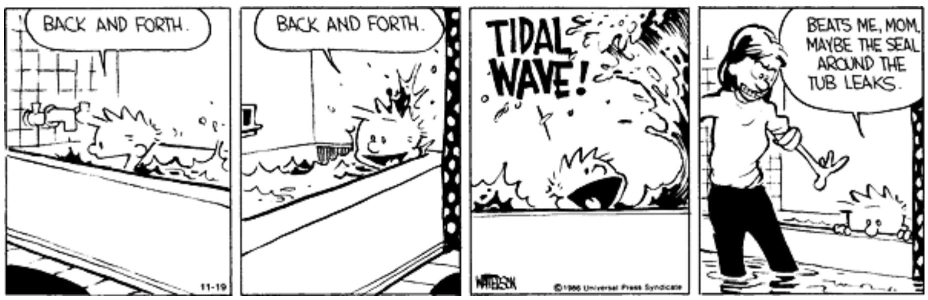
May 1, 2017 Physics 132 Prof. E. F. Redish

- **Theme Music:** **Blondie**
  Fade Away and Radiate
- **Cartoon:** **Bill Watterson**
  Calvin & Hobbes



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Outline

- Motivating the wave model
- Exploring the water wave analogy
- Huygens' principle
  - Reflection and refraction
  - The math
- Examples

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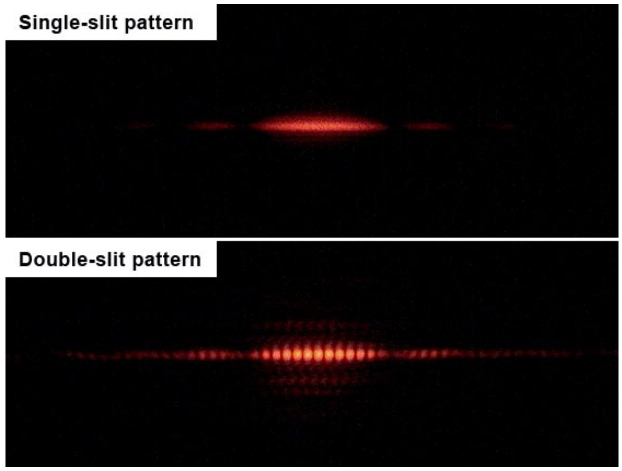
What a difference a slit makes



The big deal here is that opening an additional slit makes it *darker* in some places.
No way this happens in Newton's particle model.

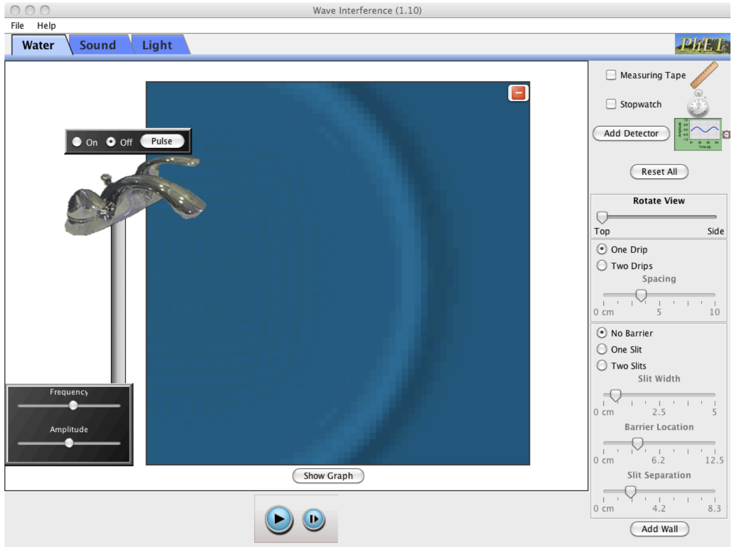
It's hard to picture waves in 3D

- Let's build some intuition by working through a simpler example.

