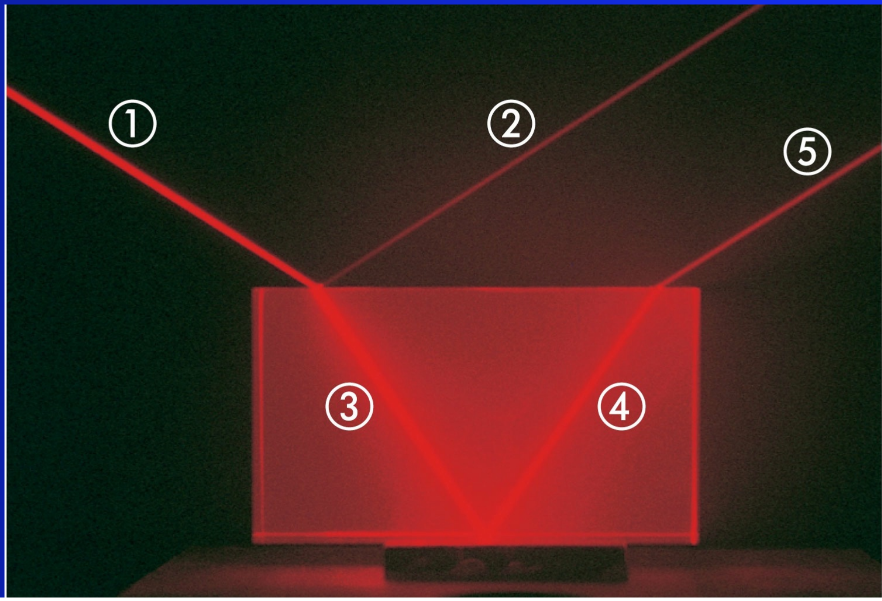
Physics 1C: Reflection & Refraction of Light

Monday, 27 April 2015



Reminders & Information

- Quiz #2 results…
- grading info now available on the TED course website: remember that quiz scores are out of 9 pts, participation out of 10
- note: my office hours will be on ***Wednesday***, not today, this week
- if you want to do extra credit assignment, it's due Friday
- if you're interested: "CIRCUS: Science Under the Big Top" exhibition from Toronto will be at Fleet Science Center starting this Saturday

a quick note on citizen science

- CosmoQuest: Mars Mappers, Moon Mappers, Mercury Mappers, other projects… http://cosmoquest.org/

- Galaxy Zoo/Zooniverse: variety of projects including Snapshot Serengeti, Cell Slider, Old Weather… http://galaxyzoo.org, http://www.zooniverse.org

International Year of Light

http://www.light2015.org/

Dual Nature of Light

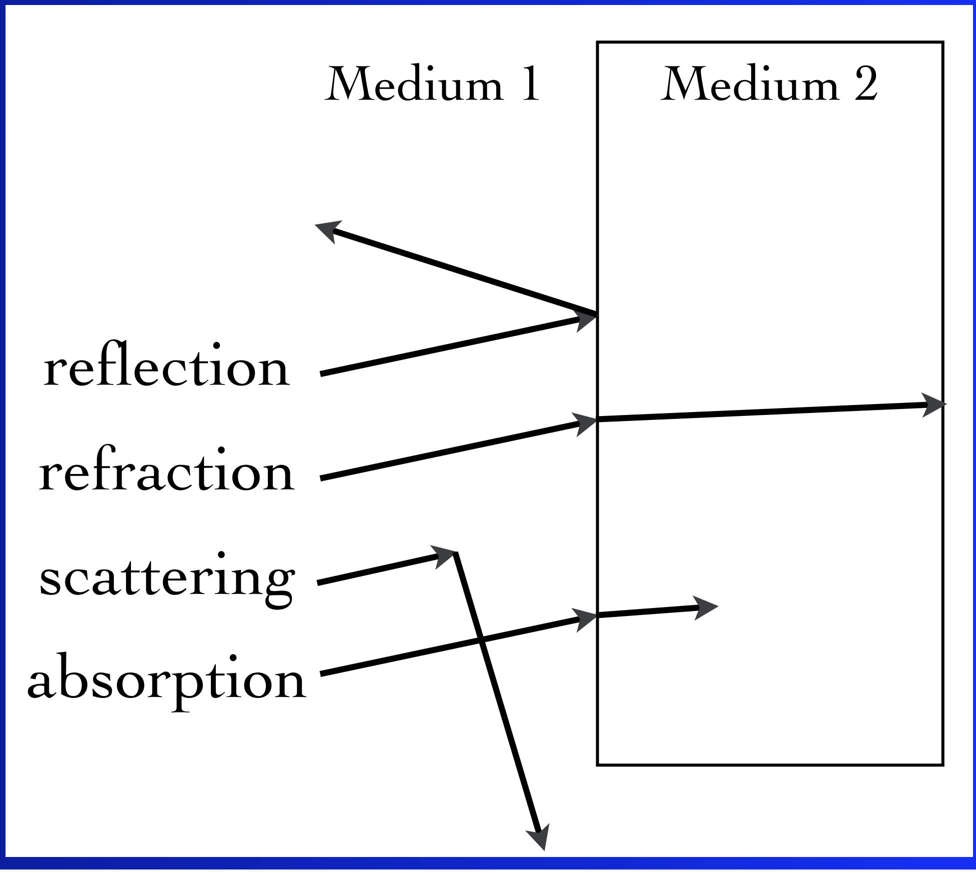
- wave nature of light discovered in 17th century by Dutch physicist & astronomer, Christian Huygens

- light usually acts as an electromagnetic wave, but *in some instances* acts as a particle, such as with "gravitational lensing," which pulls photons around massive objects

- recent discovery by Danish physicist Lene Hau (Harvard): it's possible to slow or stop light—turning it into atomic waves and then back into light!

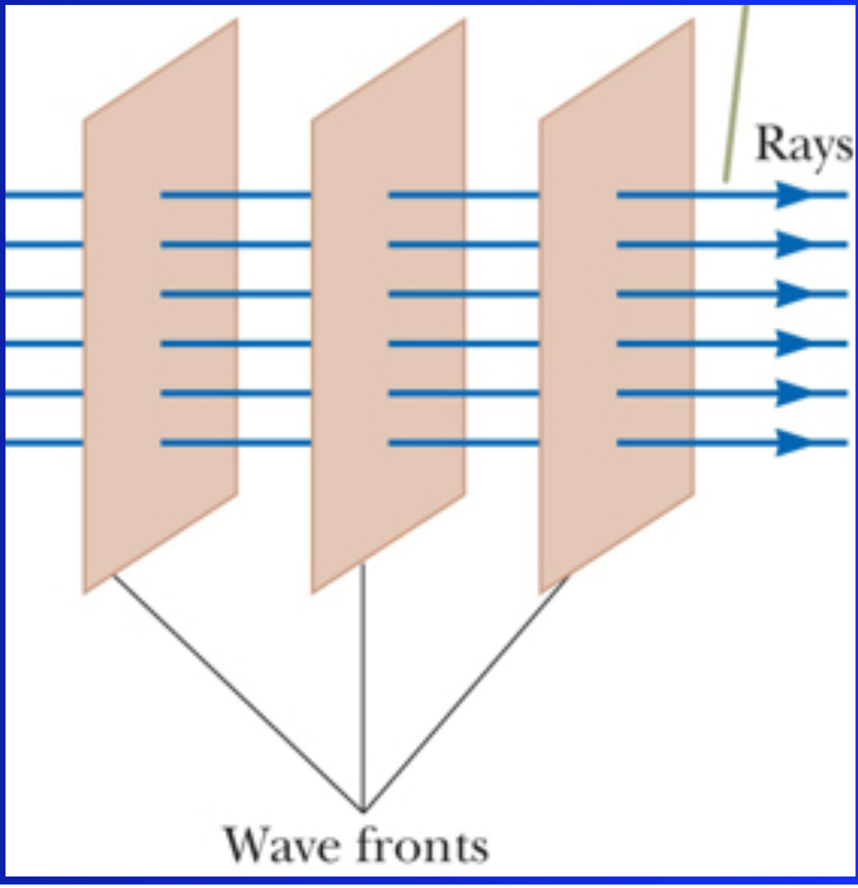
ray model of light

- light rays travel in straight lines in a given medium
- light rays can cross without affecting each other
- objects are sources of light rays
- light rays can interact with matter



