Your questions/comments

“Well looks like I'm not learning any of this until the weekend :/”

“sorry bro, i'm studying for the exam thursday and can't be worrying about this stuff now.”

“To be honest, I blew through this so that I could spend the time studying for Thursday's exam instead. Sorry!”

“can you please be nice to us on the exam on thursday? this class is killing me”

“I AM SCARED FOR TOMORROW'S EXAM. HELP.”

“Optics and lenses have always scared me. But after taking MCB 354 I'm not scared of anything else anymore.”

Phys 102 – Lecture 17

Introduction to ray optics

Physics 102 lectures on light

Light as a wave

- Lecture 15 – EM waves
- Lecture 16 – Polarization
- Lecture 22 & 23 – Interference & diffraction

Light as a ray

- Lecture 17 – Introduction to ray optics
- Lecture 18 – Spherical mirrors
- Lecture 19 – Refraction & lenses
- Lecture 20 & 21 – Your eye & optical instruments

Light as a particle

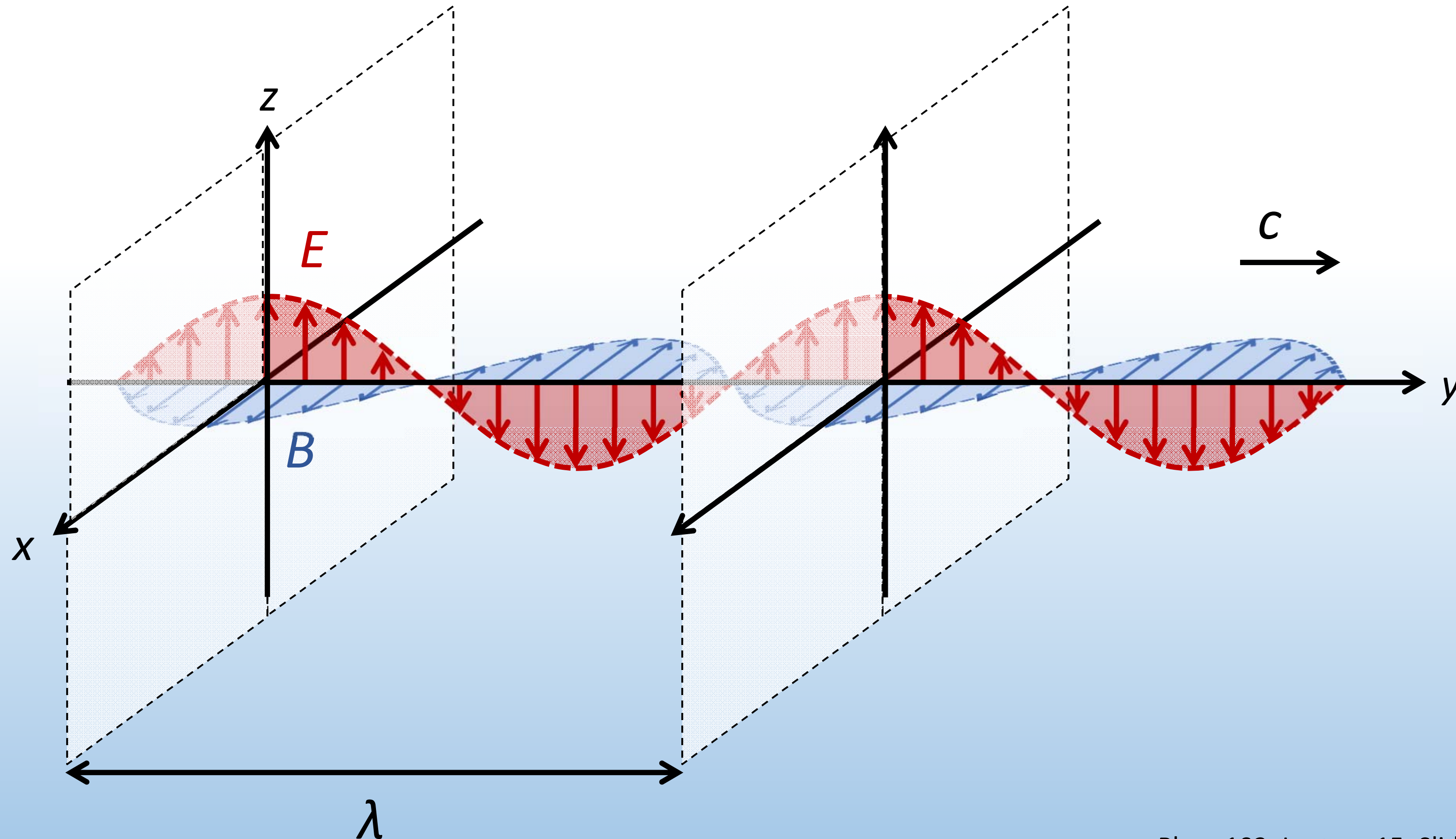
- Lecture 24 & 25 – Quantum mechanics

Today we will...

