# Electromagnetic Waves



What is light?

Maxwell: a form of EM wave

... but ...

Quantum mechanics tells light *also* has properties of a particle.

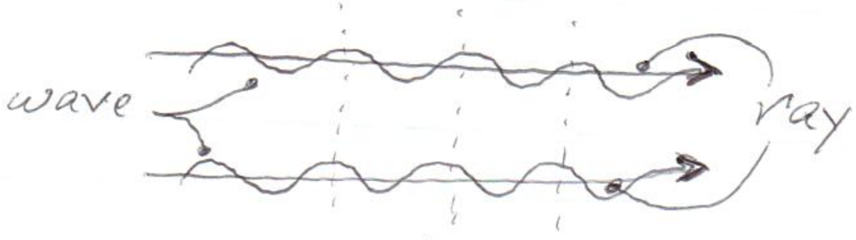
It *seems* *contradictory*, as particles have no 'extent' or wavelength, and waves have no unique location or momentum.

I encourage you to explore this topic + read about "de Broglie waves" + "wave-particle duality".

# Geometric Optics



Approximate EM waves as a series of particles or 'rays' moving ⊥ to surface of wave:




wave fronts ⊥ ray

Properties:

- straight path in uniform medium
- change direction when hit new medium
  - or nonuniformities

Assumption for validity:

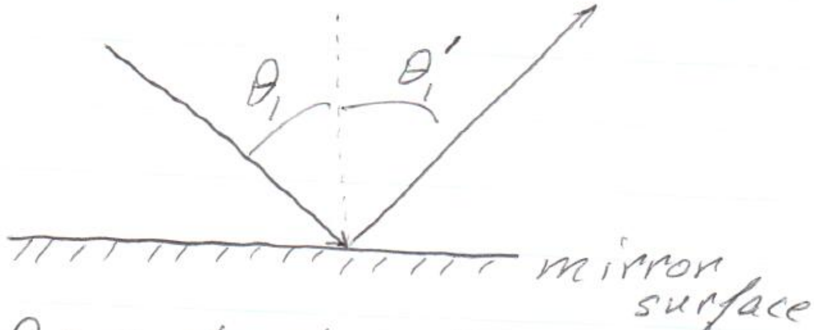
- size of aperture light passes, d

$$d \gg \lambda$$

- otherwise cannot ignore wave properties

# Law of Reflection

Define




$\theta_1$ = angle of incidence
$\theta_1'$ = angle of reflection

$$\boxed{\theta_1 = \theta_1'}$$

Known to Euclid

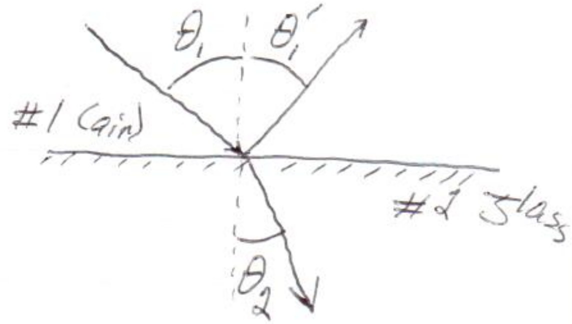
Consequence, in part, to conservation of momentum.

# Refraction:



Can use geometric optics to quantify refraction, but need wave discussion to explain it.

2 trasparent media

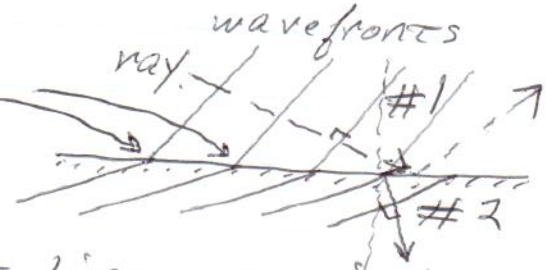



Incident ray

- part of energy penetrates medium #2
- speed of light in #2
  - absorption + radiation
  - "slows down" light