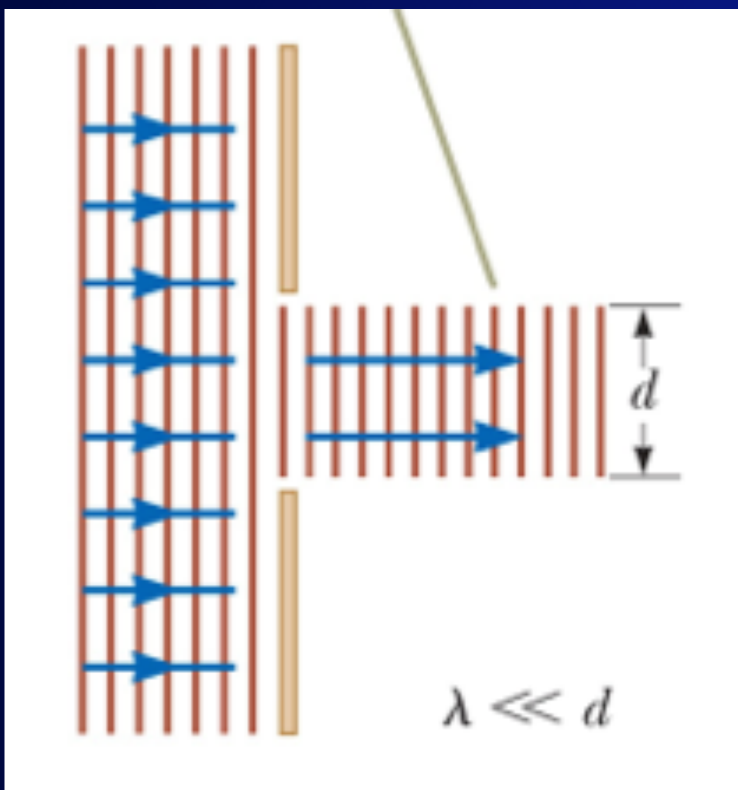
ray model in geometric optics

- "geometric optics": the study of the propagation of light
- a **ray**, or beam of light, is a straight line drawn along direction of propagation of the wave
- ray approximation: assume waves move through a medium in a straight line (in direction of its rays)

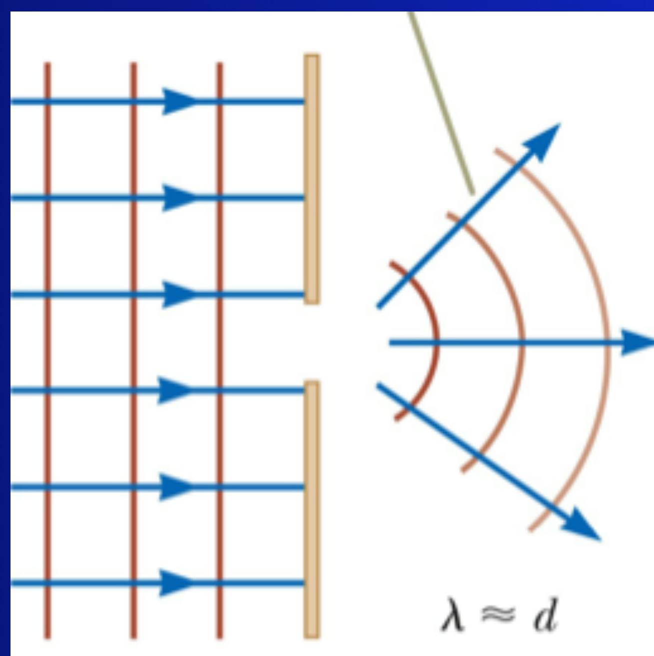


ray model in geometric optics

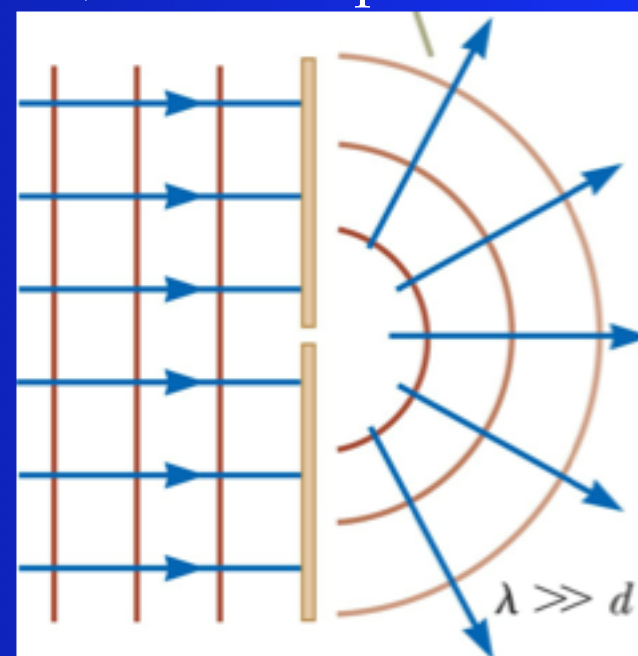
$\lambda \ll d$, ray model applies



$\lambda \sim d$, diffraction

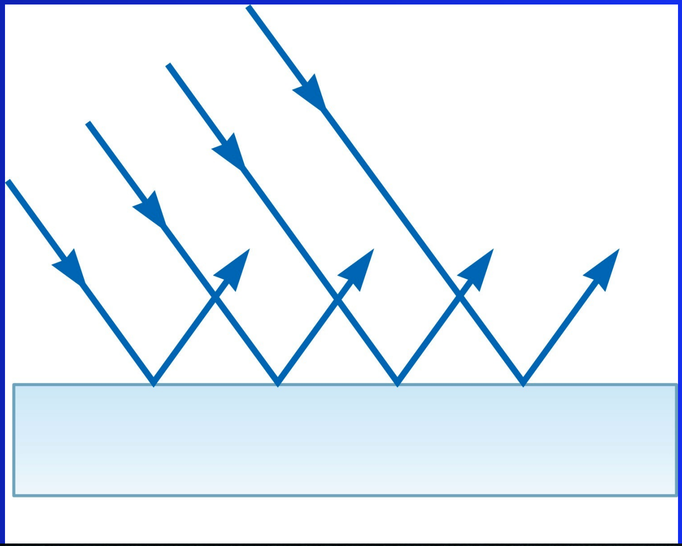


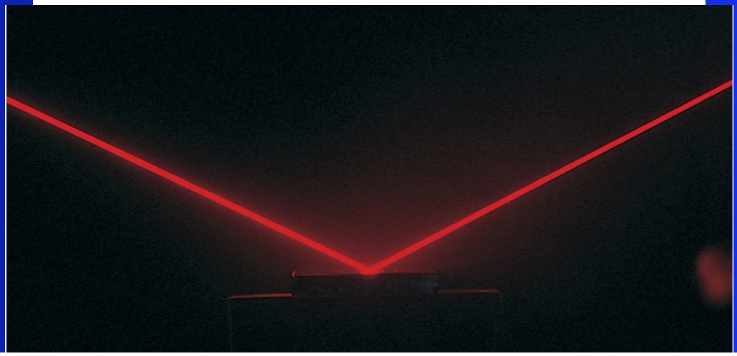
$\lambda \gg d$, slit's like point source



