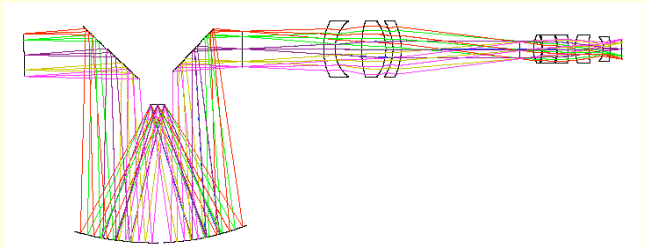
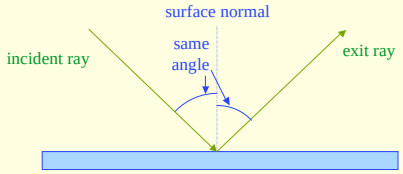


Optics

Reflection & Refraction
Optical Systems

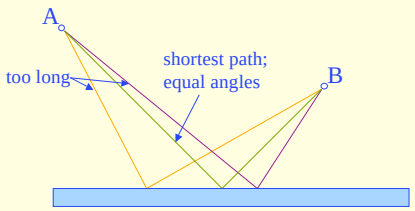
Reflection

- 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)



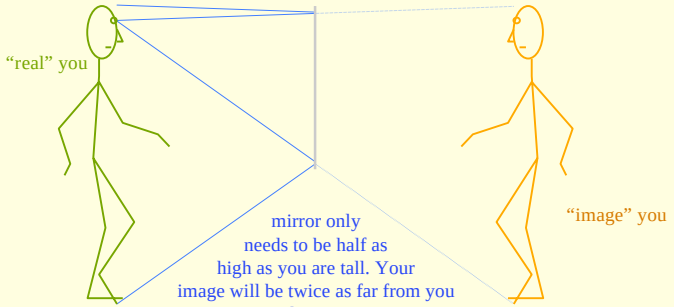
Reflection, continued

- 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



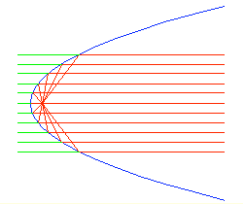
Hall Mirror

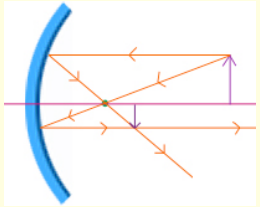
- Useful to think in terms of *images*



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



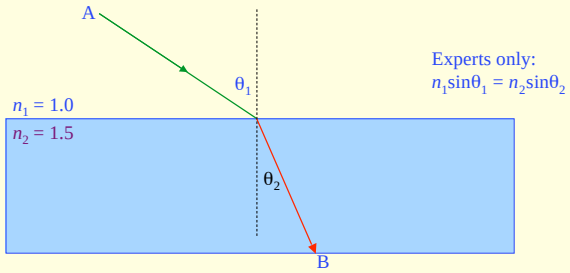


Refraction

- 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)

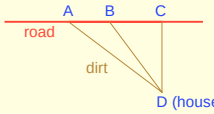
Refraction at a plane surface

- 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



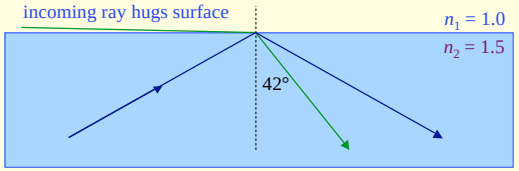
leg	dist.	Δt@5	Δt@3
AB	5	1	—
AC	16	3.2	—
AD	20	—	6.67
BD	15	—	5
CD	12	—	4