- Introduce several key concepts
  - Huygens' principle
  - Ray model of light
- Learn about interaction of light with matter
  - Law of reflection – how light bounces
  - Snell's law of refraction – how light bends
- Learn applications
  - How we see objects
  - How we see images from reflection & refraction

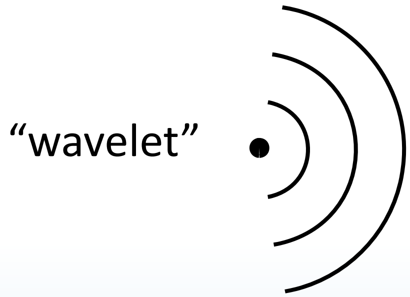
Recall wavefronts

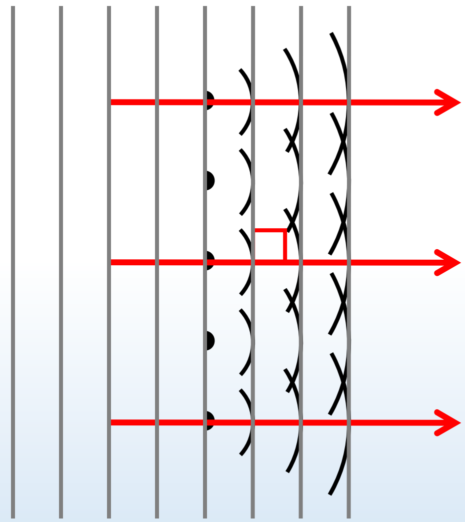
Wavefronts represent surfaces at crests of EM wave, ⊥ to direction of propagation



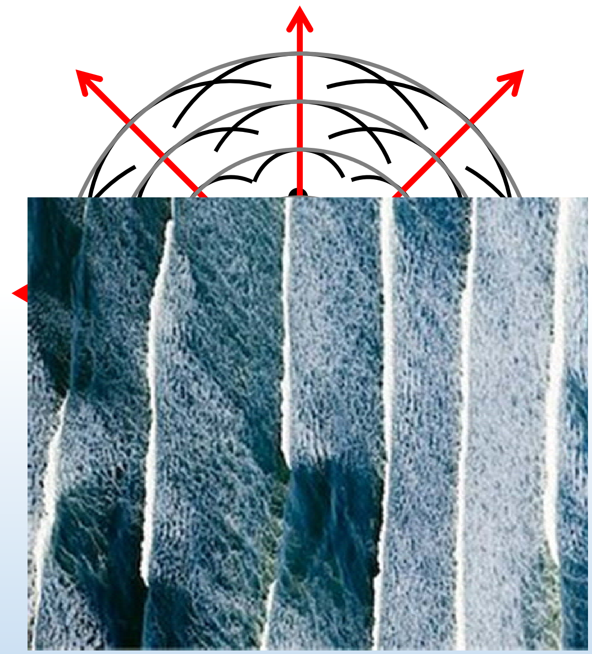
Huygens' Principle

Every point on a wavefront acts as a source of tiny spherical "wavelets" that spread outward





Planar wavefronts



Light represented as "rays" along direction of propagation

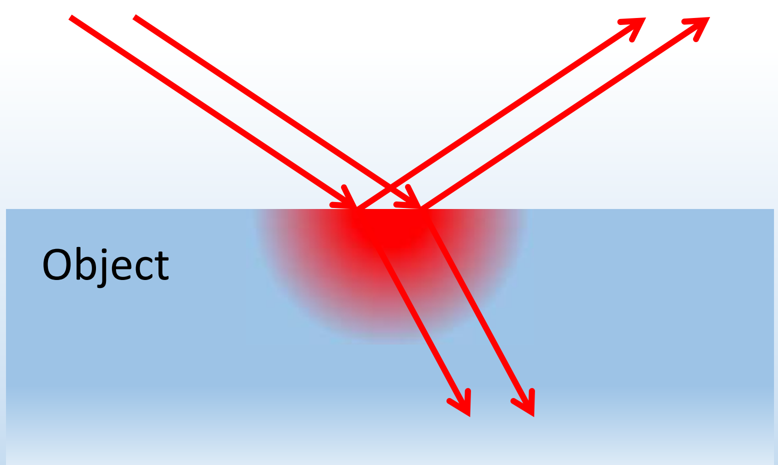
The shape of the wavefront at a later time is tangent to all the wavelets

Light rays

Rays represent direction of propagation of EM wave

Rays travel in a straight line inside transparent medium until they interact with different material

Three ways light rays interact with matter:



Absorption

Reflection

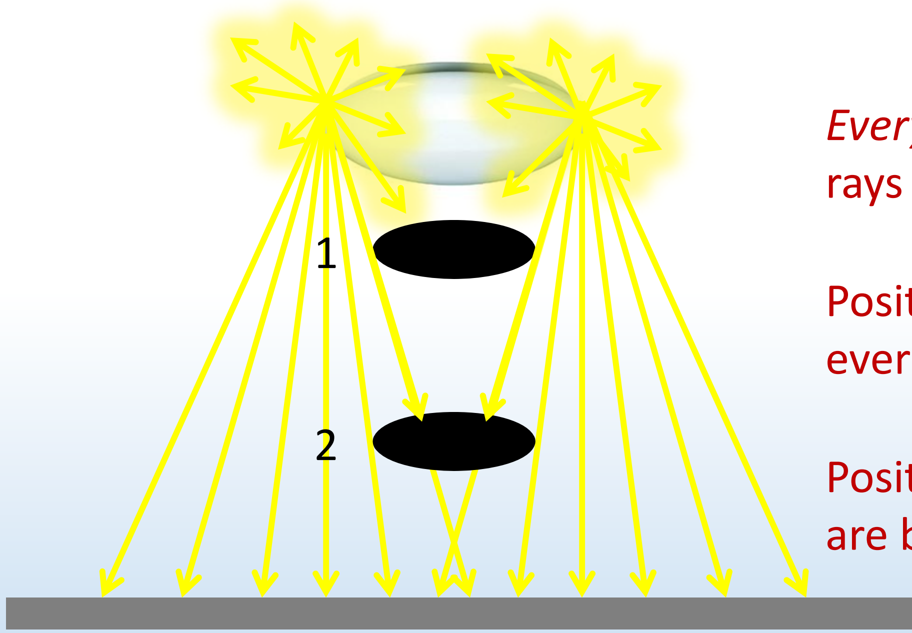
Refraction

Usually, a bit of all three

This model of light works remarkably well for objects >> wavelength

ACT: rays & shadows

A room is lit by an overhead, circular light fixture. A small opaque disk is placed in front of the light, as shown below.