wave under reflection

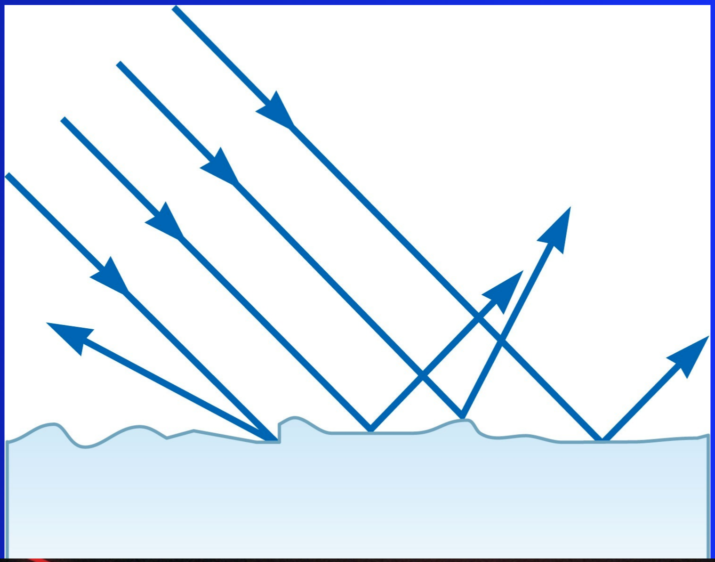
"specular reflection"
off a smooth surface

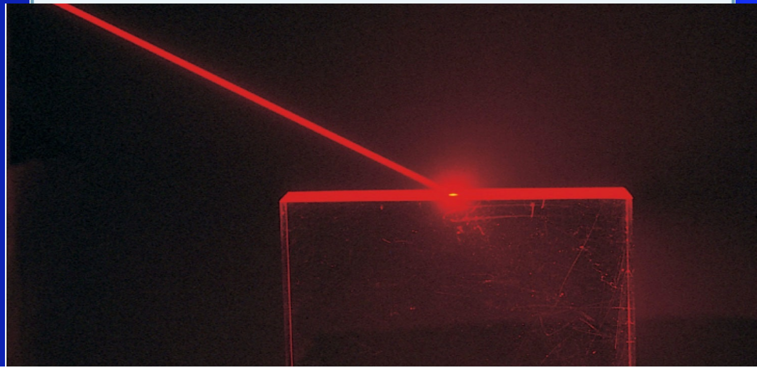




wave under reflection

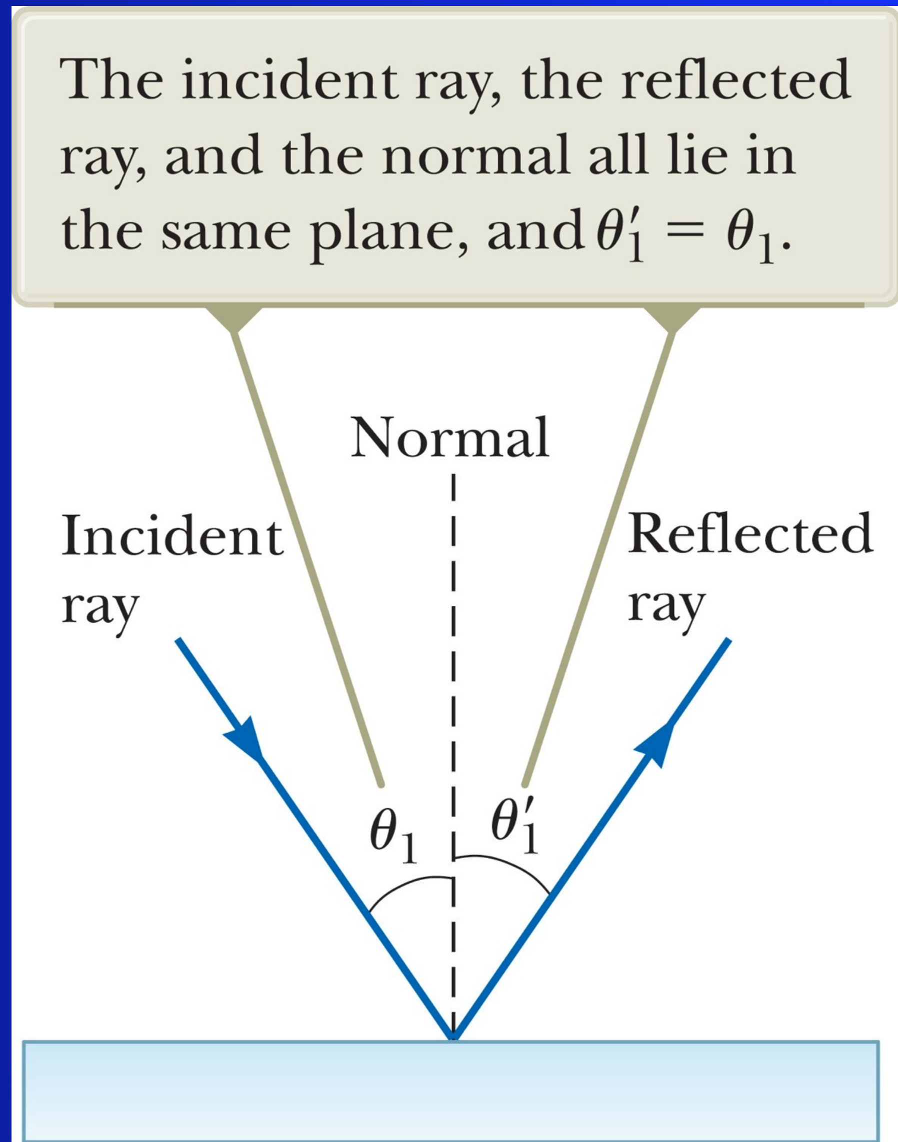
"diffuse reflection"
off a rough surface





