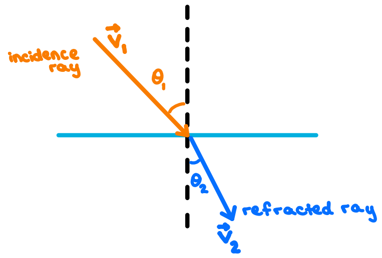



- This corresponds w/ our car travelling NE from a bumpy, dirt road onto a newly-paved road:



- Here, the driver's side is traveling faster than the passenger's side => the car will turn about the passenger (i.e., slower) side

* The analogy btwn a car traveling along bumpy/paved roads and refraction gives some intution behind Snell's law
- Diagram of light emitted from a source into a vacuum and through a glass medium (from beginning of the video):




- Let $v_1 = |\vec{v}_1| = c = 3 \cdot 10^8$ m/s be the speed of the incident ray (travelling through a vaccum, ∴ @ max speed)
  - $v_2 = |\vec{v}_2| < c$ be the speed of the refracted ray (travelling through the glass medium)
  - $\theta_1$ be the angle of incidence
  - $\theta_2$ be the angle of refraction

★Recall: pure vaccum = region w/ NOTHING (not even a single atom) in it

* **Snell's Law:**

$$\frac{v_2}{\sin\theta_2} = \frac{v_1}{\sin\theta_1}$$

- Aside: **"Index of Refraction"** (or, **"Refractive Index"**)
  - A number, $n$ assigned to materials s.t.

$$n = \frac{c}{v}$$ where $c = 3 \cdot 10^8$ m/s (speed of light in a vaccum)
$v$ = speed of light in a medium made of the material

~**Note:** $n \uparrow$ as $v \downarrow$
- For a vaccum, $n = c/c = 1$
- In air, $n \sim 1.00029$
- In a diamond, $n \sim 2.42$

- A more typical form of Snell's Law is written in terms of the Index of Refraction
  - Specifically, it substitutes in $v_i = c/n_i$ and simplifies
  - For our example, let $n_1$ denote the refractive index for the the material that the incidence ray travels through, $n_2$ be the refractive index for the material the refractive ray travels through and $c = 3 \cdot 10^8$ m/s

$$\Rightarrow \quad v_1 = \frac{c}{n_1} \quad \text{and} \quad v_2 = \frac{c}{n_2}$$

$\Rightarrow$ Rewrite Snell's Law: $$\frac{\left(\frac{c}{n_2}\right)}{\sin\theta_2} = \frac{\left(\frac{c}{n_1}\right)}{\sin\theta_1} \Rightarrow \frac{1}{n_2}\frac{1}{\sin\theta_2} = \frac{1}{n_1}\frac{1}{\sin\theta_1}$$

~Take the reciprocal of both sides:

$$\left[\frac{1}{n_2}\frac{1}{\sin\theta_2} = \frac{1}{n_1}\frac{1}{\sin\theta_1}\right]^{-1} \Rightarrow \boxed{n_2\sin\theta_2 = n_1\sin\theta_1}$$

* **Take-Home Message:** There are two forms of Snell's Law

① $$\frac{v_2}{\sin\theta_2} = \frac{v_1}{\sin\theta_1}$$ Uses the speeds of the incidence & refractive rays

② $n_2\sin\theta_2 = n_1\sin\theta_1$ Uses the refractive index, $n = c/v$ of the respective materials the incidence & refractive rays are traveling through

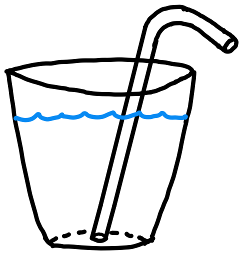
# Refraction in water

9/26/18

* Q: Why do things appear "bent" when partially submerged under water and viewed from certain angles?