Every point on light emits rays in *every* direction

Position 1: rays hit every part of the floor

Position 2: some rays are blocked

At which position(s) does the disk cast a shadow on the floor that is completely dark?

A. 1 B. 2 C. Both D. Neither

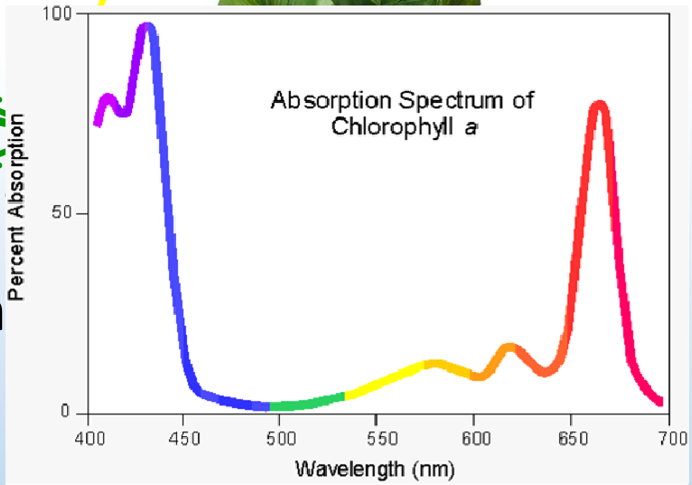
Seeing objects

How do we see objects?

We only see objects if light rays enter our eyes

We know object's location
by where rays come from

Rays from bulb *reflect* off plant and go in all directions. Some rays enter the eyes.



What about color?

Color results from some wavelengths of light being absorbed vs. others being reflected

ACT: laser pointer

Should you be able to see the light from the laser pointer in the picture below?

The rays from the laser pointer are not pointing into our eyes, so no!

We only see laser light reflecting off of objects (the screen, dust in the air...)

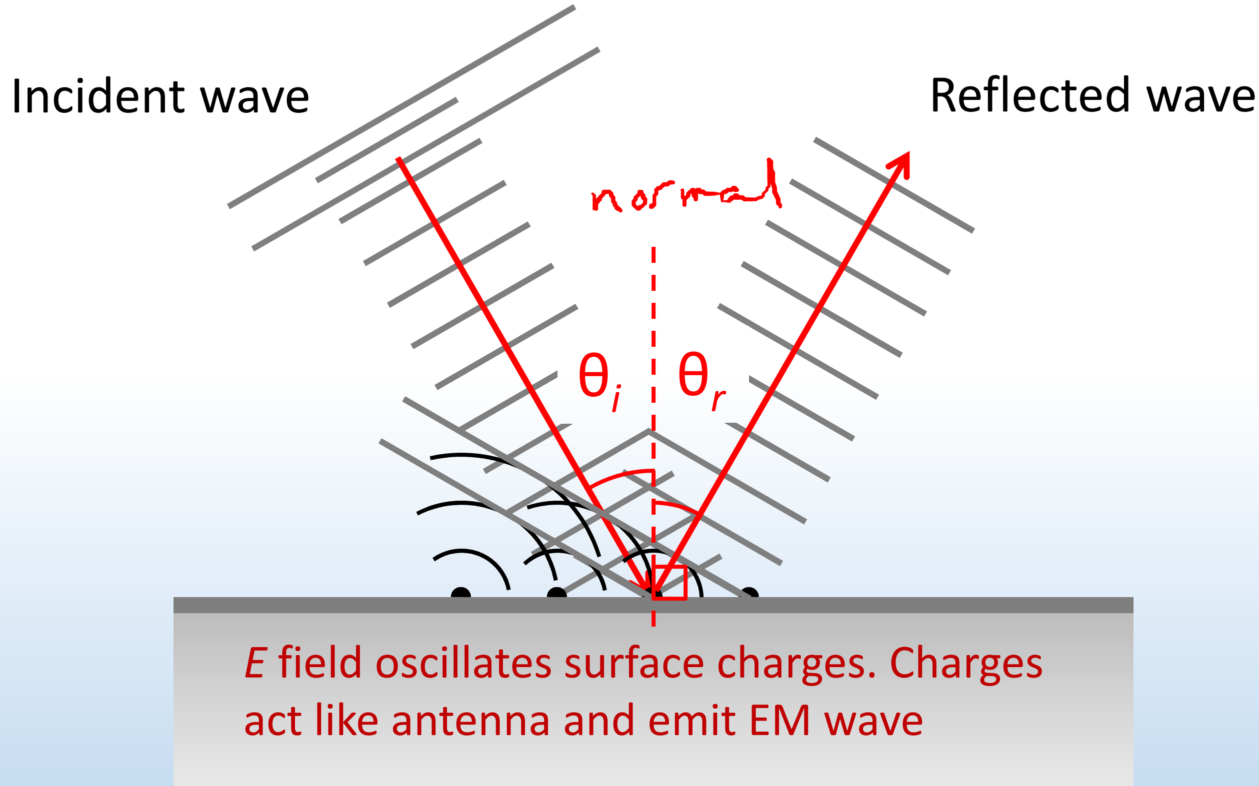
A. Yes

B. No

DEMO

Law of reflection

When light travels into a different material (ex: metal) it reflects



Angle of incidence = Angle of reflection

$$\theta_i = \theta_r$$

DEMO

ACT: Materials

Why do you think metals are “shiny”, i.e. good at reflecting light?