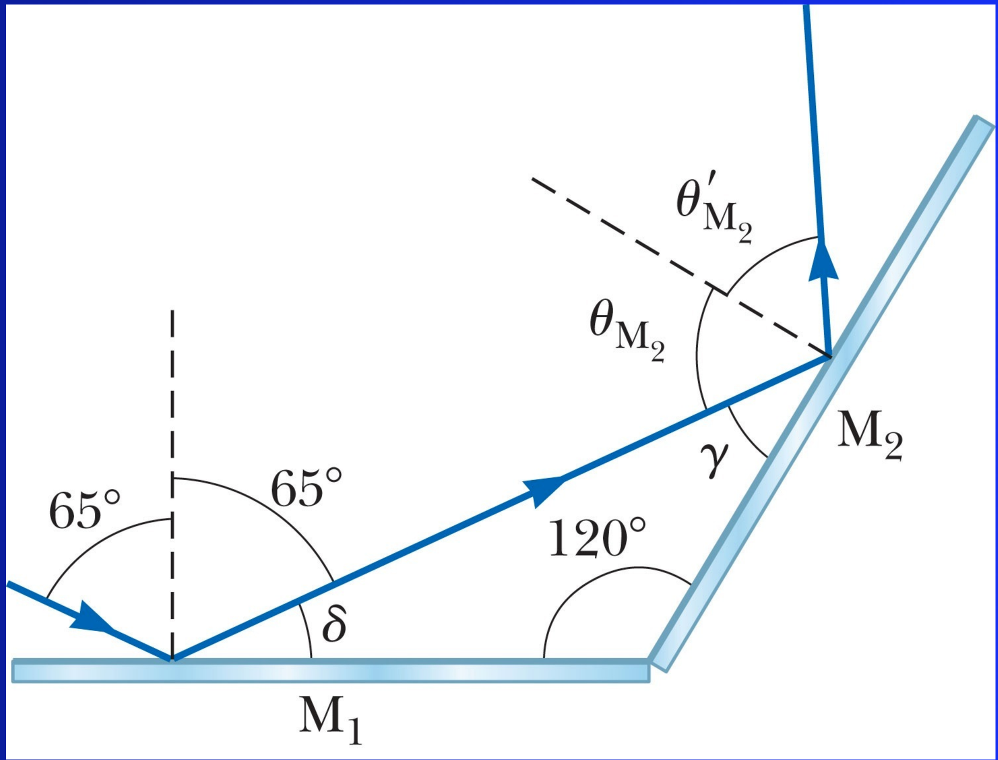
law of reflection

- the law of reflection:
  angle of incidence (θ_i) = **angle of reflection** (θ_r)
- note that all angles are measured with respect to the "normal"



example of law of reflection

Two mirrors make an angle of 120° with each other. A ray is incident on mirror M_1 at an angle 65° to the normal. Find the direction of the ray after it is reflected from mirror M_2. [Remember that $\theta_i = \theta_r$.]



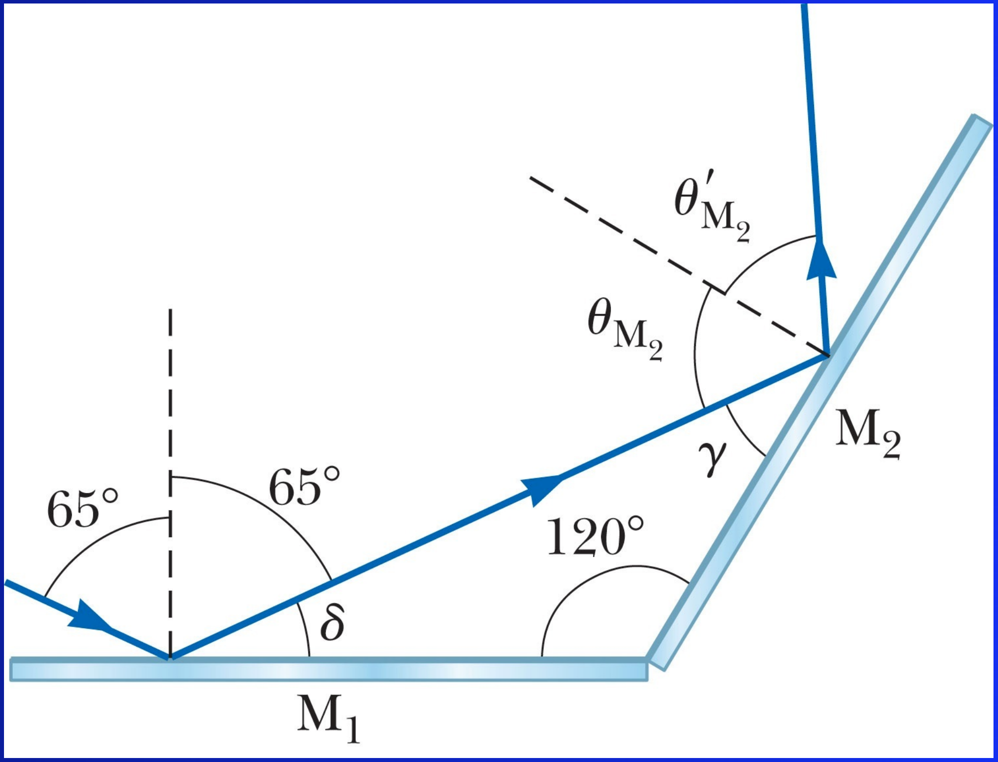
example of law of reflection

Two mirrors make an angle of 120° with each other. A ray is incident on mirror M_1 at an angle 65° to the normal. Find the direction of the ray after it is reflected from mirror M_2. [Remember that $\theta_i = \theta_r$.]

$\delta = 90° – 65° = 25°$

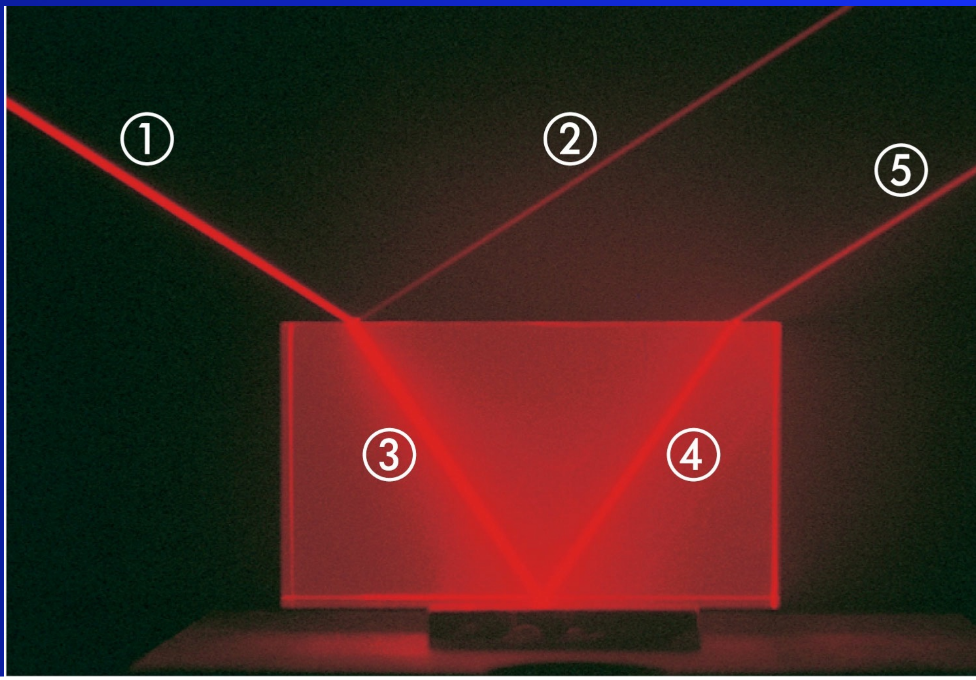
then $\gamma = 180° – 120° – \delta = 35°$