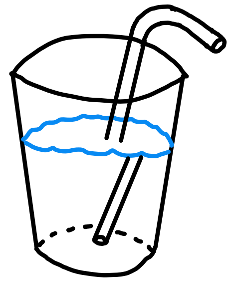
- Example: A straw in a cup of water:

Point of View 1:



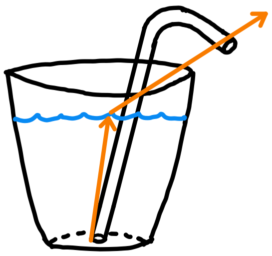
vs.

Point of View 2:



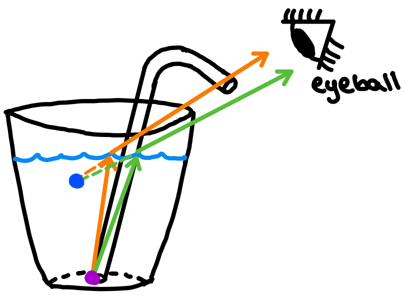
=> As it turns out, this difference is due refraction => changes in the way light behaves as it goes from one medium to another

- Recall: We know light travels slower in air than in water
  - ~ Consider a ray of light originating from the bottom of the glass at a slight angle:



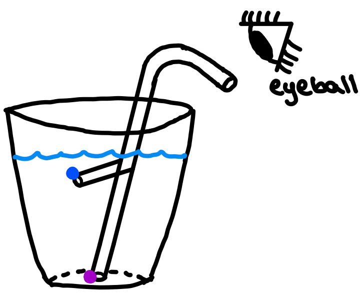
- Since the light ray is oriented at an angle, the left side of the ray is going to reach the air medium (faster) before the right side
  => Like our car analogy a few videos ago, this is going to cause our light ray to veer to the right

~ Now, consider a second light ray that originates from the same point as the first light ray:




- Our second light ray will also veer to the right for the same reasons the first light ray did

- Q: From the PoV of the eyeball, where will the two light rays appear to have originated?
  - The eyeball's brain will percieve the (bent) light rays that are hitting the eyeball as unbent
  - E.g., the diagram above shows light rays originating at the purple point on our straw will be percieved as if the originated from the blue point
    => Doing this for all points along the submerged portion of the straw causes it to appear bent:



Snell’s Law example 1

Snell’s Law example 2

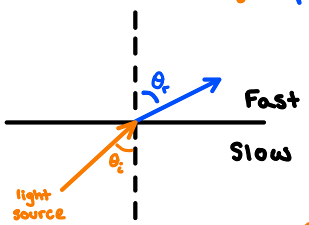
# Total internal deflection

3/1/19

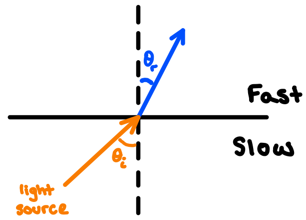
**Last Few Videos:**

- **Refraction:** Occurs when light propagates from one medium into another
- Two cases:

① Light travelling from a slow medium into a fast medium $\Rightarrow \theta_i < \theta_r$



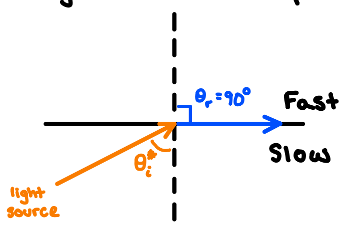

② Light travelling from a fast medium into a slow medium $\Rightarrow \theta_i > \theta_r$



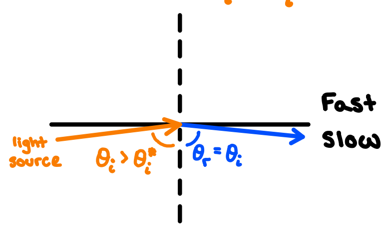

★Note: $\theta_i$ = angle of incidence
$\theta_r$ = angle of refraction

**Consider case 1**

- Q: Does there exist some "critical" incident angle $\theta_i^*$ s.t. $\theta_r = 90°$? (yes!)
  - Diagram: Light doesn't "escape" into the fast medium for $\theta_i \geq \theta_i^*$