Because:

A. Electrons are free to move in metals

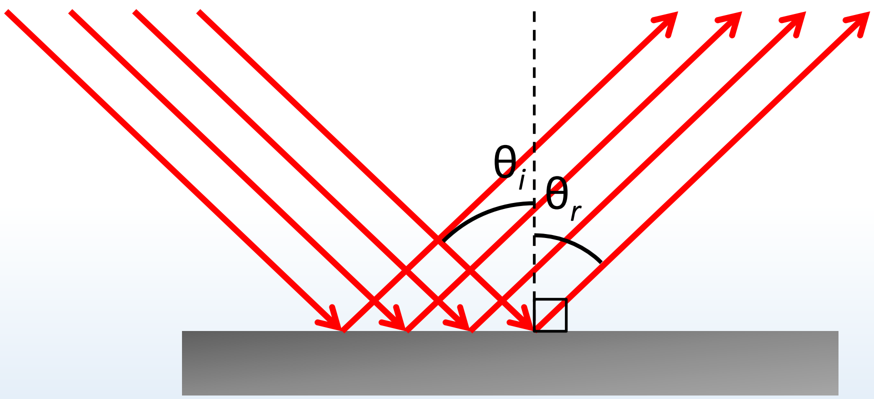
B. Metals can be polished better than insulators

C. The *E* field is zero inside conductors

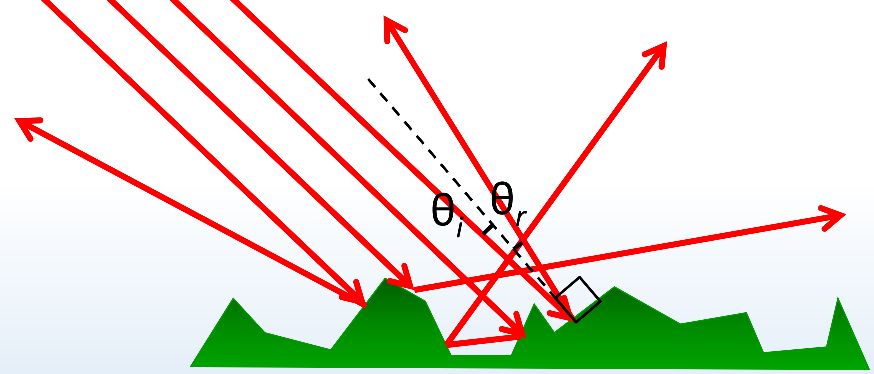
Specular & diffuse reflection

Specular reflection – reflection from a smooth surface

Diffuse reflection – reflection from a rough, irregular surface

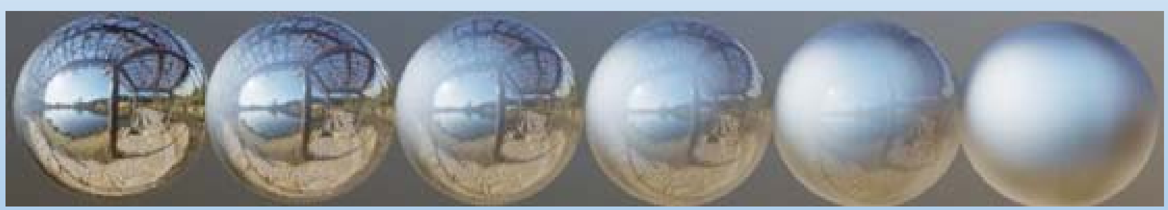


Ex: plane mirror



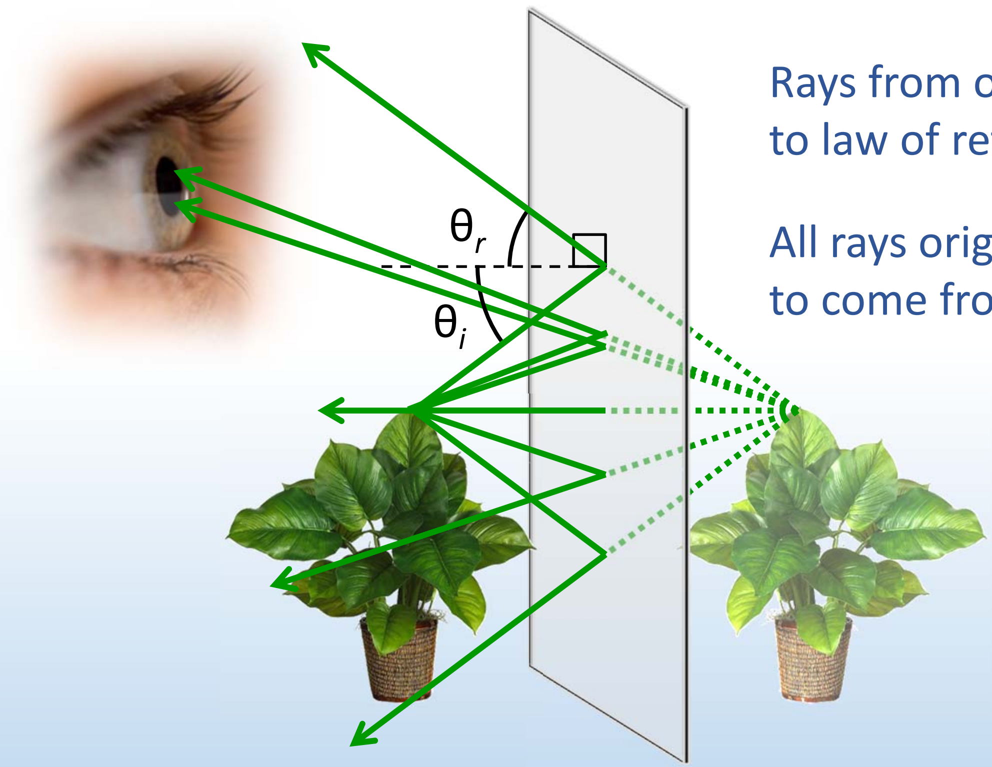
Ex: rough surface

Specular   Mixed   Diffuse



Reflection & images

How do we see reflected images in a flat mirrors?