then θ_2 must be $90° – 35° =$ **55°**



wave under refraction

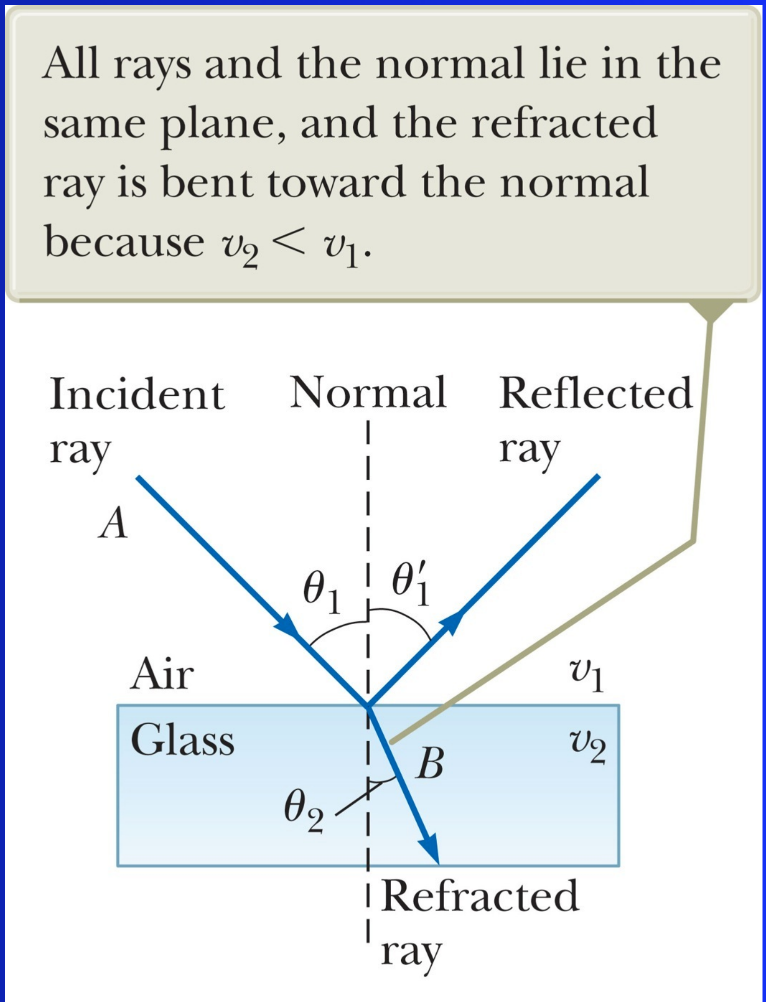
- when a light ray encounters a boundary leading to another transparent medium, part of the energy is reflected and part enters the second medium
- the part that enters the second medium is bent at the boundary due to *refraction*



wave under refraction

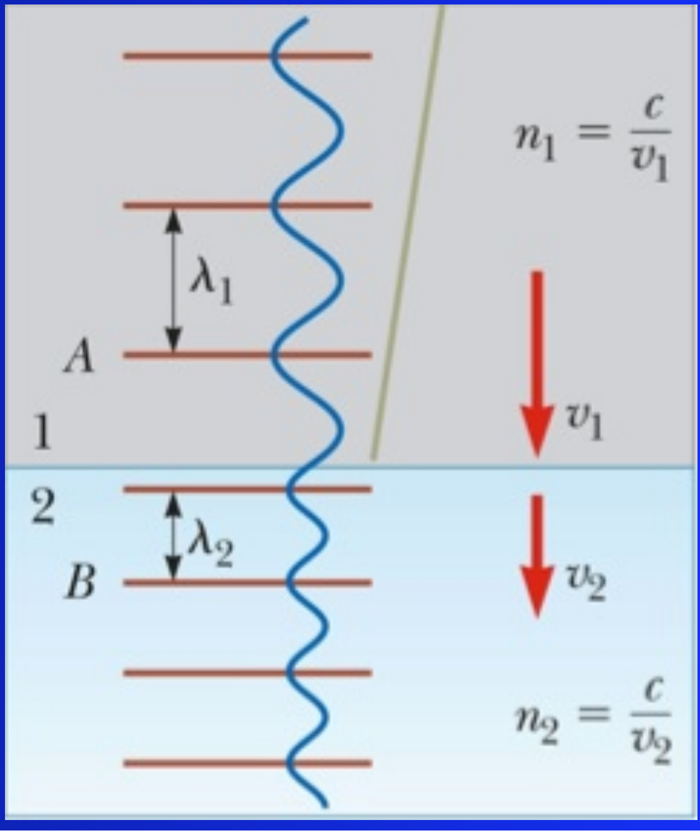
- the part that enters the second medium is bent at the boundary due to *refraction*
- index of refraction: $n = c/v_{\text{medium}}$
- refracted ray is bent toward the normal because $v_2 < v_1$, but its frequency remains constant
- angle of refraction θ_2 depends on the material and the angle of incidence θ_1

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



wave under refraction

- index of refraction: $\boldsymbol{n = c/v_{\mathbf{medium}}}$
- light travels slower in a medium than in a vacuum, where c = 299,792,458 m/s
- note that $n>1$!
- some refraction indices… glass: n=1.52; water ice: 1.309; water: 1.333; room temperature air: 1.0003
- so when light enters a block of glass, v drops to 2.0×10^8 m/s, and then its speed increases to its original value when it re-emerges into the air



example: index of refraction

- Red light travels from water (n=1.33) to air (n=1.00). When considering the light wave, which of the following is the ***SAME*** for the parts of the electromagnetic wave in water and the parts of the electromagnetic wave in air? [Recall that $n = c/v_{\text{medium}}$.]

  A. frequency

  B. wavelength

  C. both frequency and wavelength

  D. neither frequency nor wavelength

example: index of refraction

- Red light travels from water (n=1.33) to air (n=1.00). When considering the light wave, which of the following is the *SAME* for the parts of the electromagnetic wave in water and the parts of the electromagnetic wave in air? [Recall that $n = c/v_{\mathrm{medium}}$.]