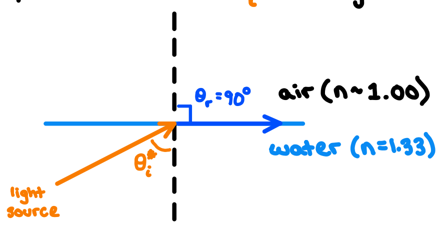



For $\theta_i = \theta_i^*$, the refracted ray propagates along the surface separating the two mediums $\Rightarrow$ agrees w/ $\theta_r = 90°$




For $\theta_i > \theta_i^*$, our refracted ray ends up reflecting back into the fast medium! $\Rightarrow$ this is called internal reflection

- Assuming $\theta_i^*$ exists, is there a way we can determine it? (yes! We can use Snell's Law)
  - ~ Example: Determine $\theta_i^*$ for light traveling from water (slow medium) into air (fast medium)




- Recall: Snell's Law, $n_r \sin\theta_r = n_i \sin\theta_i$
  - ~ Here, we have $n_r \sim 1.00$, $n_i = 1.33$, and $\theta_r = 90°$

$$\Rightarrow (1.00)\underbrace{\sin(90°)}_{=1} = 1.33\sin\theta_i^* \Rightarrow 1 = 1.33\sin\theta_i^*$$

$$\Rightarrow \frac{1}{1.33} = \sin\theta_i^* \Rightarrow \theta_i^* = \sin^{-1}(0.7519) \approx 48.7535°$$

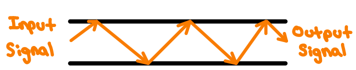
$$\Rightarrow \boxed{\theta_i^* \approx 48.7535°}$$

- More generally, we can use Snell's Law to write

$$n_r \underbrace{\sin(90°)}_{=1} = n_i \sin\theta_i^* \Rightarrow \boxed{\theta_i^* = \sin^{-1}\left(\frac{n_r}{n_i}\right)}$$

critical angle of incidence for light traveling from a slow medium into a fast medium

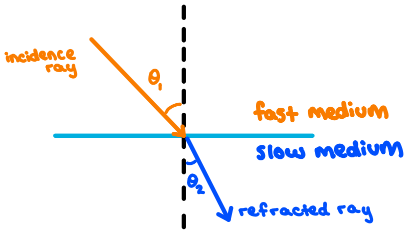
**Note: Fiber optic cables make use of internal reflection** by emitting light rays at an angle greater than $\theta_i^*$ $\Rightarrow$ reflected light rays "propagate" down a glass tube (instead of escaping into the air) $\Rightarrow$ allows info. to be sent in the form of light over long distances



# Dispersion

3/1/19

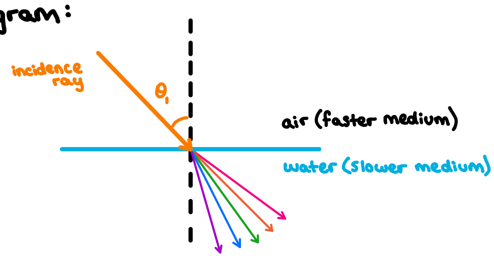
✱ **Snell's Law Review**




$$n_2 \sin\theta_2 = n_1 \sin\theta_1$$

✱ **Dispersion** occurs when an incidence ray of white light separates into individual colors after crossing into another medium

- Diagram:




- **Q: What causes dispersion?**
  - The index of refraction turns out to be a function of the wavelength of the EM signal for most substances
    ⇒ The quantities given in most textbooks list a substance's index of refraction that is an approximation in the range of visible light
    ~e.g., the index of refraction of red light in water is $n_{red} = 1.33$ while the index of refraction for blue light is $n_{blue} = 1.34$
- Note: In most materials, light w/ higher wavelengths bend more when passing btwn mediums