"Ray diagram"

Rays from object reflect off of mirror according to law of reflection. Some reach the eyes.

All rays originating from point on object ***appear*** to come from point ***behind*** mirror!

Image is:

- Virtual – no light behind mirror
- Upright
- Same size
- Left & right are reversed!

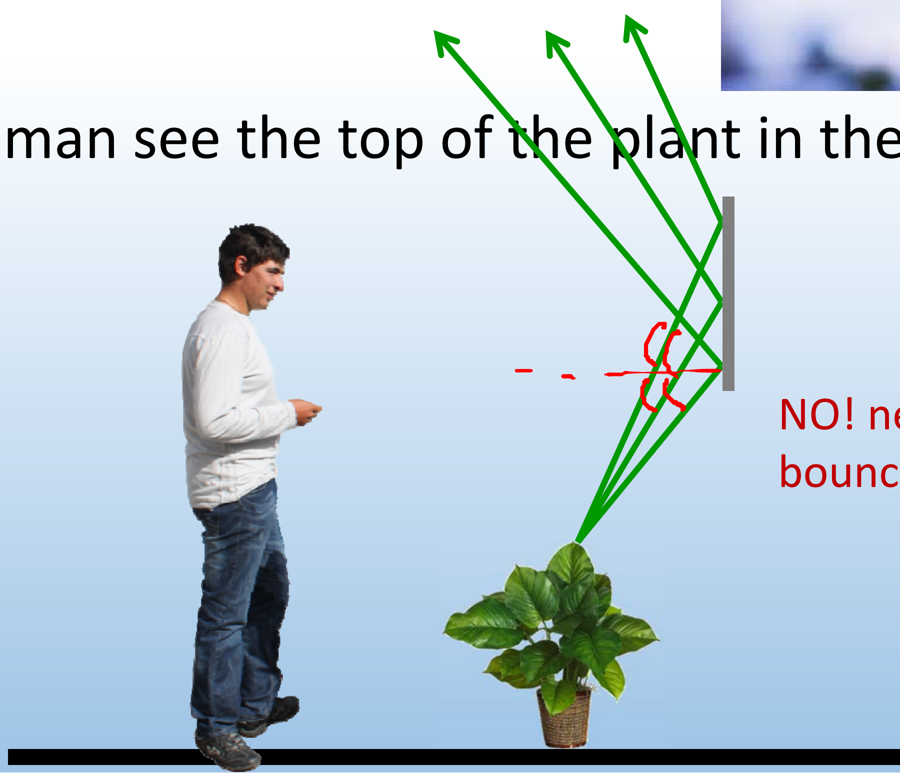
DEMO

CheckPoints 1 & 2

Why is the word "AMBULANCE" written *backwards* on the front hood of all ambulances?

Because it left/right are inverted in your rearview mirror

Can the man see the top of the plant in the mirror?



NO! need light rays from the top to bounce off mirror and reach eyes!

Calculation: Plane Mirror

HW

A man is looking at himself in a mirror on the wall. His eyes are a distance h = 1.6 m from the floor.

At what maximum height above the floor must the bottom of the mirror be to see his shoes?

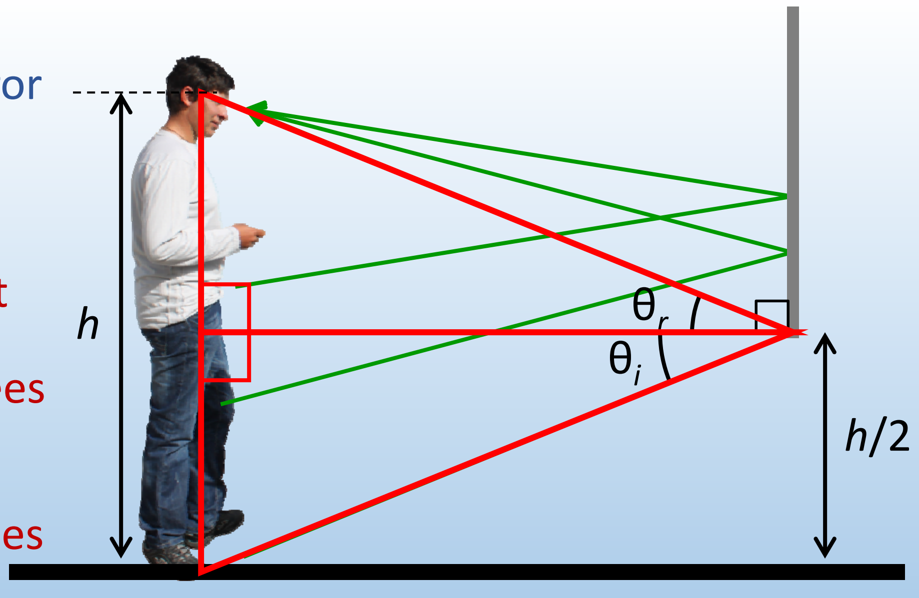
Need light rays originating from shoe to reflect into eyes

By geometry, the bottom of the mirror cannot be higher than $h/2$ = 0.8 m above the floor