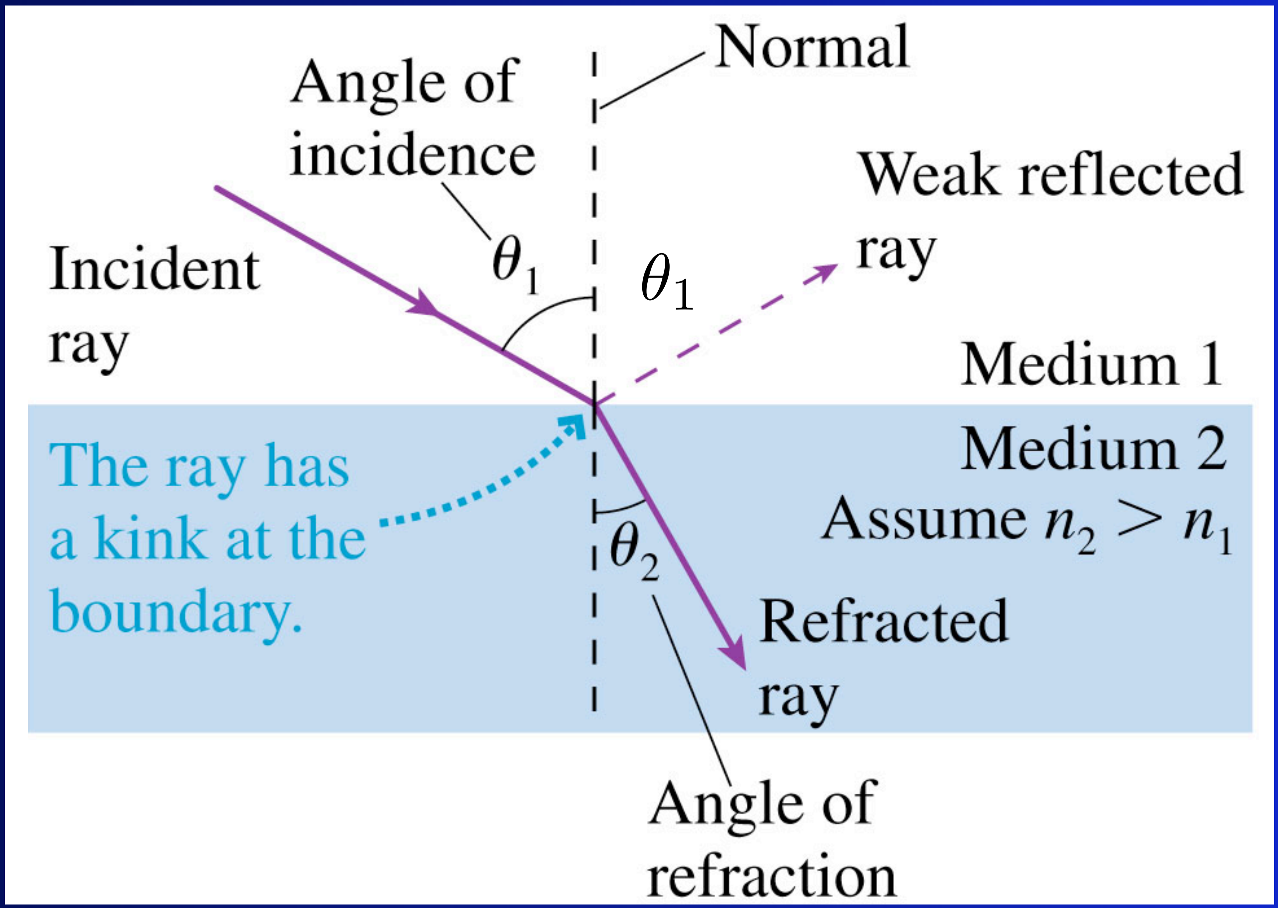
A. frequency

when n increases, v decreases, and since $v=\lambda f$, that means λ decreases too: $\lambda_1 n_1 = \lambda_2 n_2$

refraction: Snell's Law

Snell's law: $n_1 \sin\theta_1 = n_2 \sin\theta_2$

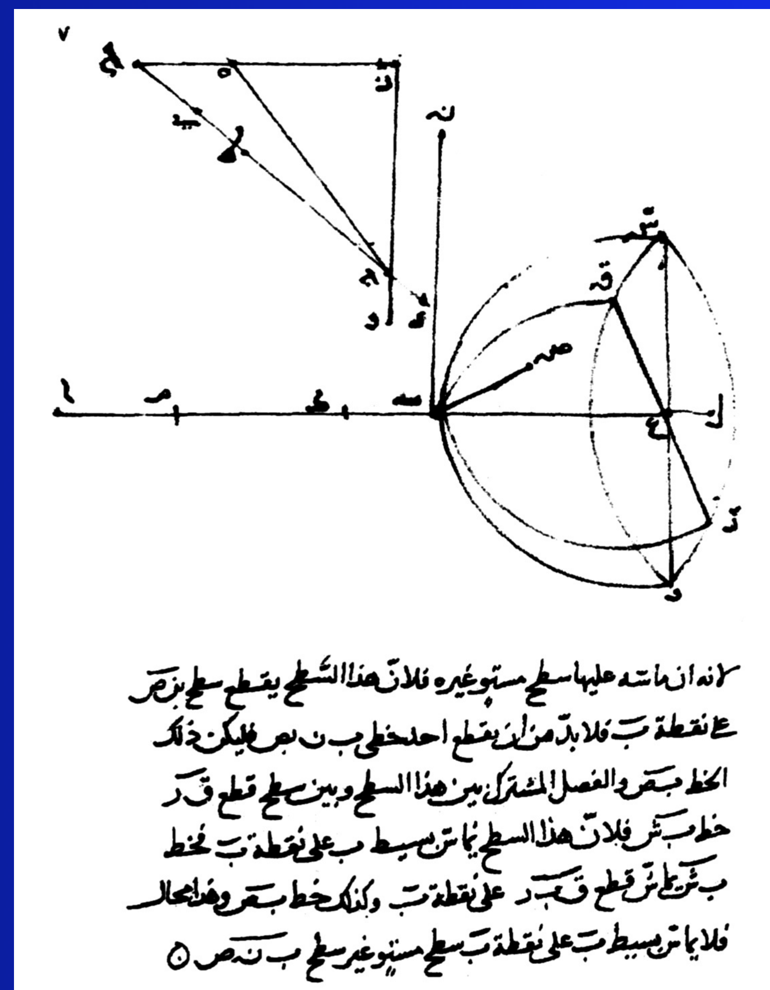
where all angles are measured with respect to normal



Snell's Law

"Snell's" law of refraction: $n_1 \sin\theta_1 = n_2 \sin\theta_2$

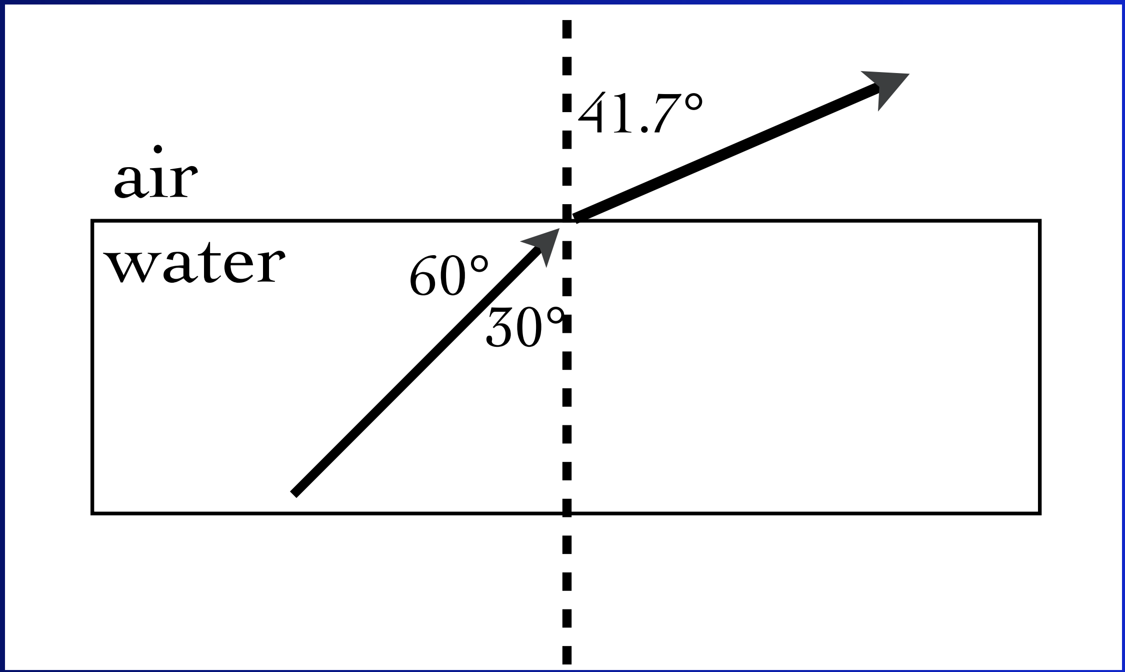
named after Dutch astronomer Willebrord Snellius (17th cent.), it was first discovered by Arabic physicist Ibn Sahl in Baghdad in 10th cent.