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

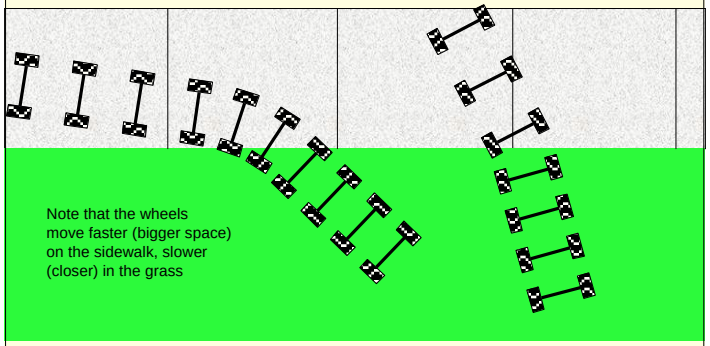
Total Internal Reflection

- 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…)



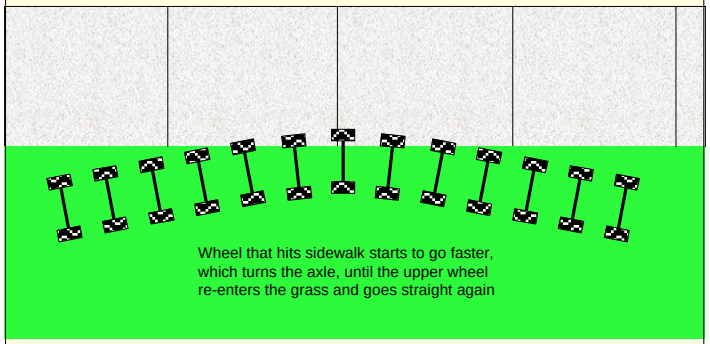
Refraction in Suburbia

- 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



Even gets Total Internal Reflection Right

- Moreover, this analogy is mathematically equivalent to the actual refraction phenomenon
  - can recover Snell's law: $n_1 \sin\theta_1 = n_2 \sin\theta_2$

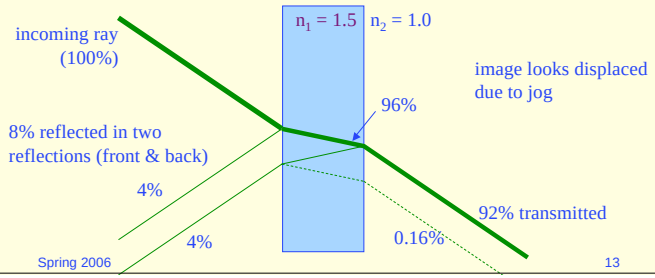


Questions

- 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)?

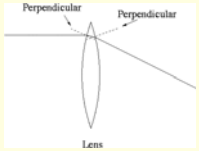
Reflections, Refractive offset

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



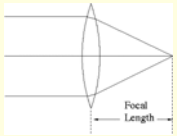
Let's get focused…

- 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.

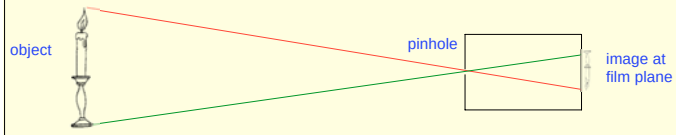
Follows laws of refraction at each surface.



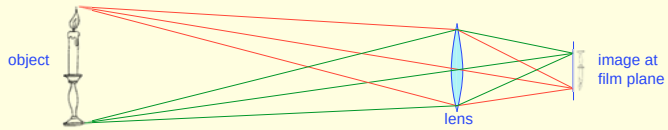
Parallel rays, coming, for instance from a specific direction (like a distant bird) are focused by a convex (positive) lens to a focal point.

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



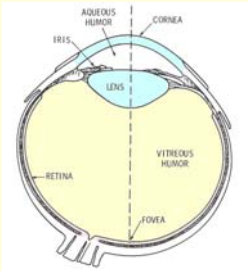
In a pinhole camera, the hole is so small that light hitting any particular point on the film plane must have come from a particular direction outside the camera



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/acads/physics/light-VIII.htm
    - lenses, etc.
  - www.howstuffworks.com/camera.htm?printable=1
    - cameras
- 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