Optics: Reflection, Refraction

Reflection

- We describe the path of light as straight-line rays
  - "geometrical optics" approach
- Reflection off a flat surface follows a simple rule:
  - angle in (incidence) equals angle out
  - angles measured from surface "normal" (perpendicular)

Reflection, continued

- Also consistent with "principle of least time"
  - If going from point A to point B, reflecting off a mirror, the path traveled is also the most expedient (shortest) route

Hall Mirror

- Useful to think in terms of images
  - "real" you
  - mirror only needs to be half as high as you are tall. Your image will be twice as far from you as the mirror.
Curved mirrors

- What if the mirror isn't flat?
  - light still follows the same rules, with local surface normal
- Parabolic mirrors have exact focus
  - used in telescopes, backyard satellite dishes, etc.
  - also forms virtual image

Refraction

- Light also goes through some things
  - glass, water, eyeball, air
- The presence of material slows light's progress
  - interactions with electrical properties of atoms
- The "light slowing factor" is called the *index of refraction*
  - glass has $n = 1.52$, meaning that light travels about 1.5 times slower in glass than in vacuum
  - water has $n = 1.33$
  - air has $n = 1.00028$
  - vacuum is $n = 1.00000$ (speed of light at full capacity)

Refraction at a plane surface

- Light bends at interface between refractive indices
  - bends more the larger the difference in refractive index
  - can be effectively viewed as a "least time" behavior
  - get from A to B faster if you spend less time in the slow medium

Driving Analogy

- Let's say your house is 12 furlongs off the road in the middle of a huge field of dirt
- you can travel 5 furlongs per minute on the road, but only 3 furlongs per minute on the dirt
  - this means "refractive index" of the dirt is $5/3 = 1.667$
- Starting from point A, you want to find the quickest route:
  - straight across (AD)—don't mess with the road
  - right-angle turnoff (ABD)—stay on road as long as possible
  - angled turnoff (ABD)—compromise between the two

$$A \rightarrow B \rightarrow C$$

<table>
<thead>
<tr>
<th>leg</th>
<th>dist.</th>
<th>$\Delta t @5$</th>
<th>$\Delta t @3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>AB</td>
<td>5</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>AC</td>
<td>16</td>
<td>3.2</td>
<td></td>
</tr>
<tr>
<td>AD</td>
<td>20</td>
<td>6.67</td>
<td></td>
</tr>
<tr>
<td>BD</td>
<td>15</td>
<td>5</td>
<td></td>
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<tr>
<td>CD</td>
<td>12</td>
<td>4</td>
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AD: 6.67 minutes
ABD: 6.0 minutes: the optimal path is a "refracted" one
ACD: 7.2 minutes

Note: both right triangles in figure are $3-4-5$
Total Internal Reflection
• At critical angle, refraction no longer occurs
  – thereafter, you get total internal reflection
  – for glass, the critical internal angle is 42°
  – for water, it’s 49°
  – a ray within the higher index medium cannot escape at shallower angles (look at sky from underwater…)

\[ n_2 = 1.5 \]
\[ n_1 = 1.0 \]

Refraction in Suburbia
• Think of refraction as a pair of wheels on an axle going from sidewalk onto grass
  – wheel moves slower in grass, so the direction changes

Note that the wheels move faster (bigger space) on the sidewalk, slower (closer) in the grass.

Questions
• What do you think you would see from underwater looking up at sky?
• Why do the sides of aquariums look like mirrors from the front, but like ordinary glass from the sides?
• If you want to spear a fish from above the water, should you aim high, right at the fish, or aim low (assume the fish won’t move)?
Reflections, Refractive offset

- Let’s consider a thick piece of glass \((n = 1.5)\), and the light paths associated with it
  - reflection fraction \(= \frac{(n_1 - n_2)}{(n_1 + n_2)^2}\)
  - using \(n_1 = 1.5\), \(n_2 = 1.0\) (air), \(R = (0.5/2.5)^2 = 0.04 = 4\%\)

Incoming ray

<table>
<thead>
<tr>
<th>Reflections (front &amp; back)</th>
<th>8% reflected in two reflections</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>4%</td>
</tr>
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<td></td>
<td>4%</td>
</tr>
</tbody>
</table>

96% image looks displaced due to jog

92% transmitted

4\%

0.16%

8\% reflected in two reflections (front & back)

8\%

4\%

4\%

4\%

Let’s get focused...

- Just as with mirrors, curved lenses follow same rules as flat interfaces, using local surface normal

A lens, with front and back curved surfaces, bends light twice, each diverting incoming ray towards centerline.

Follows laws of refraction at each surface.

Parallel rays, coming, for instance from a specific direction (like a distant bird) are focused by a convex (positive) lens to a focal point.

Placing film at this point would record an image of the distant bird at a very specific spot on the film. Lenses map incoming angles into positions in the focal plane.

Cameras, in brief

- In a pinhole camera, the hole is so small that light hitting any particular point on the film plane must have come from a particular direction outside the camera

- In a camera with a lens, the same applies: that a point on the film plane more-or-less corresponds to a direction outside the camera. Lenses have the important advantage of collecting more light than the pinhole admits

The Eye

- Now for our cameras...

- Eye forms image on retina, where light is sensed
  - Cornea does 80% of the work, with the lens providing slight tweaks (accommodation, or adjusting)

Refractive indices:

- air: 1.0
- cornea: 1.376
- fluid: 1.336
- lens: 1.396

Central field of view (called fovea) densely plastered with receptors for high resolution & acuity. Fovea only a few degrees across.
Questions

• Why are contacts and corneal surgery (e.g., radial keratotomy) as effective as they are without messing with innards of eye?

• Why can’t we focus our eyes under water?

• Why do goggles help?

References and Assignments

• References
  – www.education.eth.net/acad/physics/light-VII.htm
  – www.howstuffworks.com/camera.htm?printable=1

• Assignments
  – Q/O #4 due Friday, 5/26 at 6PM
  – HW #7 (due 06/01): TBA

• Think up topics you’d like to see covered before the end of the quarter
  – use the WebCT discussion board to contribute ideas
  – or e-mail me