He can see his belt

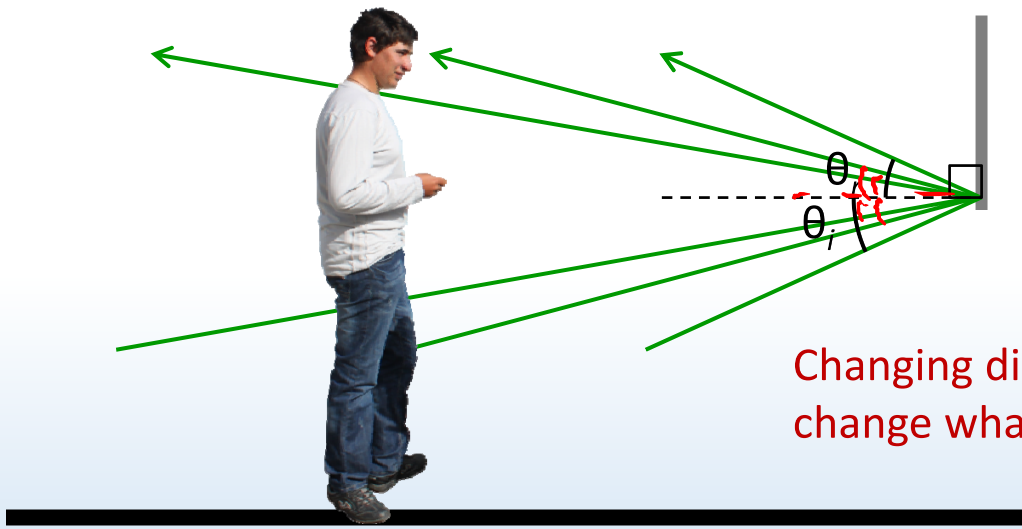
He can see his knees

He can see his shoes



ACT: Plane mirror

The man is standing in front of a short flat mirror that is placed too high, so he can only see down to his knees



Changing distance does not change what he sees of himself!

To see his shoes, he must move:

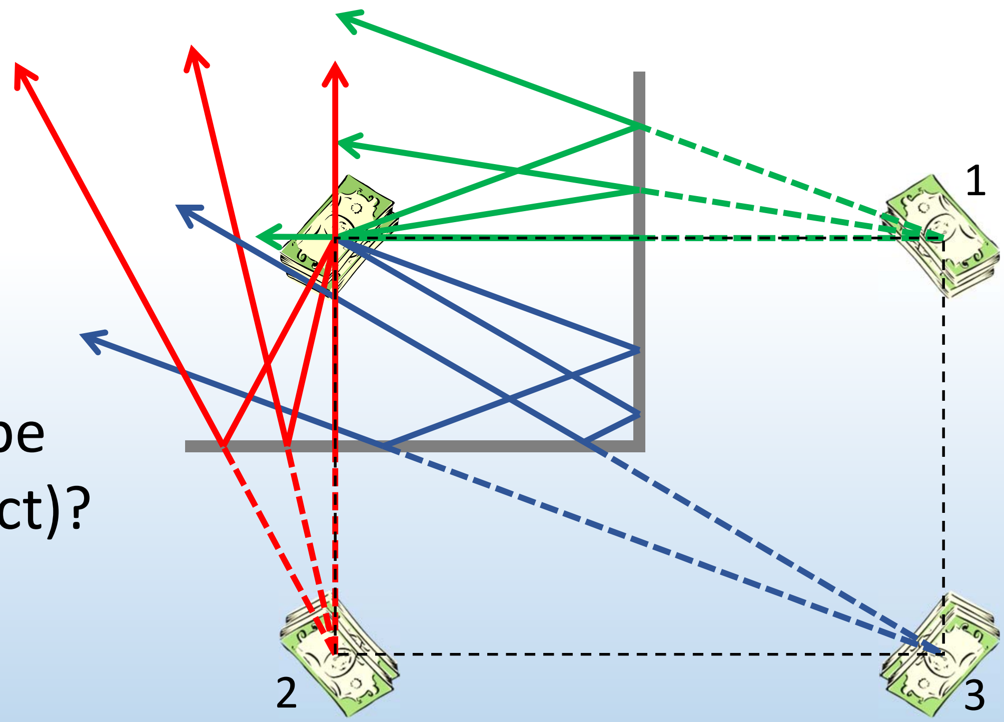
DEMO

A. closer to the mirror
B. further from the mirror
C. moving closer or further will not help

ACT: Two mirrors

An object is placed in front of two perpendicular plane mirrors

Approach:
1. Trace 2 (or more) rays into mirror
2. Trace reflected beams ($\theta_i = \theta_r$)
3. Image is located where reflected beams *appear to originate from*



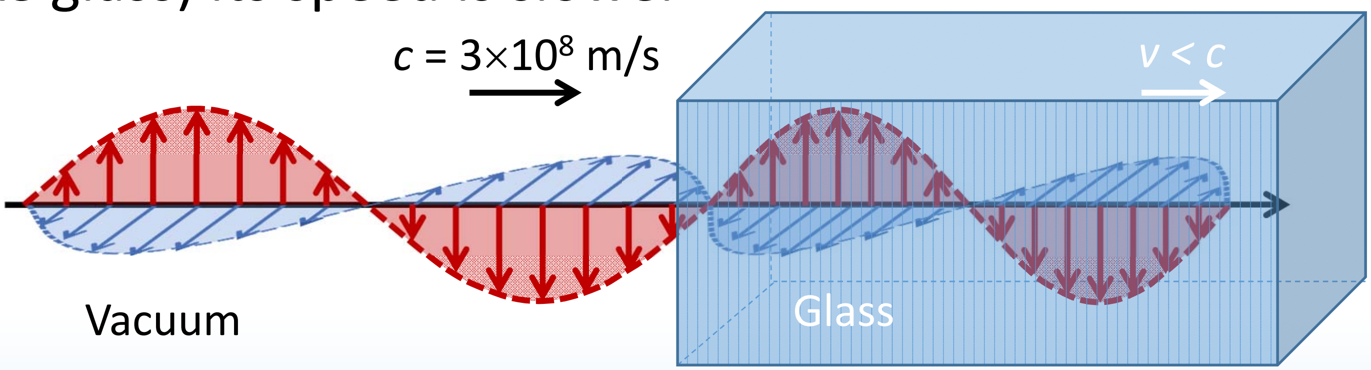
How many images will there be (not including the actual object)?

