February 25, 2011 Physics 122 Prof. E. F. Redish

- **Theme Music:** **Santana**
  Put Your Lights On
- **Cartoon:** **Bob Thaves**
  Frank & Ernest

3/4/09 Physics 122 **1**

Outline

- Recap: Curved mirrors
  - Equations
  - Finding the dog
- Refraction and Snell's Law
  - The phenomenology
  - Newton's model
  - Total internal reflection

2/25/11 Physics 122 **2**

"Finding the dog" in the mirror equation

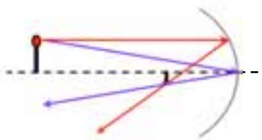
- What happens to the image when
  - the object moves farther from the mirror?
  - the object moves closer to the mirror?
  - the object moves to the focal point?
  - the object moves inside the focal point?
- Consider both position and size of the image.

$$\frac{1}{f}=\frac{1}{i}+\frac{1}{o} \qquad \frac{h'}{h}=\frac{i}{o} \qquad f=R/2$$

2/25/11 Physics 122 **4**

When the object moves closer to the mirror the image gets ….

1. Closer to the mirror and larger
2. Closer to the mirror and smaller
3. Farther from the mirror and larger
4. Farther from the mirror and smaller
5. Something else



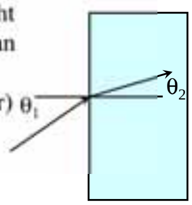
2/25/11 Physics 122 5

Snell's Law

- Observation: When a ray of light enters a transparent medium at an angle (or goes from one transparent medium into another) the ray bends according to the rule

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

where n is a property of the medium (air, water, glass, …) For air we take $n \sim 1$. (Actually for vacuum.)



2/25/11 Physics 122 7

Index of Refraction

- Light propagating into a material with a larger n bends towards the normal.
- Light propagating into a material with a smaller n bends away from the normal.
- The property n is called *the index of refraction* of a material.
- The n of empty space (vacuum) is taken to be 1.
- The index of refraction of a material can depend on the color (frequency) of the light.

2/25/11 Physics 122 8

Modeling Refraction

- When a ray of light enters a transparent medium at an angle, it appears to bend.
- Newton suggested that this was because light was made up of little particles and different media were like different (uniform) PEs for these particles.
- Light would speed up in a dense medium according to

$$\tfrac{1}{2}mv_1^2 + U_1 = \tfrac{1}{2}mv_2^2 + U_2$$

- Newton proposed that denser media had more negative PEs.

2/25/11 Physics 122 **9**

Foothold Ideas 1a
The Model

- Light consists of tiny particles that move very fast.
- The speed of light in a medium is determined by a property of the medium: a potential energy.

$$\tfrac{1}{2}mv_1^2 + U_1 = \tfrac{1}{2}mv_2^2 + U_2$$

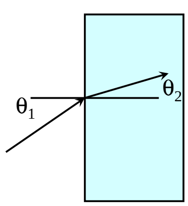
- Potential energies are lower in dense media so light travels faster in them.
- The index of refraction in a medium is given by

$$n_{med} = \frac{v_{med}}{c}$$

2/20/09 Physics 122 **10**

Snell's Law (in Newton's model)

- Entering a dense medium is then like rolling off a cliff. (?)
- You speed up in the direction perpendicular to the surface.
- Your speed in the direction parallel to the surface stays the same.



$$v_{1y} = v_{2y}$$

$$v_1 \sin\theta_1 = v_2 \sin\theta_2 \qquad n_{\text{Newton}} = v/c$$

2/25/11 Physics 122 **11**

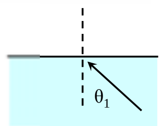
Puzzle

- What happens if the ray comes from inside the dense medium so that there is no external angle for which Snell's law holds?

$$\sin\theta_2 = \frac{n_1}{n_2}\sin\theta_1$$

$n_1 > n_2$

Choose an angle so $\sin\theta_1 > \frac{n_2}{n_1}$



2/25/11 Physics 122 13

Total Internal Reflection

- If we are going from one medium to a less dense medium ($n_2 < n_1$) then

$$\sin\theta_2 = \frac{n_1}{n_2}\sin\theta_1$$

- Since $n_1/n_2 > 1$ there will be some angle θ_1 above which there is no solution for θ_2. (You need $\sin\theta_2 > 1$ and this is impossible.)
- At angles of incidence above this angle, there is not transmission, only reflection.

2/25/11 Physics 122 14

Demos

2/25/11 Physics 122 15