Waves on the surface of water

(treating the height of the surface only – that moves up and down – transvers to the wave motion: the actual bits of water move in small circles)

Explore the PhET sim



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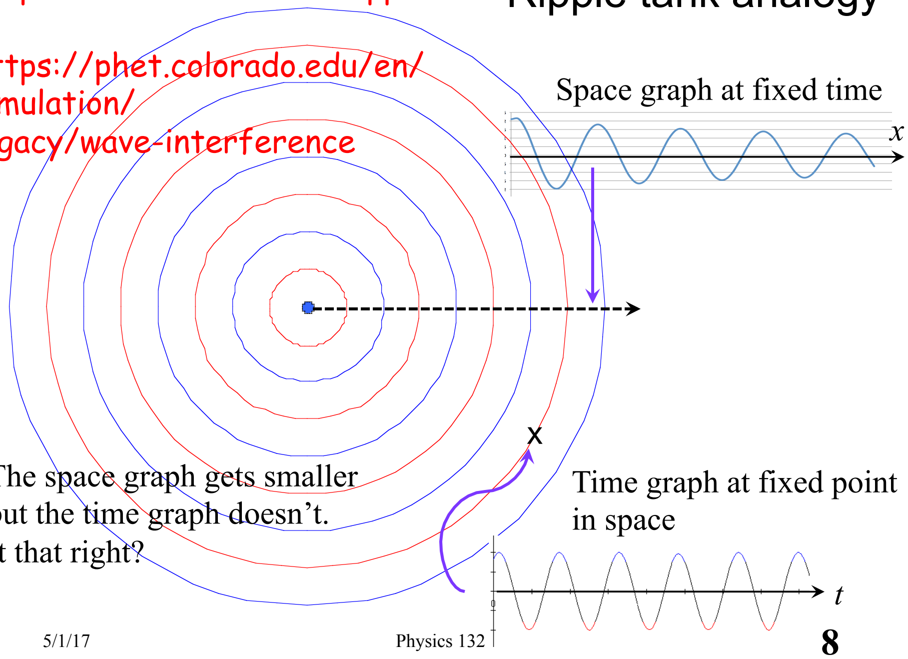
http://www.falstad.com/ripple/

Ripple tank analogy

https://phet.colorado.edu/en/simulation/legacy/wave-interference

Space graph at fixed time



Time graph at fixed point in space

The space graph gets smaller but the time graph doesn't.
It that right?

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Foothold wave ideas: Huygens' Model

- The critical structure for waves are the lines or surfaces of equal phase: wavefronts.
- Each point on the surface of a wavefront acts as a point source for outgoing spherical waves (wavelets).
- The sum of the wavelets produces a new wavefront.
- The waves are slower in a denser medium.
- The reflection principle and Snell's law follow from the assumptions of the wave model.
- We can even make rays – sort of.

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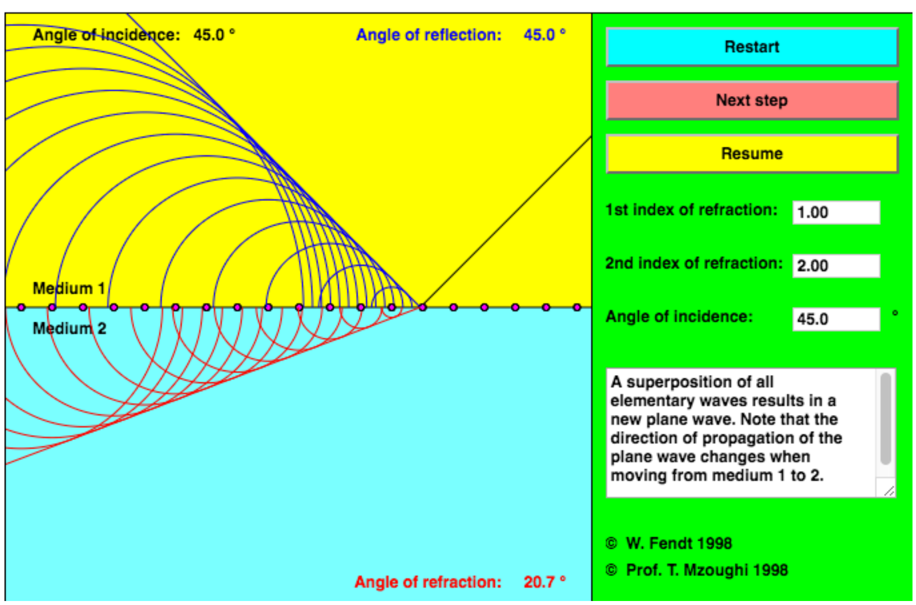
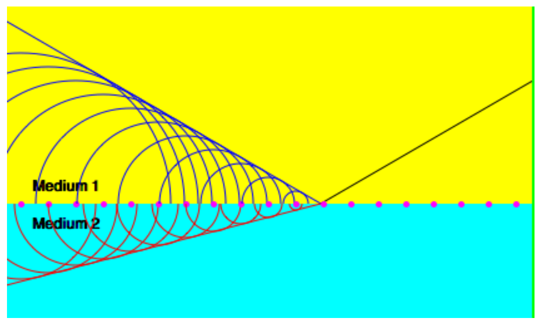