# Snell's Law of Refraction 24.6

Same oscillations on both sides of boundary




- crests must line up with crests
  - or will have $\infty \frac{\Delta E}{\Delta x}$ at boundary

$$\therefore f_1 = f_2 (= f) \text{ but } \lambda_1 \neq \lambda_2$$

Since $v_1 = f\lambda_1$

$$\frac{\cancel{f}\lambda_1}{\cancel{f}\lambda_2} = \frac{v_1}{v_2} = \frac{c/n_1}{c/n_2} = \frac{n_2}{n_1}$$

So $\underline{v_1/v_2 = n_2/n_1}$

Since the crests are fixed at the interface, a reduced $v_2$ ($< v_1$) can only happen by corresponding change in angle.

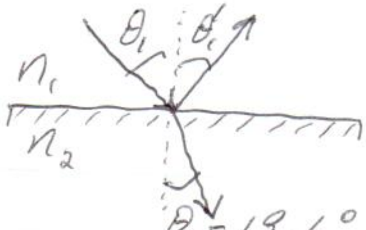
$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2} \Longrightarrow \boxed{n_1 \sin\theta_1 = n_2 \sin\theta_2}$$

## Example

A block of crown glass ($n=1.52$) has light incident such that angle of refraction is 19.6°. The block is submerged in water ($n=1.33$).

What is the incidence angle?

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




$$\theta_1 = \sin^{-1}\left(\frac{n_2}{n_1}\sin\theta_2\right)$$

$$\boxed{\theta_1 = 22.5°}$$

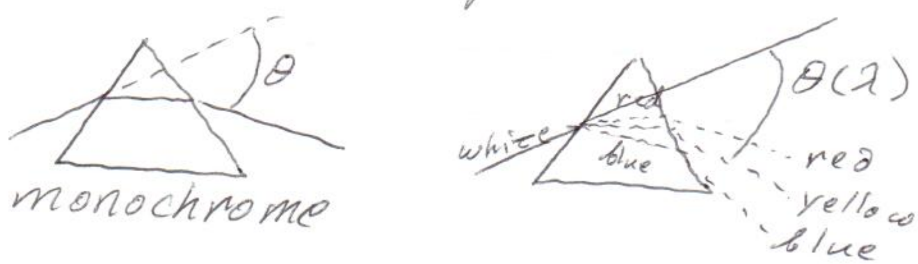
What is angle of reflection?

$$\boxed{\theta_1' = \theta_1 = 22.5°}$$

# Dispersion & Prisms

Index of refraction
- can vary with $\lambda$
  - e.g. fused quartz
    - varies by ~1% over visible $\lambda$s

Chromatic dispersion
- consider a prism



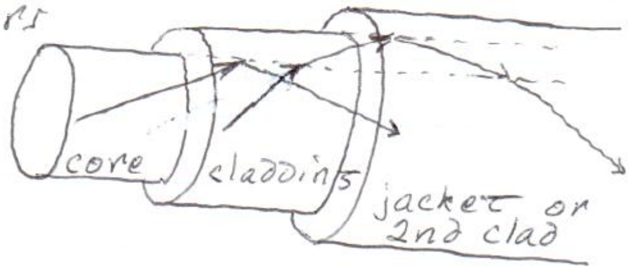

- different $\lambda$s refracted to different angles
- violet 'bends' most, red least

Rainbow
- light enters airborne water droplets
- refracted, & observer @ unique position for sun's angle to give arc of angles of refracted light.

24.10

# Optical Fiber

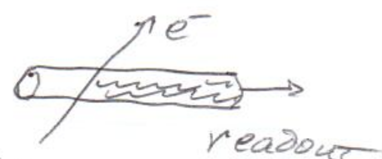
Plastic or
Glass Fibers




At each boundary: $n_{out} < n_{in}$
- at $\theta_c$ → keep light in
- 2nd cladding keep more light

Uses:

- particle physics




- telecommunications

- medecine
  - cardiac catheterization
  - look at inaccessible locations