Bending Light

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Learning Goals

Resources

http://en.wikipedia.org/wiki/Snell's_law

http://en.wikipedia.org/wiki/List_of_refractive_indices

http://www.lon-capa.org/~mmp/kap25/Snell/app.htm

http://www.falstad.com/ripple/

http://wildcat.phys.northwestern.edu/vpl/optics/snell.html

Features

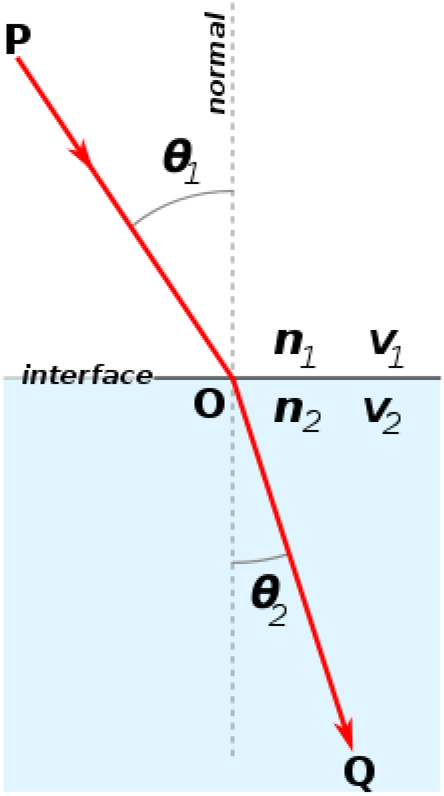
- Tab 1: Laser pointer and 2 media
  - Top media and bottom, separated by horizontal line
  - Different colors for media
  - Show normal as dashed line (default on?)
  - Sliders have ticks labeled for air, water, plastic, glass, etc
  - What to do when angle of incidence is zero? Overlapping rays...
  - Be able to hide reflected/transmitted beams (default on with checkbox)
  - Single wavelength of light - green or red (probably red)
- Can change angle of pointer and medium, see light ray refracted
  - Readouts of angles in ray view
  - Harder to do this in wave view
  - Can only set angle of incidence
- Intensities?
  - Show always or turn on / off?
  - Show a number for intensity reflected and refracted, and show as transparency of ray arrow

    - Or have intensity meter for numeric readout?
    - Note that intensities depend on polarization of incident ray - we should just pick one and put this in teacher tips
- Wave view
    - Need something that you can grab and move
    - Show just tip of laser pointer? Problems with scale.
    - Different speeds of waves, needs to be based on correct model (have MD and KP check)
- Tools box
    - draggable protractor (transparent)
    - intensity meter (magic box)
        - reads 100% in incident beam, less in reflected and refracted
        - what to do in overlaping wave area? just label “???”
- Can change index of refraction (*n*)
    - Continuous slider with points marked for plastic, glass, water, oil (?)
- Can change wavelength of light
- Can set to white light or monochromatic
- Different shapes of glass (rectangle, triangle, circle, trapezoid, square?)
- Be able to change wavelength or n and see ray direction or colors change
- Multiple glass shapes at same time?
- Use two trapezoids to build a “lens”?
- Ray or wave view
    - Can see wave speed and wavelength change in different media
- See reflected and refracted percentages?
- Applications:
    - Fiber optic cable (total internal reflection) - make a signal go through
    - Swimming pool - total internal reflection, or change in apparent position of objects
    - Glass with object inside (pencil? straw?) - change in apparent position of objects
- More???

Physical Model

Snell’s law determines the angles of incidence and refraction for light passing through the boundary between different media (e.g. air and glass).

The figure below shows a light ray, P, Incident on an interface at O and the *transmitted* ray Q. (Note that this diagram does not include the *reflected* ray which would be present in medium 1.) Below, $n_2 > n_1$ which causes the ray to bend towards the normal when entering medium 2.



Incident beams with parallel and perpendicular E fields.

We should probably pick one of these polarizations and stick with it. My vote is for perpendicular, since that lets us show the E-field as “ripples” coming out of the screen. Or, we could have an option which lets users choose, showing the E-field as a sinusoid for parallel.

From “Principles of Physical Optics”, C.A. Bennet, p 70.

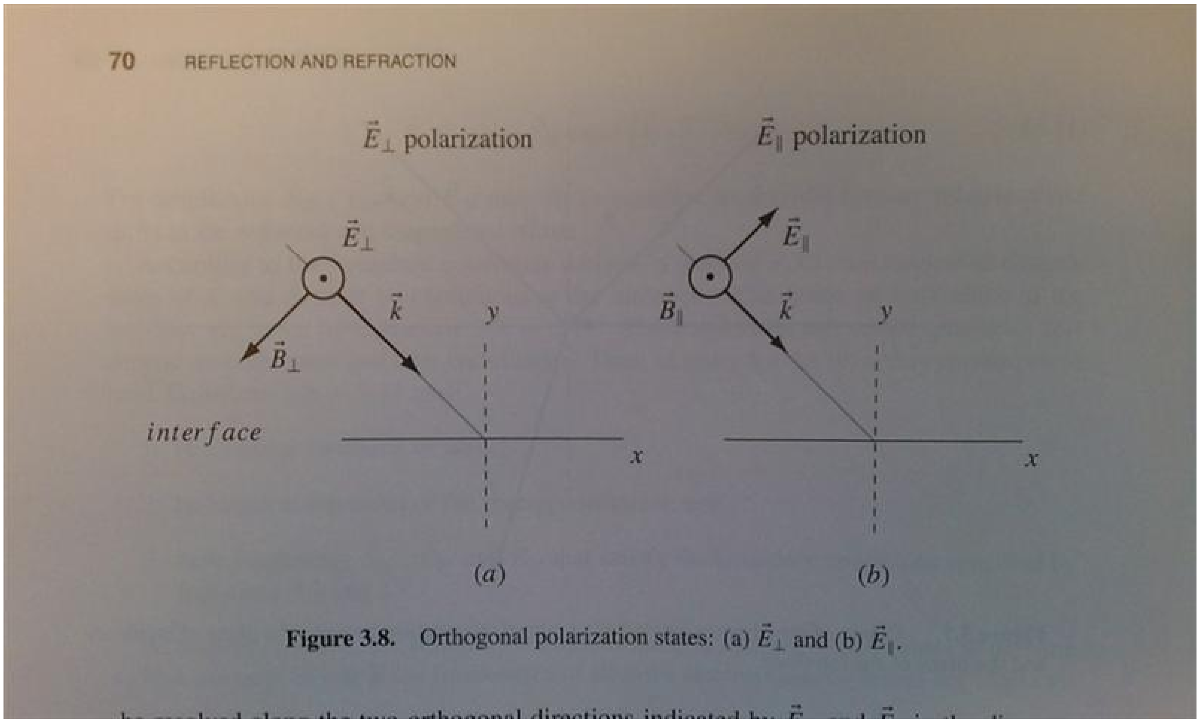


Figure 3.8. Orthogonal polarization states: (a) $\vec{E}_\perp$ and (b) $\vec{E}_\parallel$.

Variables

Variable	Description	Units
θ_i	Angle from normal of incident beam*	none (0-90 deg)
θ_t	Angle from normal of transmitted beam	none (0-90 deg)
θ_c	Critical angle (Value of θ_i for total internal reflection)	none (0-90 deg)
v_i	Speed of light for incident beam*	m/s
v_t	Speed of light in for transmitted beam	m/s
n_i	Refractive index of medium for incident beam*	none (min=1.0)
n_t	Refractive index of medium for transmitted beam	none (min = 1.0)
λ_i	Wavelength of light in medium for incident beam*	m
λ_t	Wavelength of light in medium for transmitted beam	m
f	Frequency of light (same in both media)	1/s
R	Reflectivity (% of incident power reflected)	%
T	Transmissivity (% of incident power transmitted)	%

*θ, v, n, and λ are equal for incident and reflected beams.

Constants

Constant	Units	Value	Description
c	m/s	3.0x10^8 m/s	Speed of light in vacuum
n_{vacuum}	none	1.0	n for vacuum
n_{air}	none	1.000293	n for air
n_{water}	none	1.3330	n for water
n_{glass}	none	1.50	n for glass*
$n_{diamond}$	none	2.419	n for diamond

*There are many types of glass. 1.50 is a typical value.