http://www.walter-fendt.de/html5/phen/refractionhuygens_en.htm

- Huygens' principle satisfactorily explains both the reflection and refraction principles (just as Newton's particle model does).
- In Huygens' wave model, light travels <u>slower</u> in dense media.

$$n = \frac{c}{v}$$



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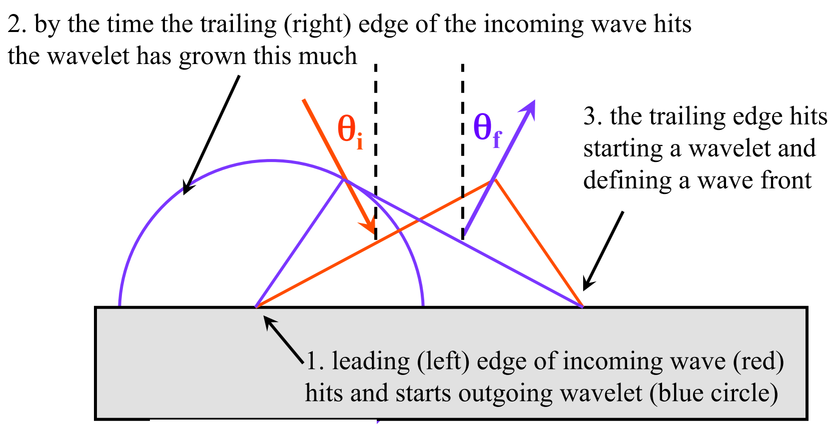
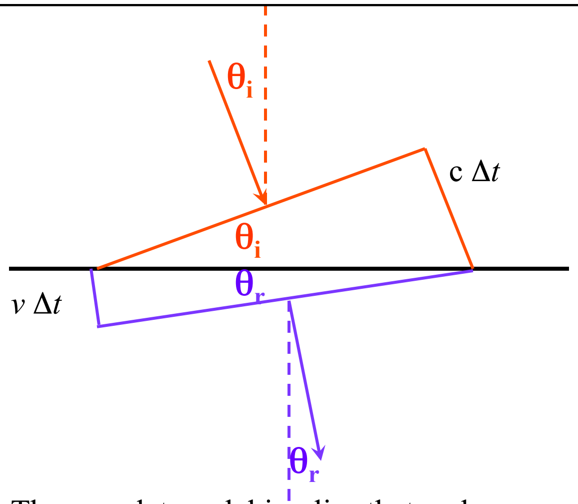


4. Since the red and blue triangles are similar, $\theta_i = \theta_f$

The wavelet model implies that a plane wave will reflect off a mirror according to the rule:
angle of incidence = angle of reflection. **12**