لأنه ان ماسه عليها سطح مستو غيره فلان هذا السطح يقطع سطح ب ن ص
على نقطة ب فلا بد من ان يقطع احد خطي ب ن ب ص فليكن ذلك
الخط ب ص والفصل المشترك بين هذا السطح وبين سطح قطع ق ر
خط ب ش فلان هذا السطح يماس بسيط ب على نقطة ب فخط
ب ش يماس قطع ق ع د على نقطة ب وكذلك خط ب ع وهذا محال
فلا يماس بسيط ب على نقطة ب سطح مستو غير سطح ب ن ص ○

example: refracted ray

Someone underwater shines a light toward the air.
Let's determine the refracted ray…



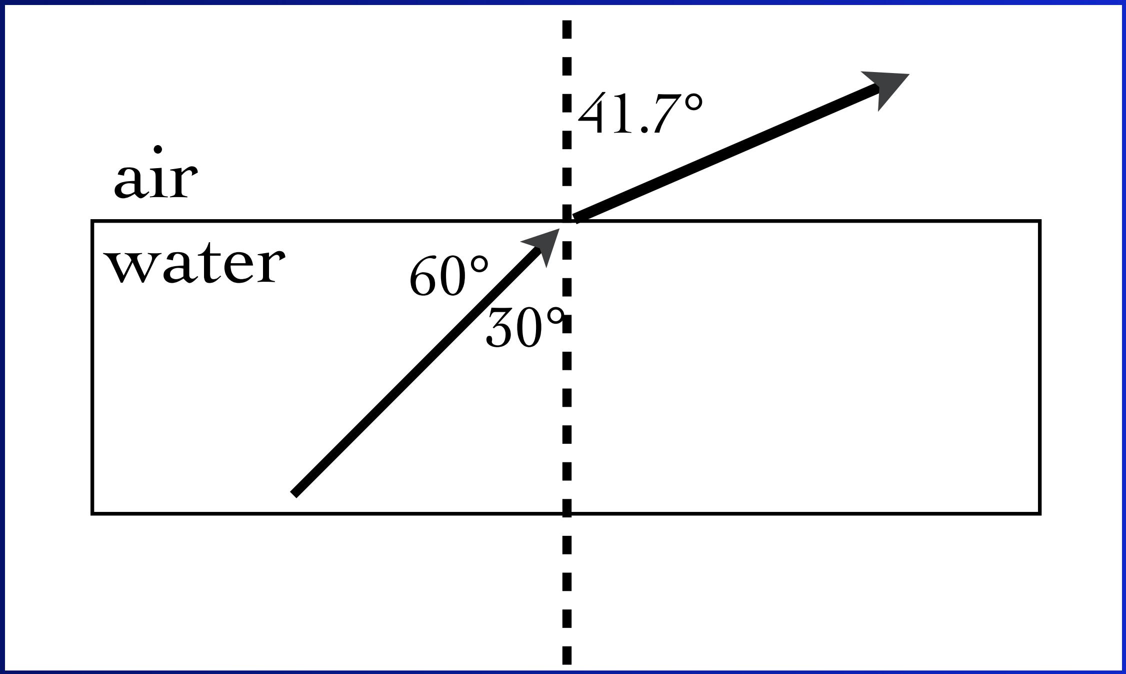
$n_1 \sin\theta_1 = n_2 \sin\theta_2$, so $(1.33)\sin 30° = (1.00)\sin\theta_2$

then $\sin\theta_2 = 0.665$, so $\boldsymbol{\theta_2 = 41.7°}$

example: refracted ray

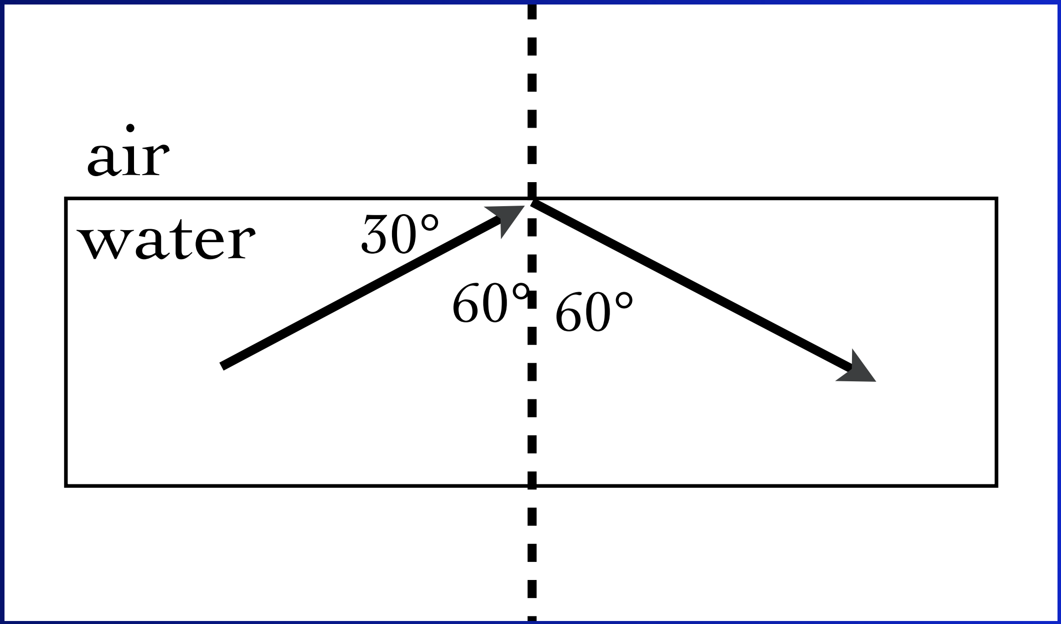
remember…

- high $n \rightarrow$ low n: angle goes away from the normal
- low $n \rightarrow$ high n: angle goes toward the normal



another example of refracted ray

Someone underwater shines a light toward the air, but at a larger angle. Let's determine the refracted ray…



$(1.33)\sin 60° = (1.00)\sin\theta_2$

then $\sin\theta_2 = 1.15$, so $\theta_2 = ???$ this is ***total internal reflection!***

total internal reflection

If the incident angle is larger than the critical angle θ_c, we have total internal reflection.

If the incident angle is smaller than the critical angle, refraction will occur.