Formulas

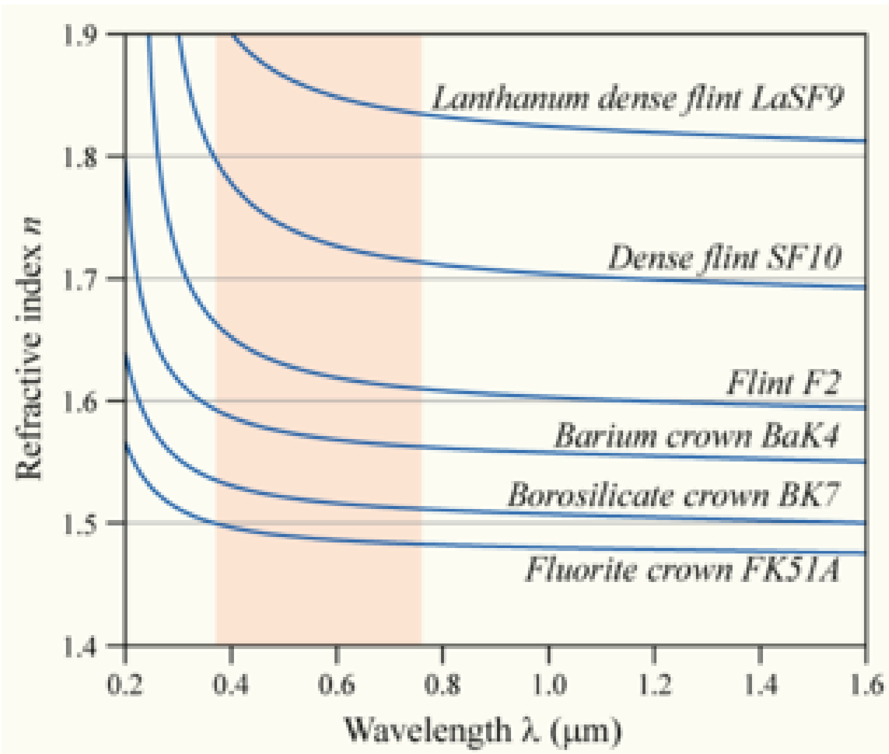
Formula	Description
$\frac{sin(\theta_i)}{sin(\theta_t)} = \frac{v_i}{v_t} = \frac{n_t}{n_i} = \frac{\lambda_i}{\lambda_t}$	Snell's Law
$\theta_t = sin^{-1}(\frac{n_i sin(\theta_i)}{n_t})$	Example of calculating θ_2 from n_1 and n_2. θ_2 can be calculated from other variables in a similar way.
$\theta_c = sin^{-1}\frac{n_t}{n_i}$	Value of θ_i for total internal reflection
$v_t = v_i\frac{n_i}{n_t}$	Calculating velocity in medium 2
$\lambda_t = \frac{v_t}{f} = \frac{v_i n_i}{f n_t}$	Calculating wavelength in medium 2
$v = \frac{c}{n}$	Speed of light in medium of refractive index n
$R_\perp = \left(\frac{n_i cos\theta_i - n_t cos\theta_t}{n_i cos\theta_i + n_t cos\theta_t}\right)^2$	% power of perpendicular reflected beam*
$T_\perp = \frac{4 n_i n_t cos\theta_i cos\theta_t}{(n_i cos\theta_i + n_t cos\theta_t)^2}$	% power of perpendicular transmitted beam*

$R_{\parallel} = \left(\frac{n_i cos\theta_t - n_t cos\theta_i}{n_i cos\theta_t + n_t cos\theta_i} \right)^2$	% power of parallel reflected beam*
$T_{\parallel} = \frac{4 n_i n_t cos\theta_i cos\theta_t}{(n_i cos\theta_t + n_t cos\theta_i)^2}$	% power of parallel transmitted beam*

* From “Principles of Physical Optics”, C.A. Bennet, p 88-89

n vs Wavelength

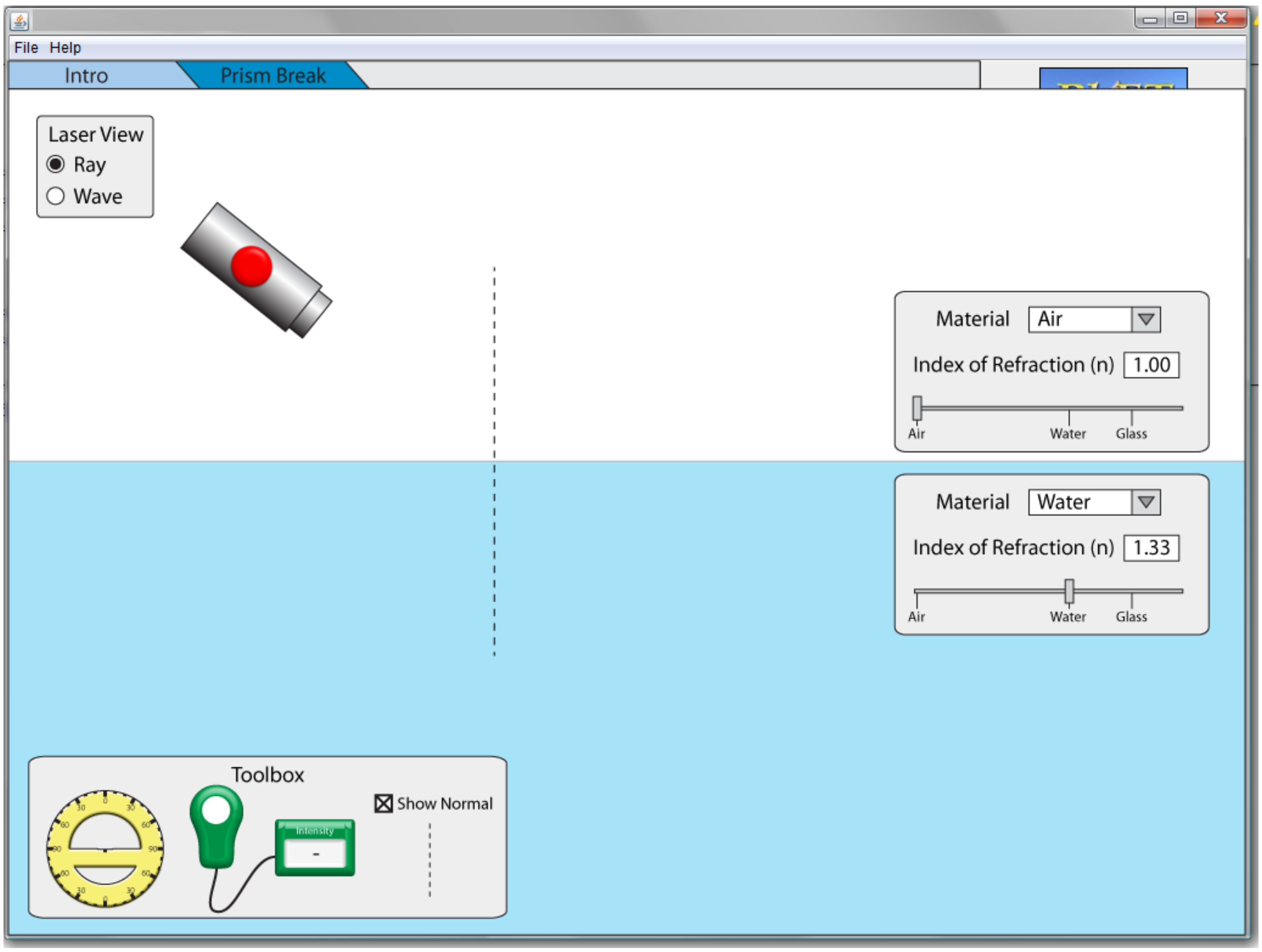
Refractive indes (n) is actually a fundtion of wavelength.