A. 1
B. 2
C. 3
D. 4

DEMO

Index of refraction

When light travels in a transparent material (ex: a dielectric like glass) its speed is slower



$c = \lambda f$

EM wave must oscillate at same *frequency*, so *wavelength* and *speed* decrease: $v = \lambda f$

Speed of light in vacuum

Speed of light in material → $$v = \frac{c}{n}$$

Refractive index

$\lambda = \frac{\lambda_{vac}}{n}$

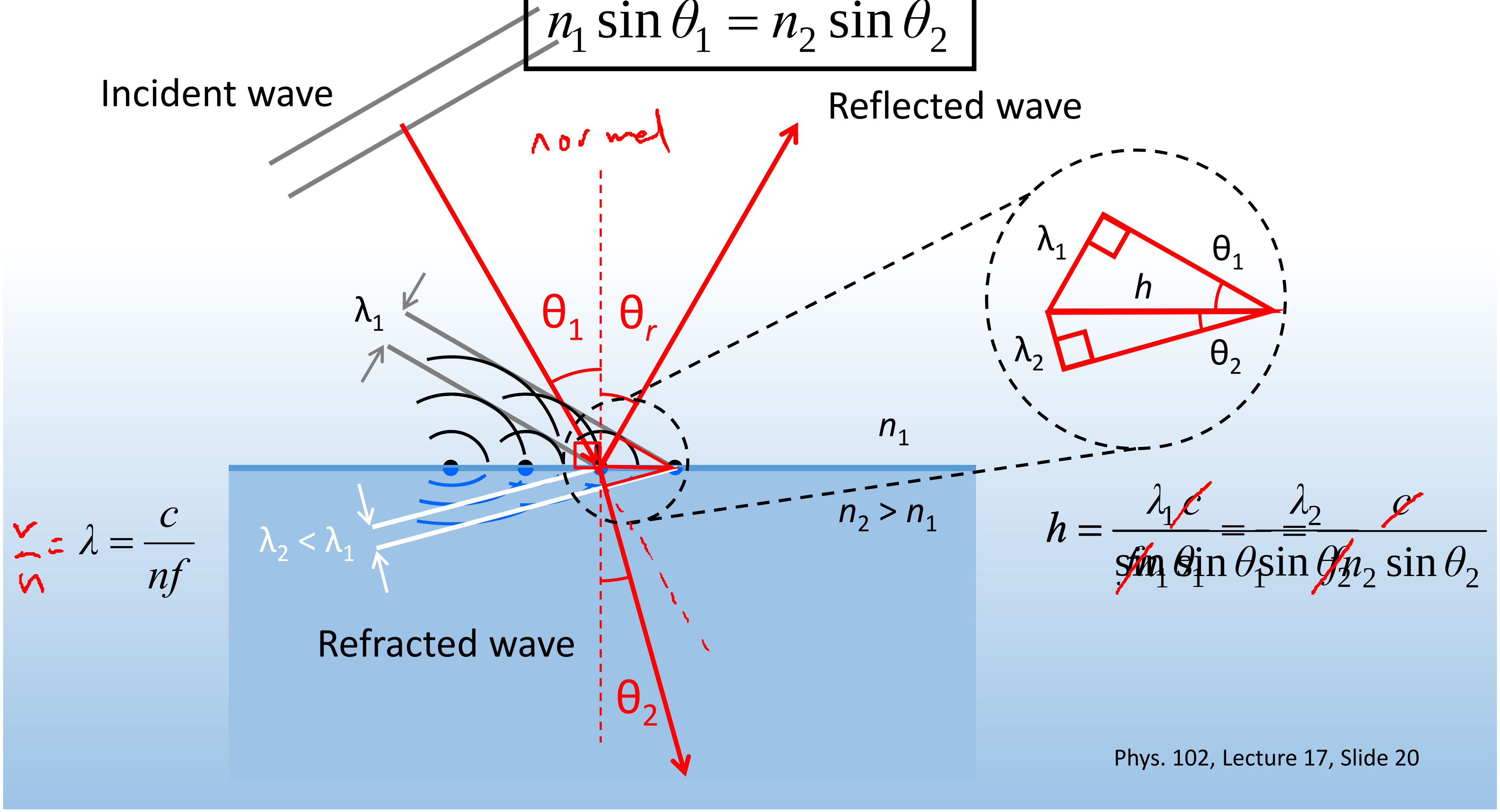
$f = f_{vac}$

Material	n (λ = 590 nm)
Vacuum	1 (exactly)
Air	1.000293
Pure water	1.333
Oil	1.46
Glass	1.5-1.65
Diamond	2.419