$$\sin \theta_c = n_2/n_1$$

REFRACTION REVIEW

index of refraction: $\boldsymbol{n = c/v_{\mathrm{medium}}}$

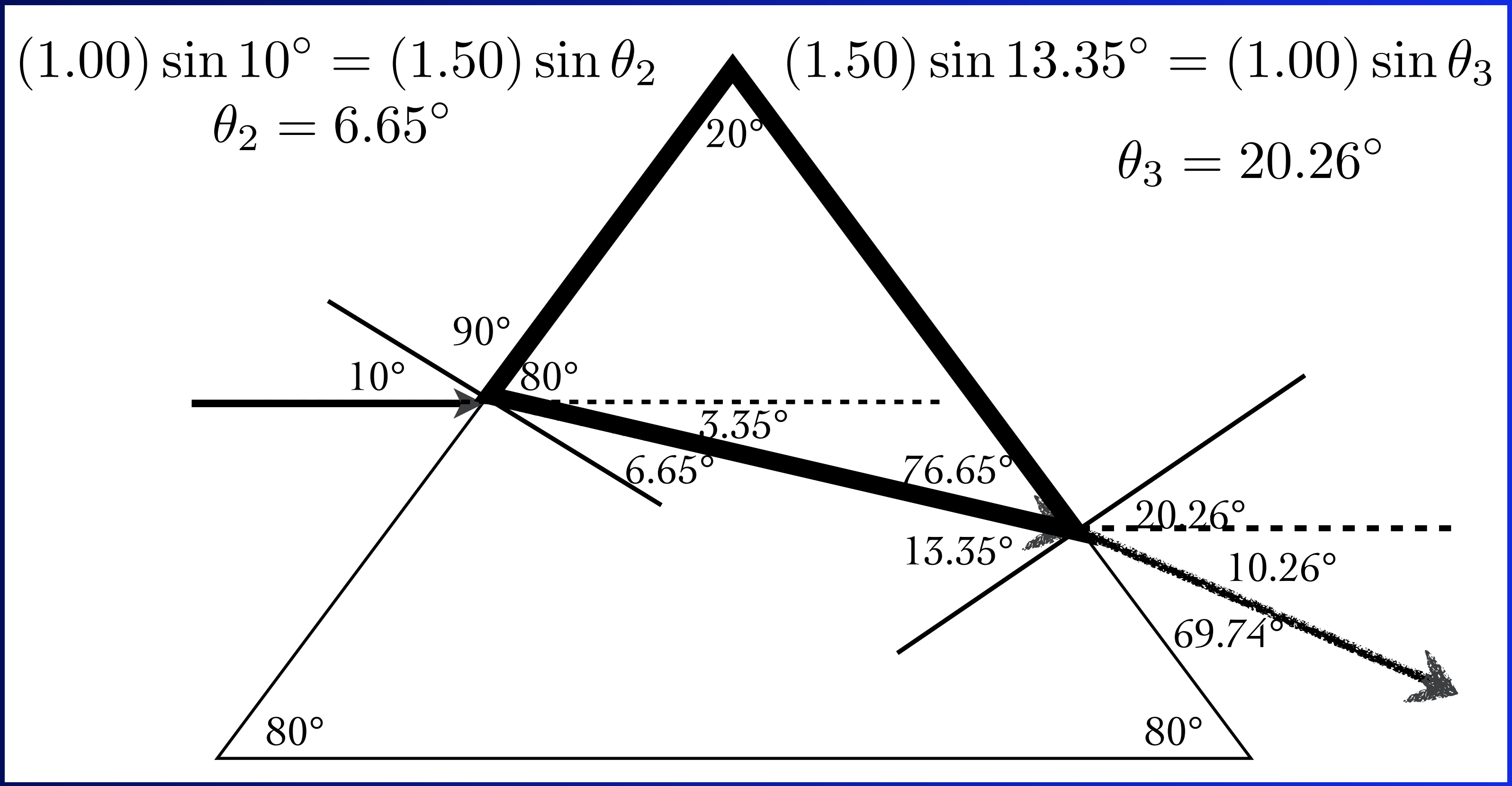
(and λ is modified too because $v = \lambda f$, but f=const.)

Snell's law: $\boldsymbol{n_1 \sin\theta_1 = n_2 \sin\theta_2}$

total internal reflection: $\boldsymbol{\sin\theta_c = n_2/n_1}$

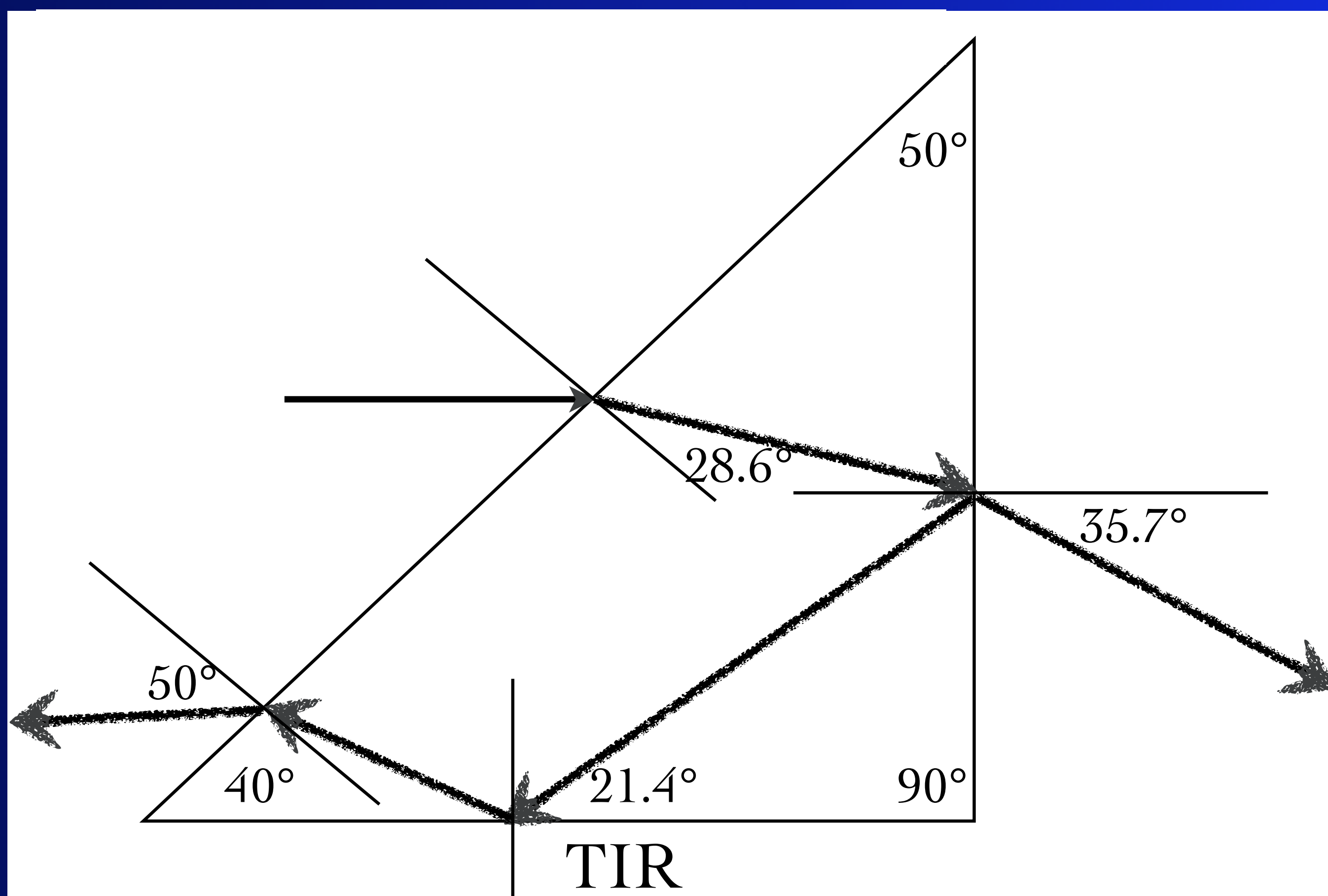
example: refraction through a prism

A ray of light travels from air into the glass (*n*=1.50) prism shown below. The triangle is isosceles with the top angle=20°. Determine the refracted ray…



example: refraction through a prism

A horizontal ray travels from air to a medium with n=1.60. At what angle does the ray exit the right side of the triangle? and the bottom? what about the left side?



For Wednesday:

1. make sure you understand the laws of reflection and refraction
2. read the next few sections of chapter 25 (up to 25.7)
3. start working on the HW problems