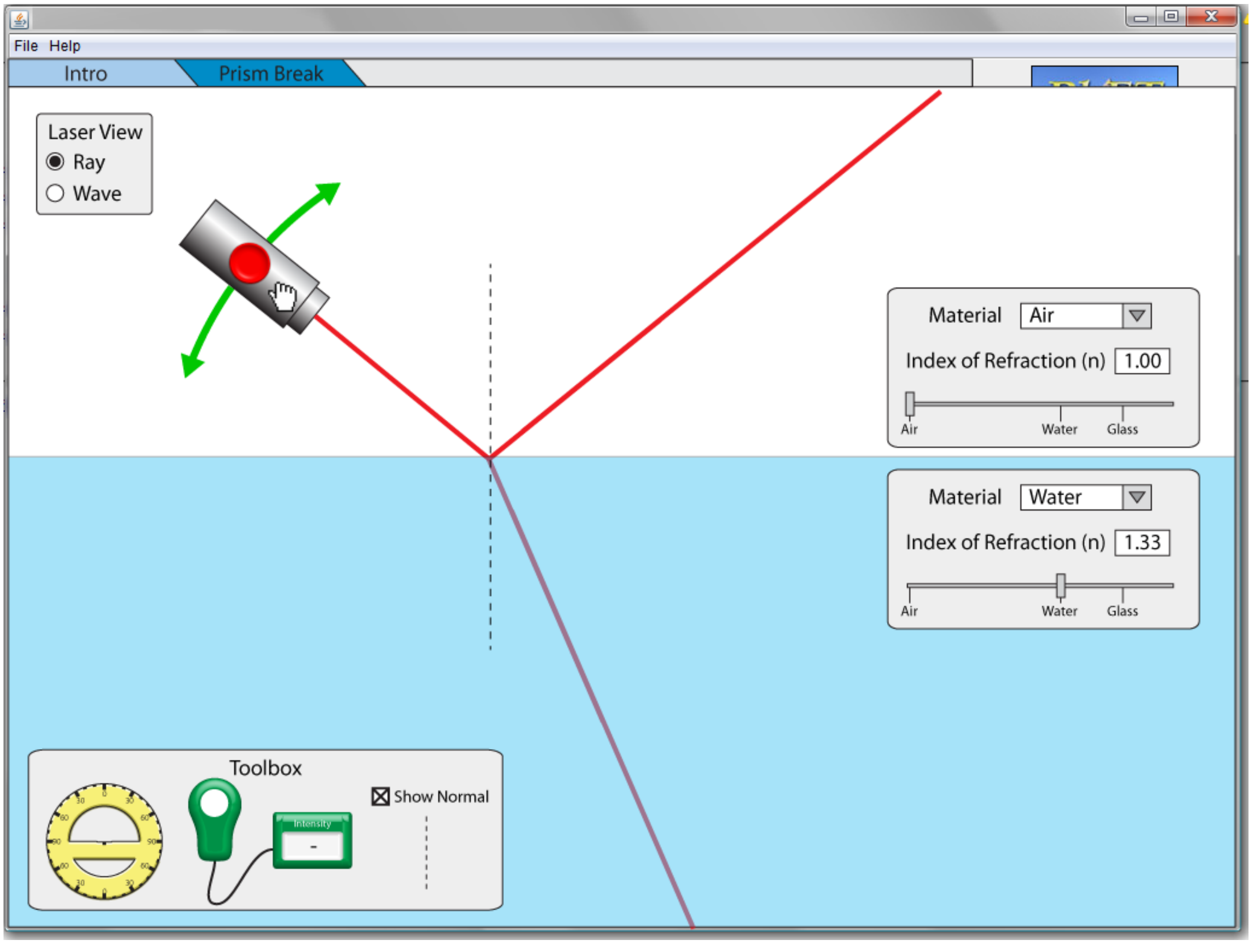
Tab 1 - Intro

- Single interface between two media.
- Laser
  - On/off button (starts off)
    - NP can provide images for pressed / unpressed button
  - Grab laser to rotate - shows green arrows with mouse hover (see below)
  - Rotates around the point of ray intersection
  - Can rotate from 0-90 deg
- Change index of refraction with sliders or text boxes
  - Ticks for air, water,glass
  - Can choose material with menu (air, water, glass, mystery, and custom)
  - If slider is moved to region without tick mark, menu switches to custom

- Can choose ray or wave view (see below)
    - Start in Ray View
- Toolbox that holds:
    - Protractor (see below)
    - Intensity Meter
    - “Show Normal”, turns on / off normal line, default on
- Play pause needed for wave view (waves will move)

