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

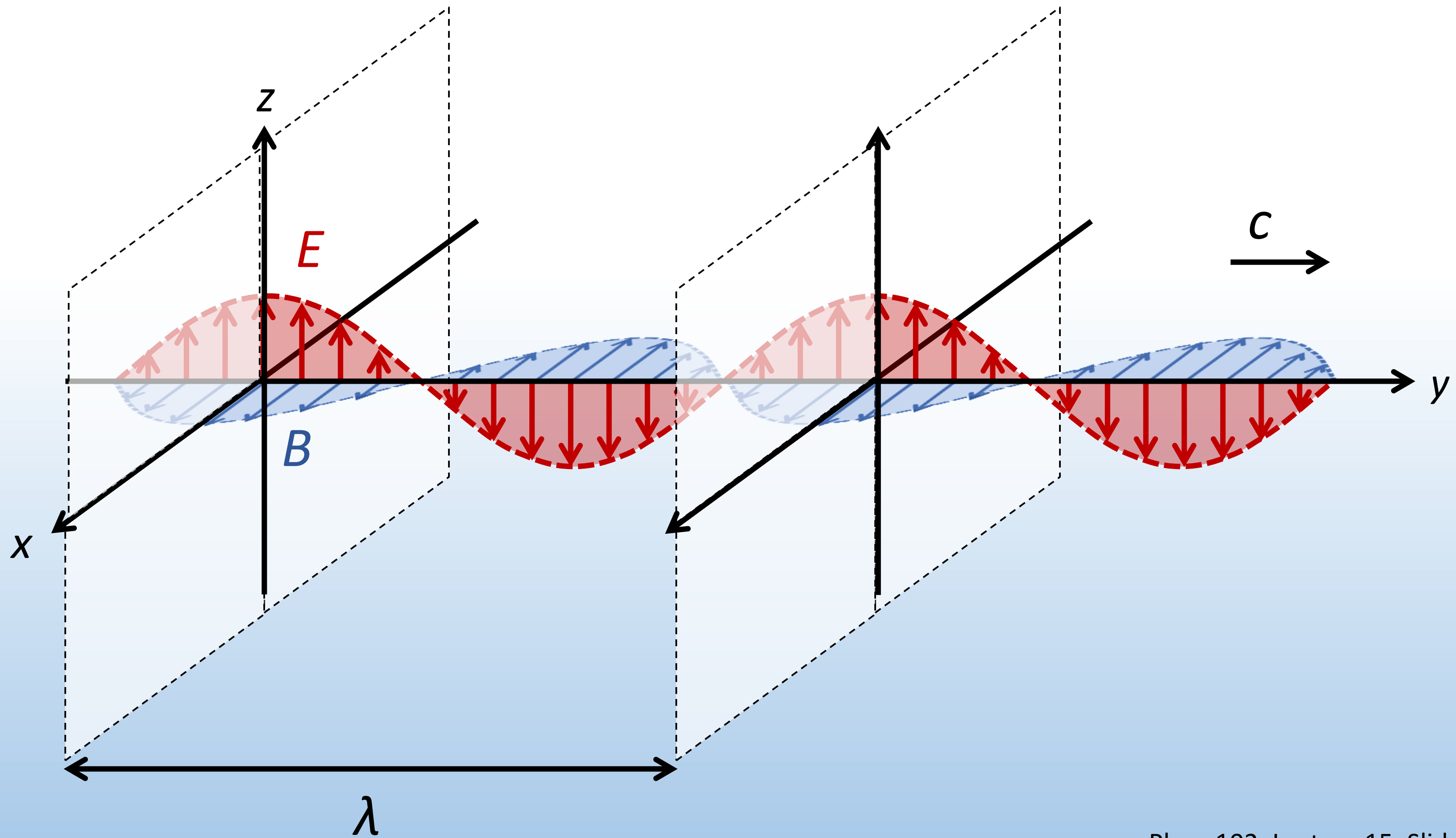
- Lecture 24 & 25 – Quantum mechanics

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

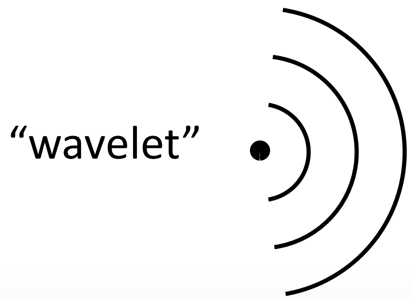
Recall wavefronts

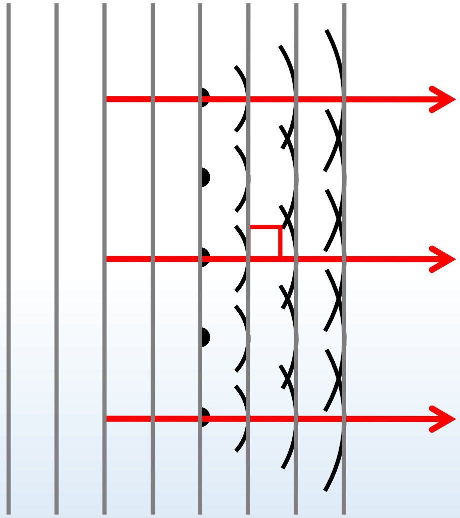
Wavefronts represent surfaces at crests of EM wave, ⊥ to direction of propagation



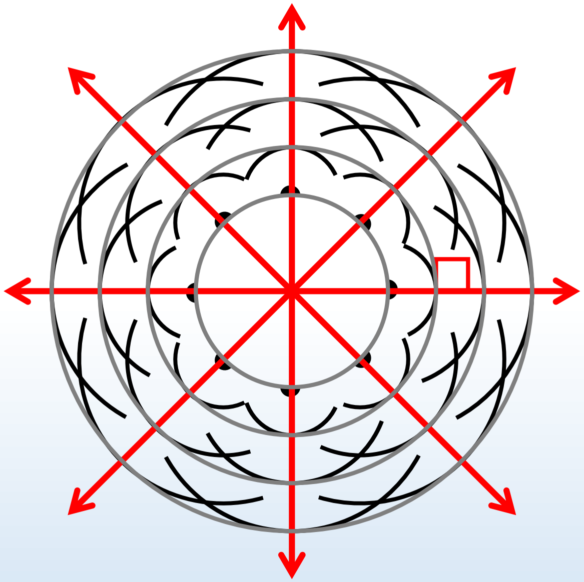
Huygens' Principle