Snell's law of refraction

Light bends when traveling into material with different *n*

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

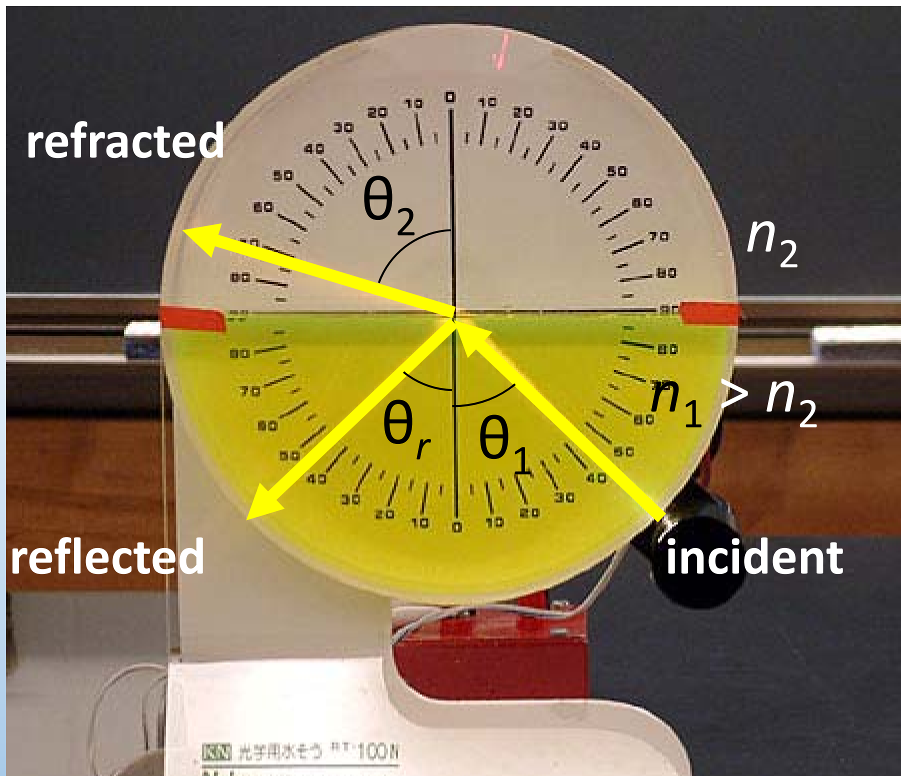


$$\lambda = \frac{c}{nf}$$

$$h = \frac{\lambda_1}{\sin\theta_1} = \frac{\lambda_2}{\sin\theta_2} = \frac{c}{n_2 \sin\theta_2}$$

Calculation: Snell's law

A ray of light traveling through the water (*n* = 1.33) is incident on air (*n* = 1.0). Part of the beam is *reflected* at an angle θ_r = 45°. The other part of the beam is *refracted*. What is θ_2?



Reflection

$$\theta_1 = \theta_r$$

Refraction

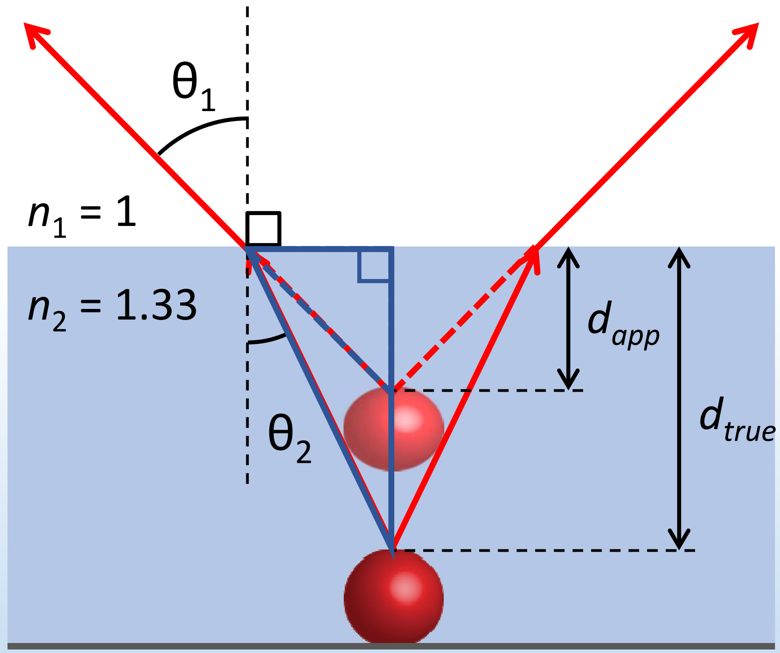
$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

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

$$= \sin^{-1}\left(\frac{1.33}{1}\sin 45^\circ\right) \approx 70.1^\circ$$

Calculation: refraction & images

A ball is placed at the bottom of a bucket of water at a depth of d_{true}. Where does its image appear to an observer outside the water?



"Apparent depth" $d_{app} < d_{true}$

Note: Angles are exaggerated

x

d_{app}

θ_1 d_{true}

θ_2

$$x = d_{app} \tan\theta_1 = d_{true} \tan\theta_2$$

$$d_{app} \approx d_{true} \frac{\tan\theta_2}{\tan\theta_1}$$

$$= 0.75\, d_{true}$$

For small angles:

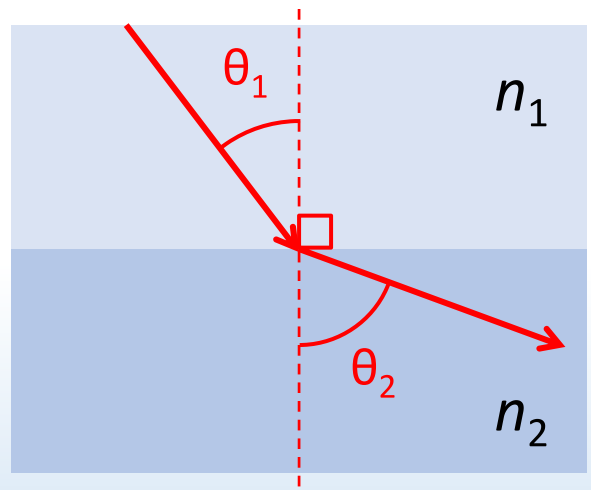
$$\theta \approx \sin\theta \approx \tan\theta$$

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

DEMO

ACT: CheckPoint 3

A ray of light travels through two transparent materials as shown below.



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

$\theta_1 < \theta_2$ so $n_1 > n_2$

Compare the index of refraction of the two materials:

A. $n_1 > n_2$

B. $n_1 = n_2$

C. $n_1 < n_2$

Summary of today's lecture

- Ray model of light

  We see objects if emitted or reflected light rays enter our eyes

- Light rays can be absorbed, reflected & refracted

  Law of reflection $\theta_i = \theta_r$

  Snell's law of refraction $n_1 \sin\theta_1 = n_1 \sin\theta_2$

- Images from reflection & refraction

  We see images from where light rays appear to originate