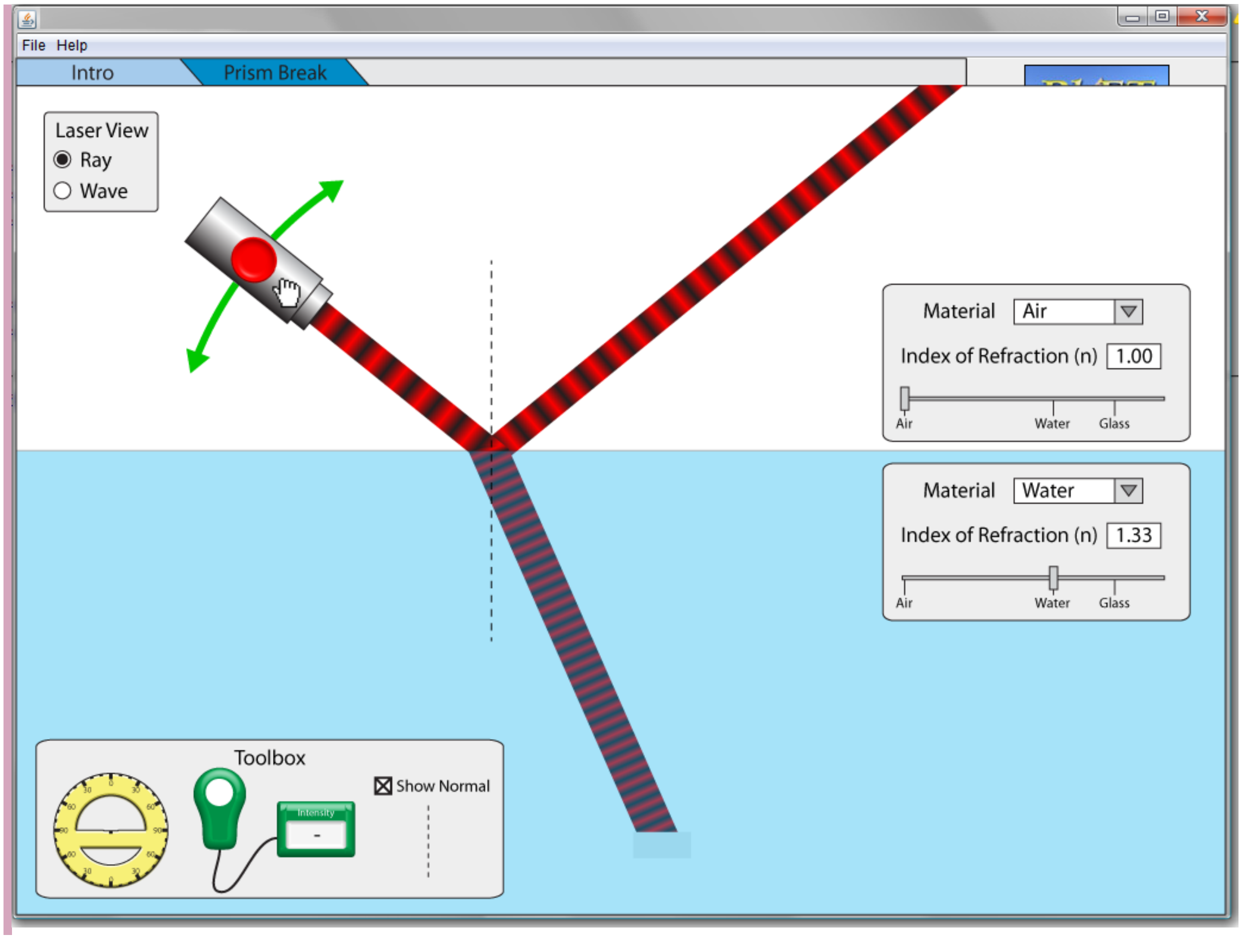


Ray View



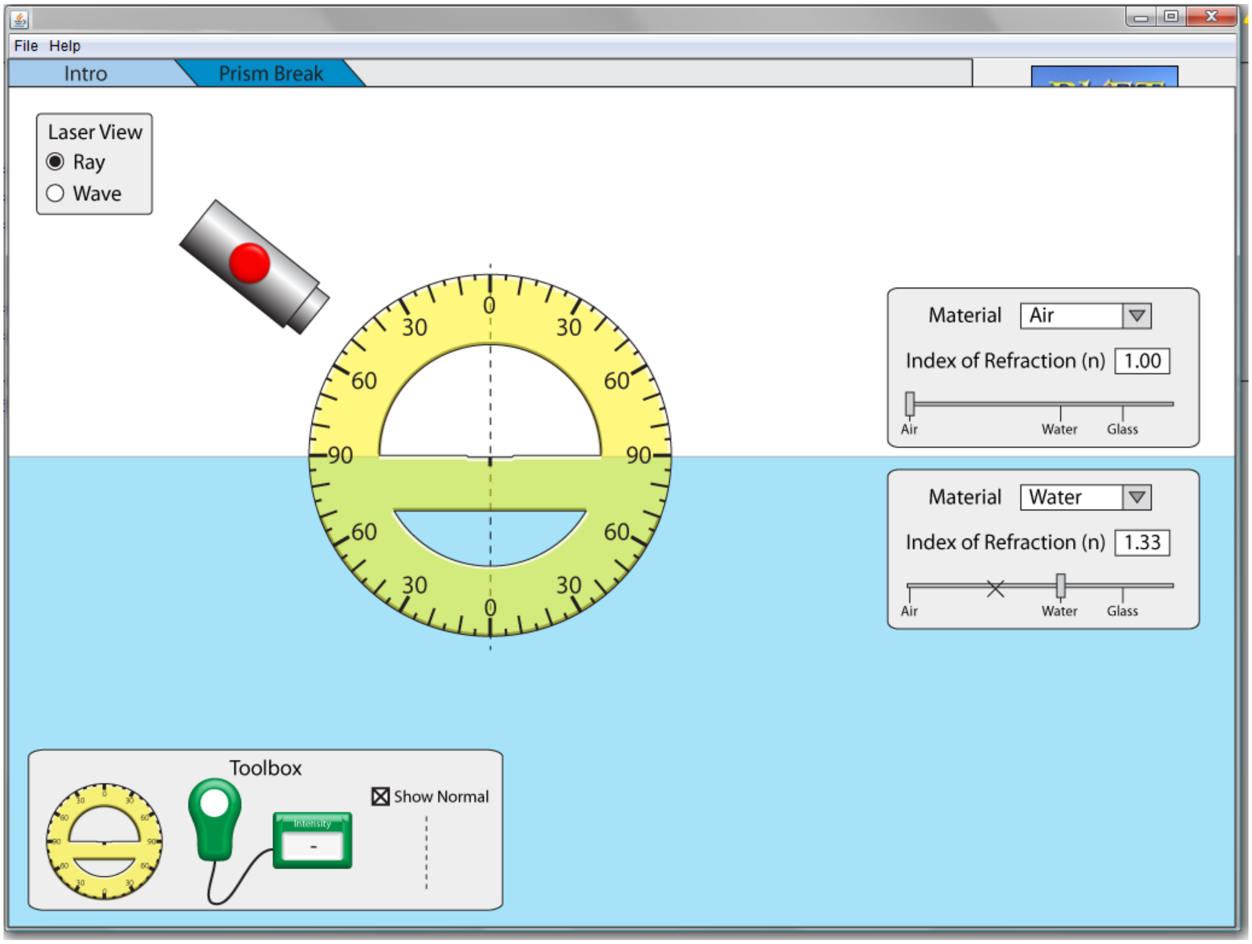
Wave View

- Note that waves need to be synced at point of incidence (this should come out of the equations, but need to make sure they are synced on the screen)
- Waves are all the same color (i.e., same frequency) but different wavelength in different media
- Wave propagates from source when laser is tuned on (like wave interference)
  TL:I like the mockup in Mike's book where the wave fronts are wider and it seems like student may infer something from the change in color that this picture has.2/8/11 3:45.



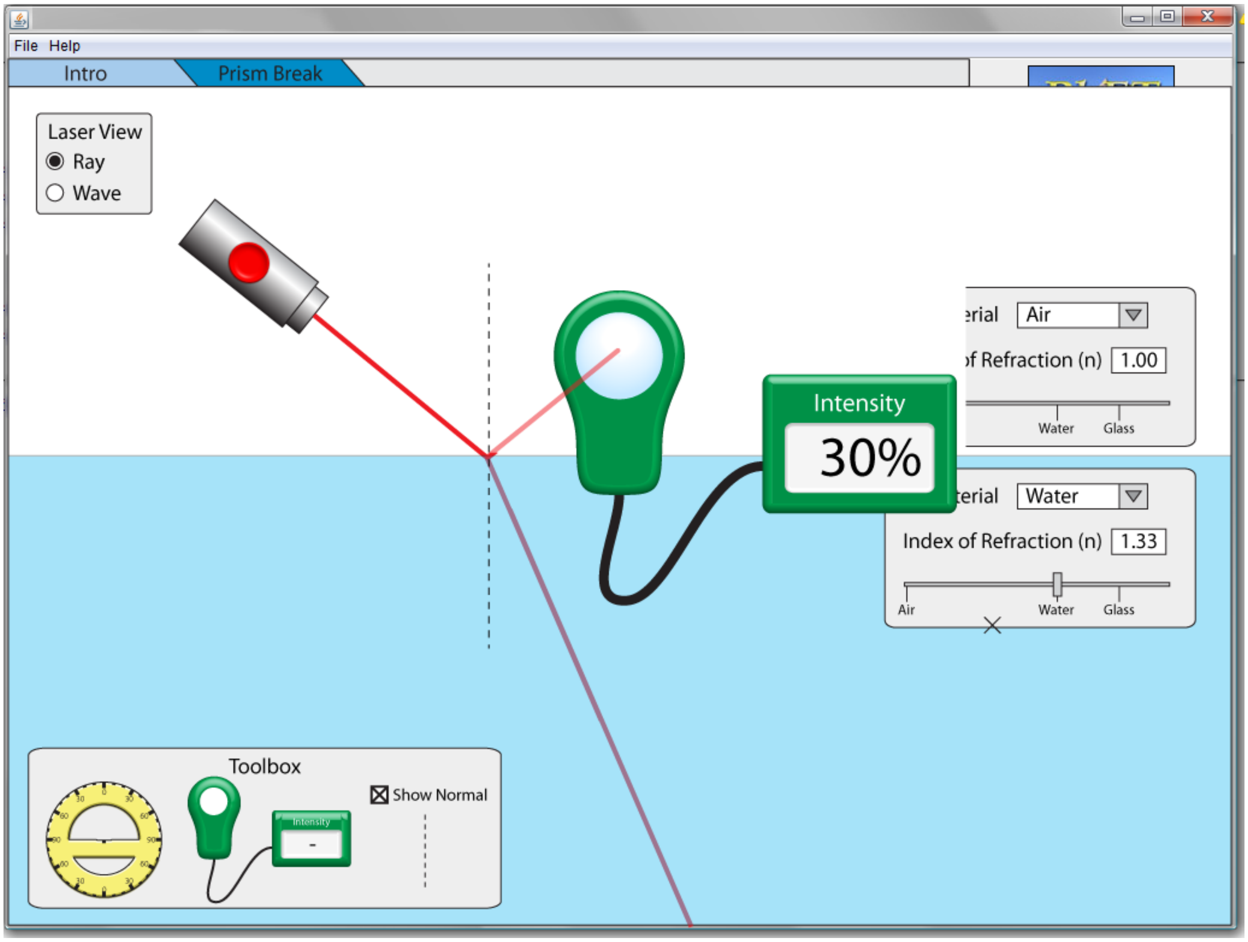
Protractor

- Protractor can be dragged from the toolbox (note that there is only one protractor - in the image below it should not remain in the toolbox).
- Protractor is draggable
    - Not rotatable in this tab (but will be in prism tab)
- Protractor image below drawn by NP (can be modified as needed).