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





Planar wavefronts



Spherical wavefronts

Light represented as "rays" along direction of propagation

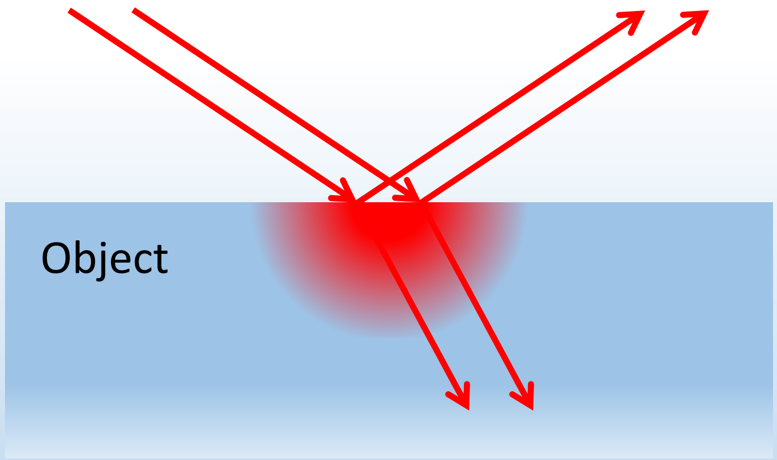
The shape of the wavefront at a later time is tangent to all the wavelets

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

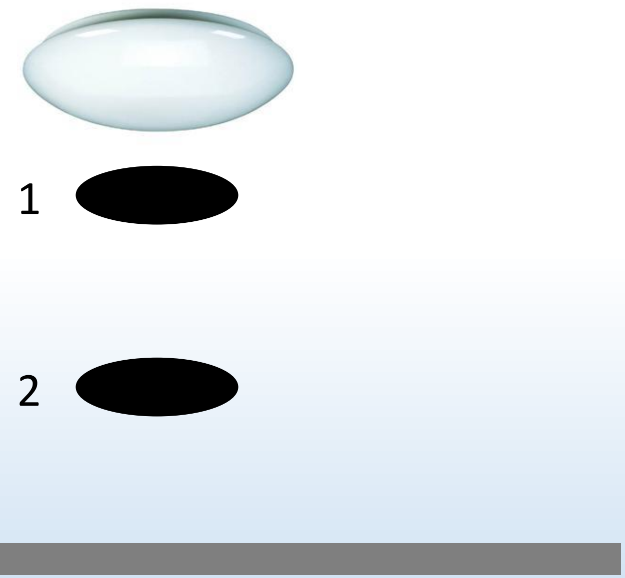
Refraction

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.