$$\sin\theta_i = \frac{c\Delta t}{h}$$

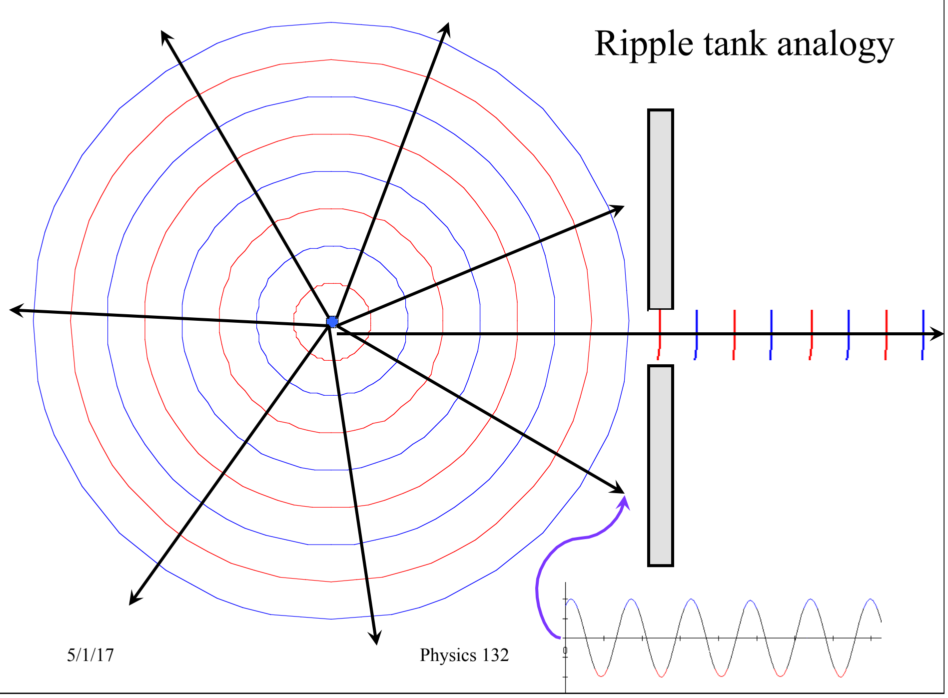
$$\sin\theta_r = \frac{v\Delta t}{h}$$

$$\frac{1}{v}\sin\theta_r = \frac{1}{c}\sin\theta_i$$

The wavelet model implies that a plane wave will refract into a medium according to the Snell's law and tells us that n = c/speed of light in the medium.

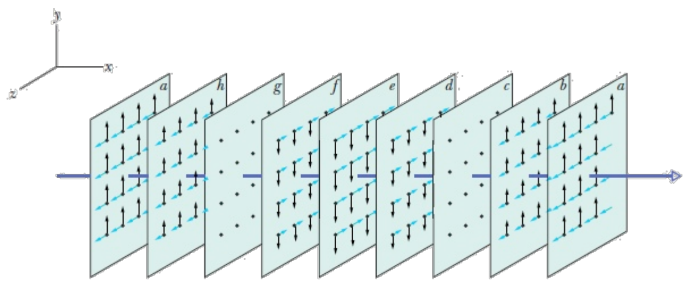
http://www.walter-fendt.de/html5/phen/refractionhuygens_en.htm
http://www.phy.ntnu.edu.tw/java/propagation/propagation.html

Ripple tank analogy



What is light?...Really?

- A useful mode of light is an oscillating electromagnetic wave. (Long story)
- A ray-like example: a plane wave



$$\vec{E}(x,y,z,t) = \vec{E}_0 \sin(kx - \omega t)$$

The math

- Outgoing pulse:

$$y = \frac{f(r - v_0 t)}{\sqrt{r}} \quad \text{(in 2D)}$$

$$y = \frac{f(r - v_0 t)}{r} \quad \text{(in 3D)}$$

- Outgoing sinusoidal:

$$y = \frac{A\sin(kr - \omega t)}{\sqrt{r}} \quad \text{(in 2D)}$$

$$y = \frac{A\sin(kr - \omega t)}{r} \quad \text{(in 3D)}$$

These factors reduce the amplitude slightly as the waves go out to conserve total energy (prop. to square of y).

We will tend to ignore them since the sin factors vary much more.

More math

- Consider what the wave looks like at a fixed point in space.
- The wave from a source a distance r_0 away looks like a sinusoidal wave with a phase shift (that depends on r_0).

$$y(r,t) = \frac{A\cos(kr_0 - \omega t)}{r_0} = \frac{A\cos(\omega t - kr_0)}{r_0} = \frac{A\cos(\omega t - \phi)}{r_0}$$

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