Intensity Meter

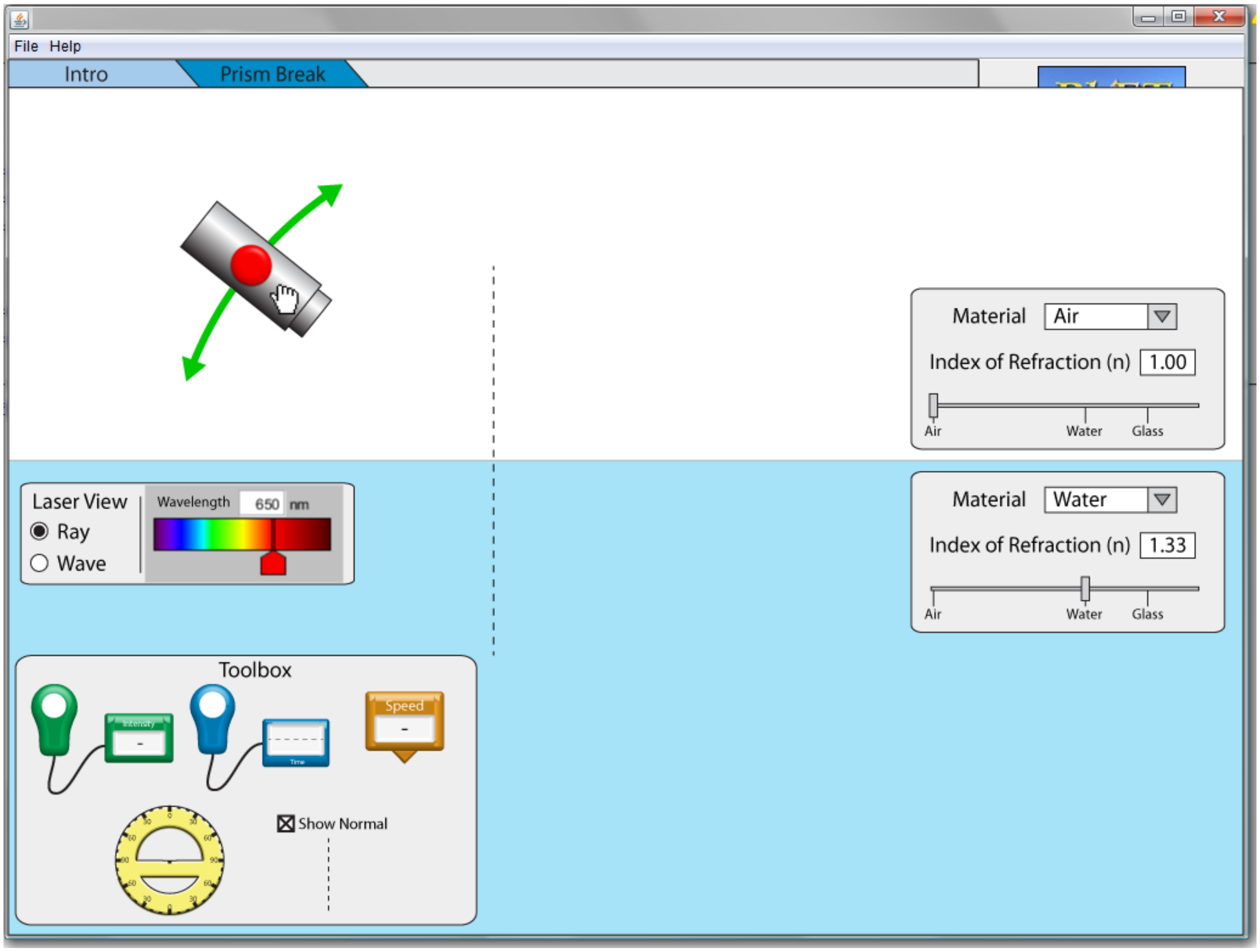
- This meter is drawn by NP (based on real meter shown below) - can provide separate images for sensor and readout box
- Both senor and readout box are draggable (note that there is only one meter - in the image below it should not remain in the toolbox).
- Shows intensity of light that intersects the white bubble in the sensor.
  - Reading given if light hits anywhere in the white bubble
- Beam stops where it hits the sensor
  - Cut off beam ½ way across the round white area
- Shows as % of incident beam (which is always 100%)
- Meter shows “-” if there is no light on sensor.
- If two beams hit sensor at same time, meter should show sum of beams



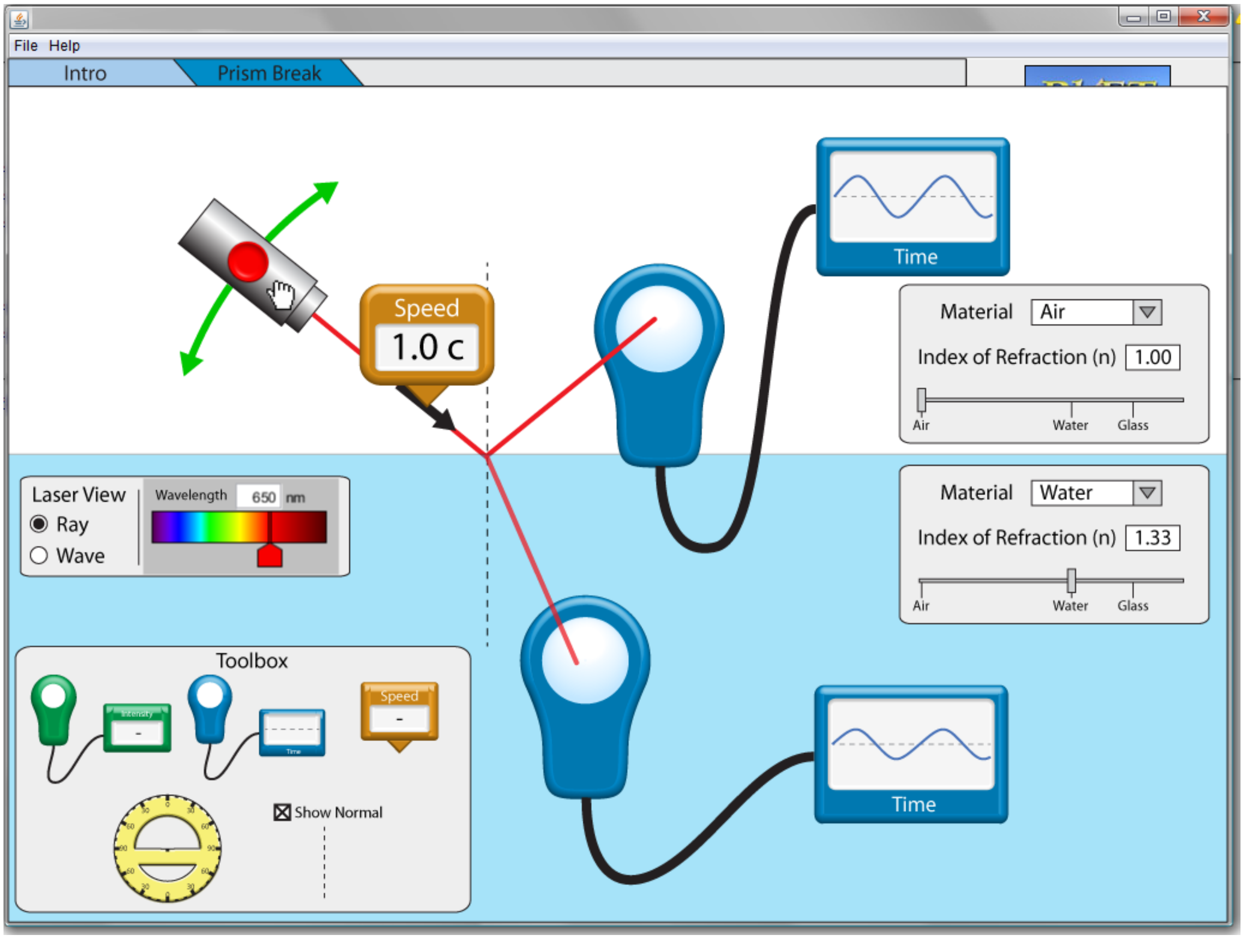
A light intensity meter.

Tab 2 - More Tools (name?)

- Adds two more tools to toolbox
- Wave detector (blue)
- Speed sensor (orange)



- Wave detector shows sine wave:
    - Amplitude proportional to light intensity (actually, sqrt(intensity))
    - Frequency proportional to freq of light
    - Sine wave travels to the left with time
- Can have up to 3 detectors
    - Keep dragging them from tool box
    - When 3 detectors are out, no more shown in toolbox
- Speed detector shows speed of light
    - Can move detector around and it shows speed when the tip intersects a beam of light
    - Equal to 1.0c in air
    - Arrow length is proportional to speed, direction shows direction of light propagation



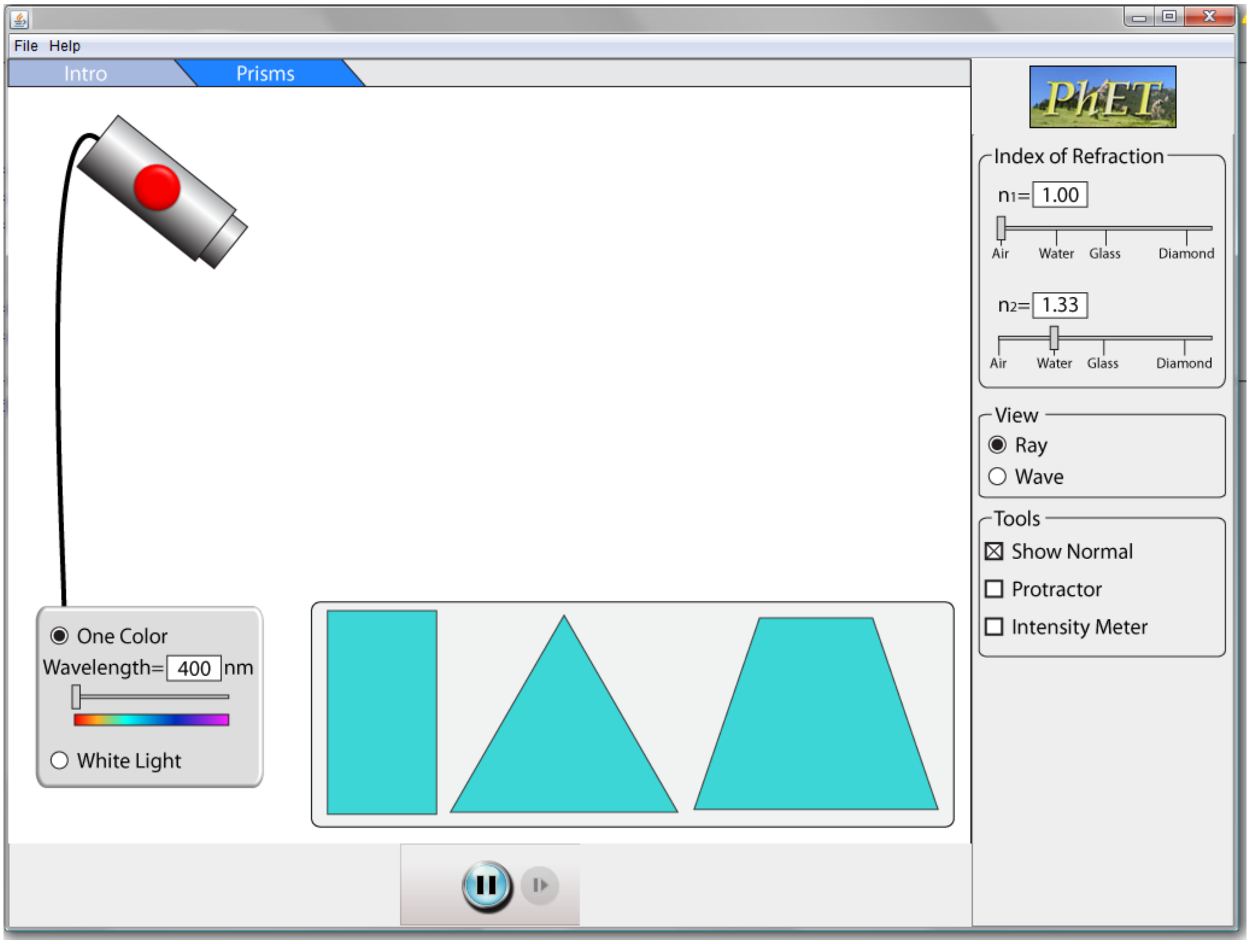
Tab 2 "Prisms"

- Need to check on programming difficulty with having beam entering or not entering at all
  - JO: shouldn't be hard for anything that you can compute a ray intersection and normal (line, circle/ellipse, etc.)
- **Please code this flexibly in case people request different size/shape objects**
- Have objects that let you "build" a lens??
- Laser can be rotated 360 deg in this tab
  - Need to be careful about laser getting stuck behind objects
  - Maybe laser should always be in top-most layer?
- Index of refraction
  - n1 is surrounding medium, n2 is object
  - all objects are the same index
  - object color changes with index
- Normal line

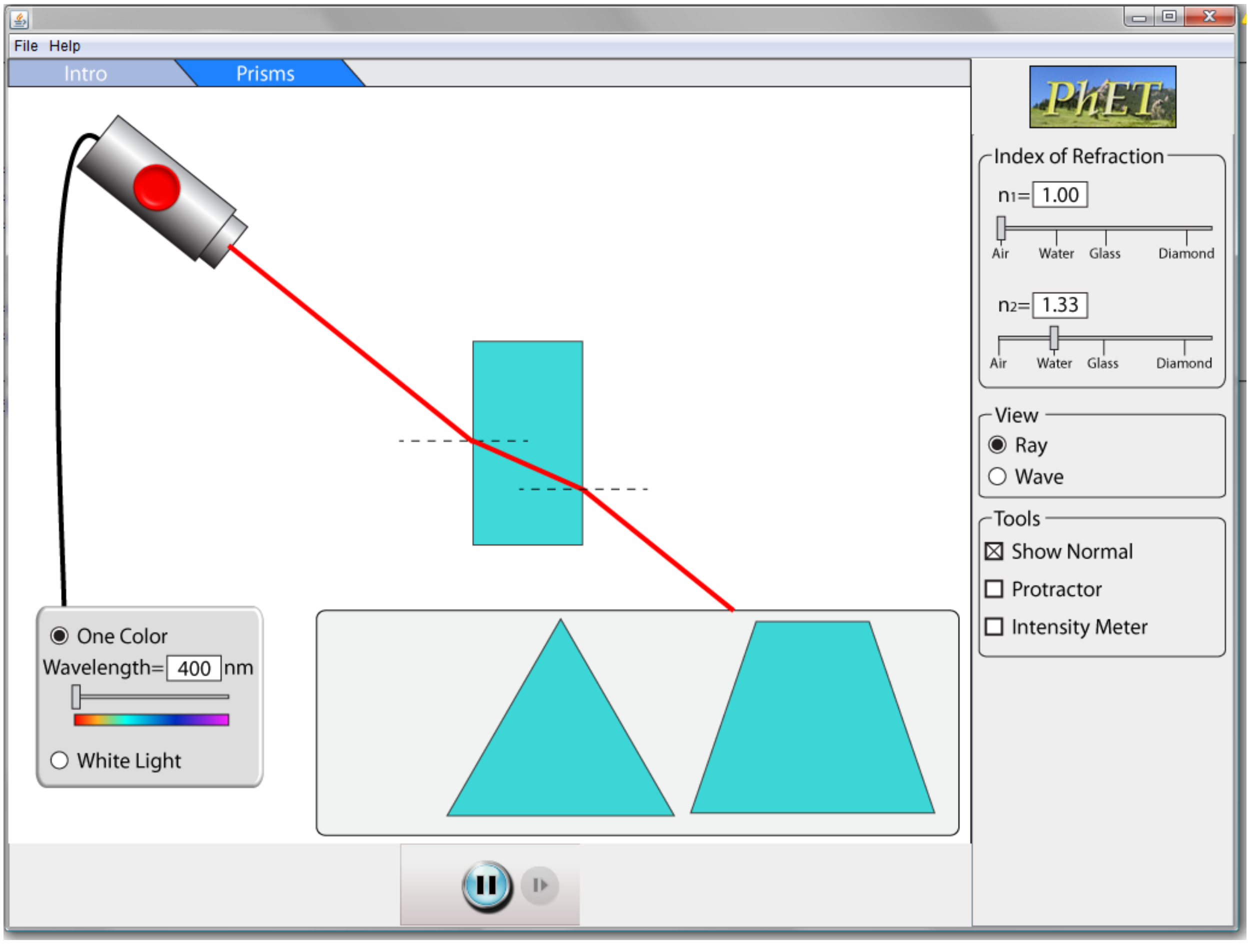
  Appears at intersection of incident ray
  - Appears at center of spread colors (see below)

- Start tab with 3 objects in box at bottom: rectangle, triangle, and trapezoid
  TL: It is very common to use a semi-circular object with the ray incoming on the curved side. The use of this is to help students make sense of why we use the normal line for measuring rather than the interface. When I showed the sim to another physics teacher, the first question he asked me was “where are the curved shapes?” I know that the Geometric Optics sim addresses what happens for convex lenses, but since there is no way to measure the angles, it would be helpful to allow curved shapes in this sim.2/8/11 3:35.
  - Objects can be dragged out of box
  - Objects move slightly when clicked (to cue user that they are draggable). See how this works in Membrane Channels for grabbing channels
  - Can we have rotation of objects? Or just one position?
  - Do we just have 3 objects, or multiple copies of each? Then drag back to box to throw them away?
- Box attached to laser:
  - Can choose “one color” (monochromatic) or “white light”
  - Wavelength slider when “one color” is chosen
  - Slider is grayed out when “white light” chosen (see below)
- Model for white light (refracted into different wavelengths)
  - Best idea thus far: white light is made up of many colored beams superimposed
  - Appears white (or slightly gray) in incident beam
  - Splits up into colors when refracted (see below)
  - Will need a lot of colored rays to make the rainbow look continuous

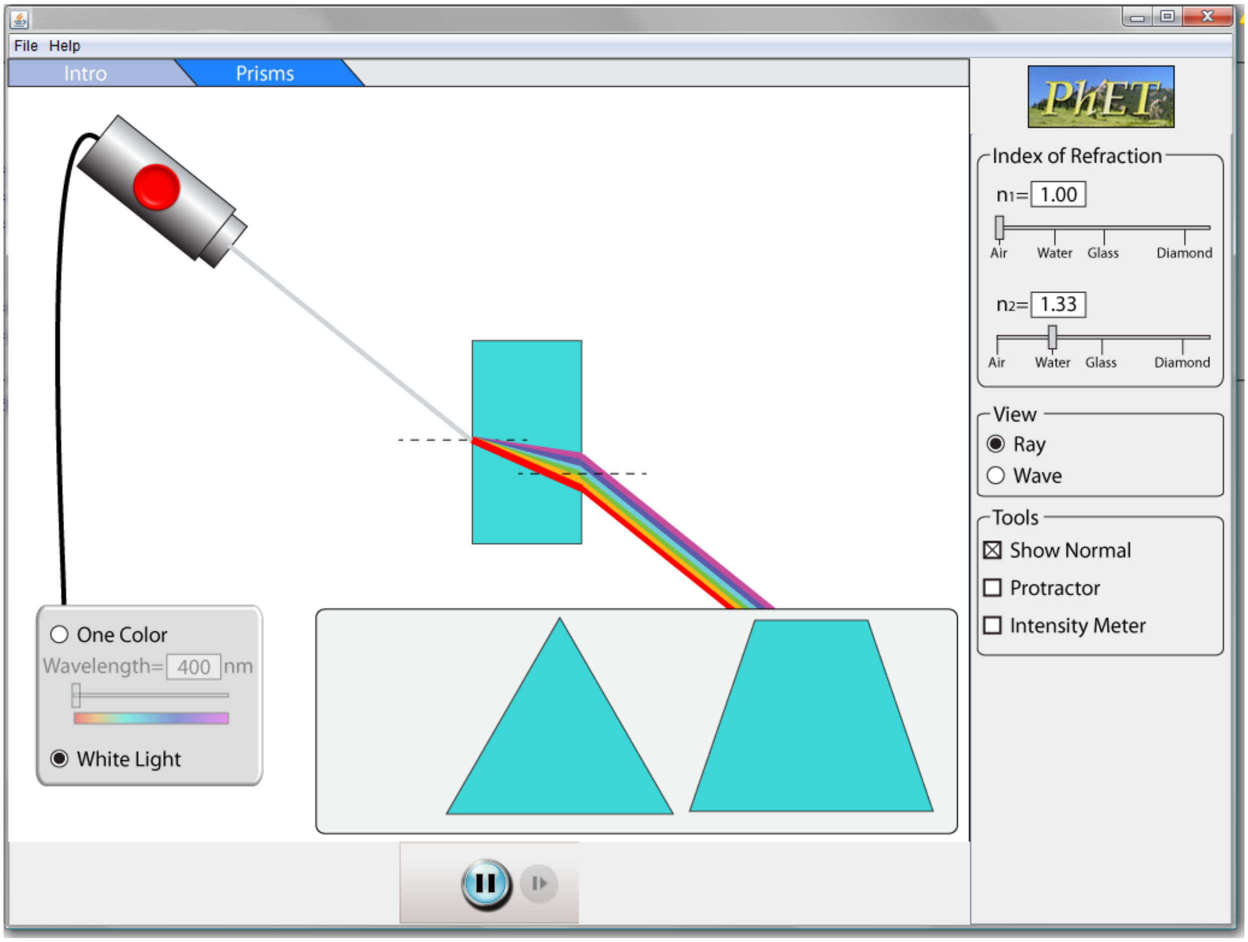
Start up state for Tab 2



Light beam going through rectangular object



White light dispersing at intersection



Tab 3

- Total internal reflection (TIR)
- Choose swimming pool or fiber optic
  - Can change inside and outside media
  - See that angle of laser needs to be right to get TIR
- Fiber optic is deformable (like track in skater)
  - Narrow aspect ratio and local curvature so you don't get escaping rays
  - Image of computer or DVD player at one end?

Design Meeting Images

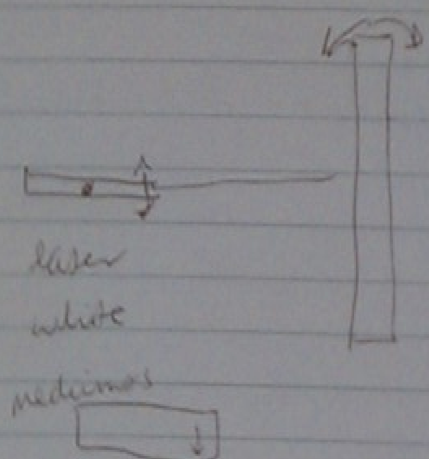
Snell's L...

fib...

· Laser pointer & glass (medium)

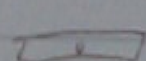
· Air could be medium also

·Read outs of angle



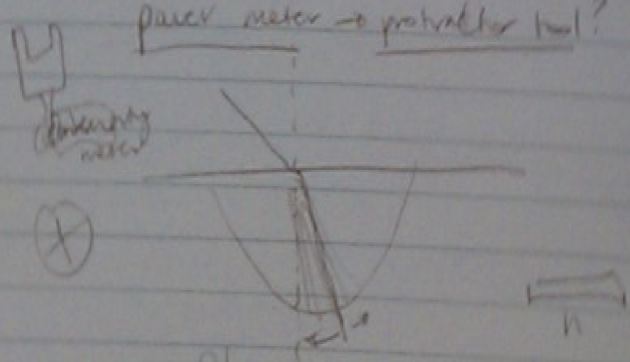
glass index of refraction

n



intensities depend on angle.

power meter → protractor tool?

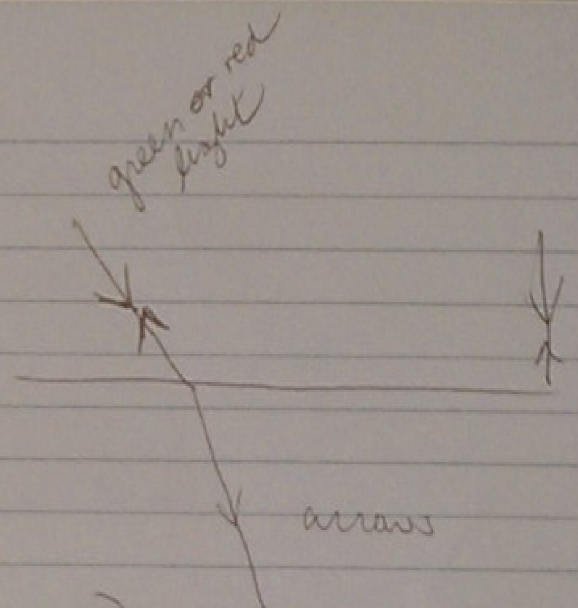


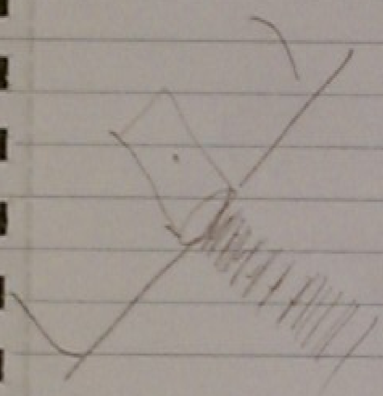
(✓) show normal

→ reflected intensity

transmitted

n





n =
diamond - 2.5

☐ Show reflected beam
☐ Show transmitted beam

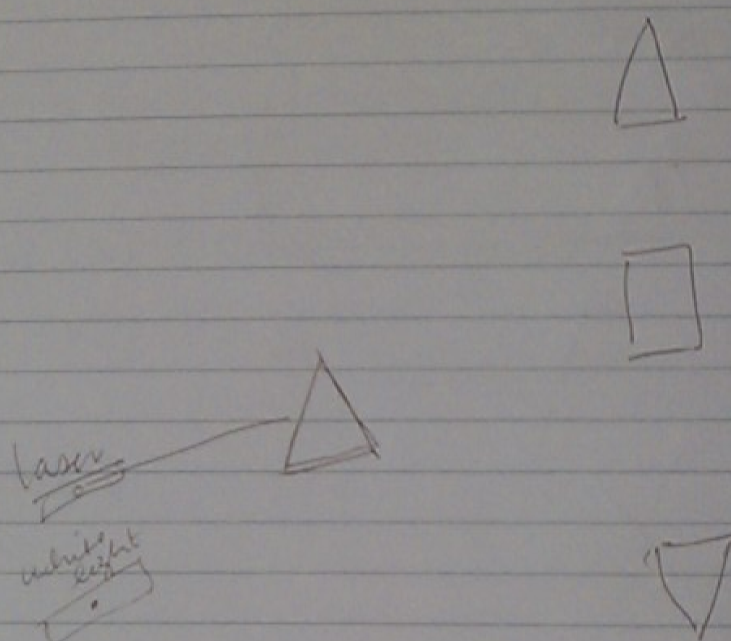
- Get speeds correct
- Wave fronts mesh at interface

Tab 1 intro ↑

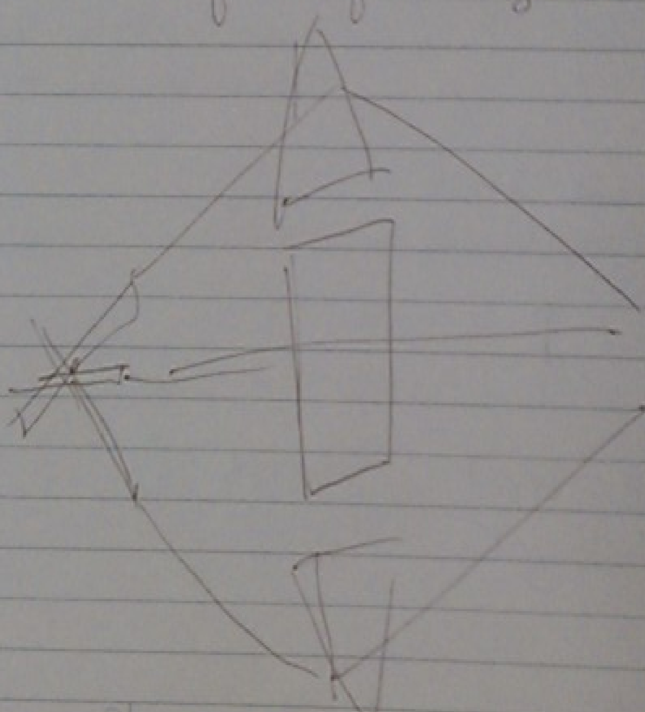
First tab - fixed wavelength of light

2 Snell's Law

fiber opt.



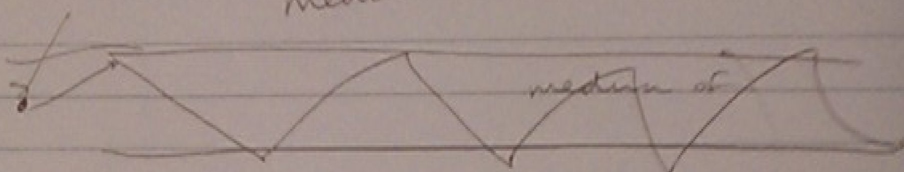
n is function of wavelength

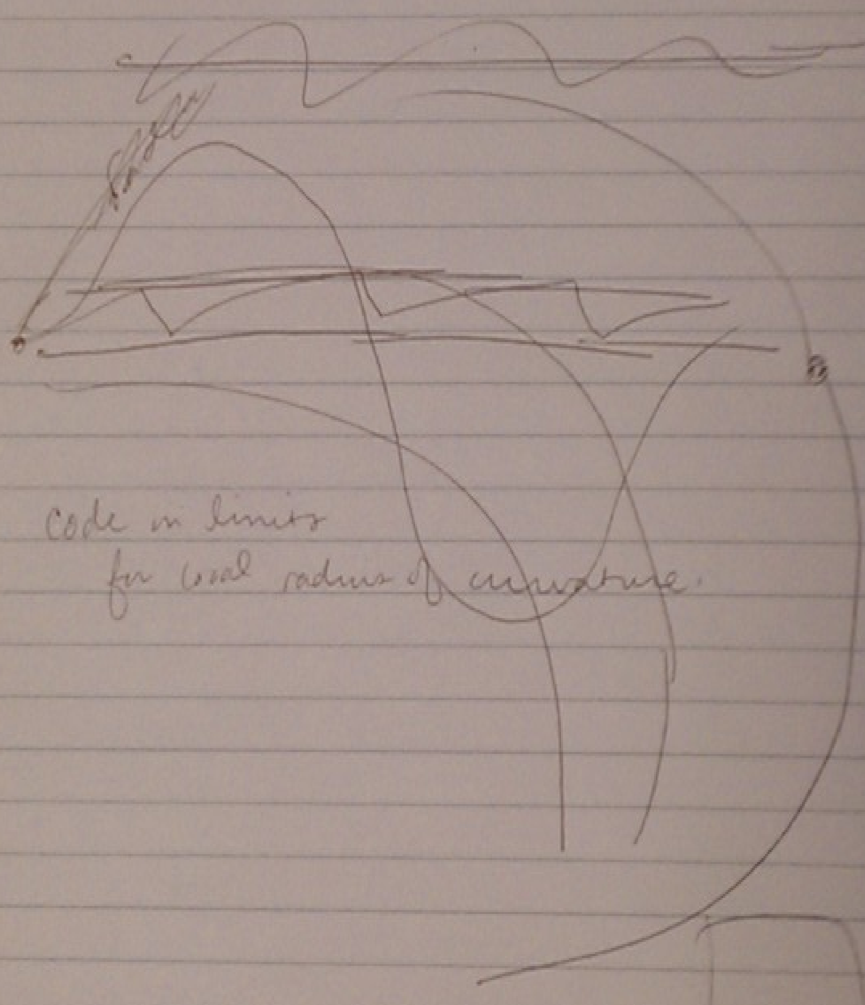


tab 3 – light tunnel

· swimming pool · fiber optic

medium





Code in limits
for local radius of curvature.

Decisions

SR: Should the protractor snap to the origin?

KP: I don't feel strongly

SR: Okay, I'll skip it to save time /complexity

SR: Maintain instead of resetting laser phase while changing index of refraction or laser angle

SR: This looks like it could be expensive. How much time is this feature worth, or is it essential?

KP: If this refers to the fact that the motion of the wave view pauses while you adjust index of refraction. This behavior looks fine to me.

Performance acceptable?

KP: Test white light performance on old blue laptop. If that's okay, then no performance improvements necessary.

SR: I can test this Thursday

Performance ok