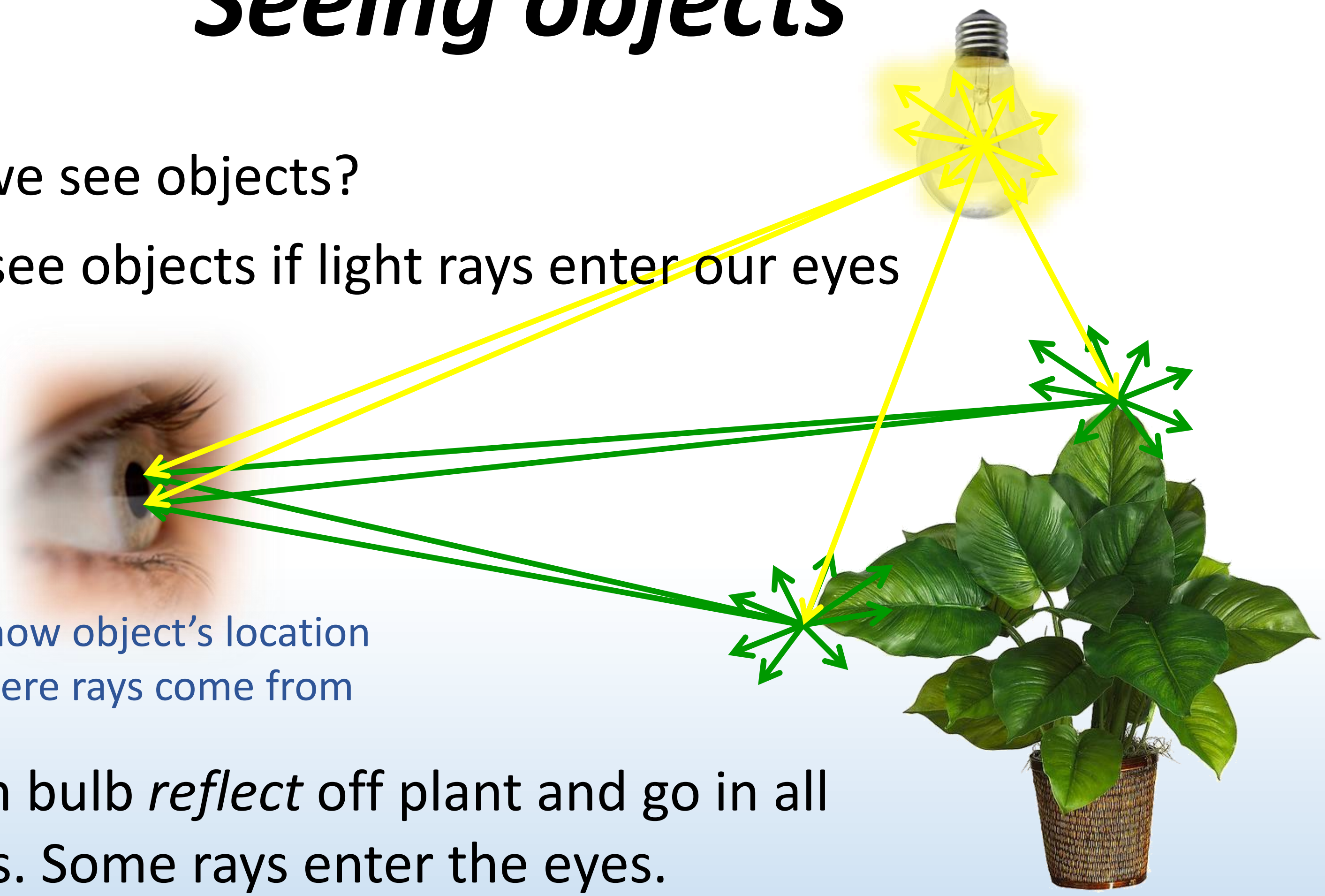
At which position(s) does the disk cast a shadow on the floor that is completely dark?

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 if object does not emit light?

What about color?

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

ACT: laser pointer

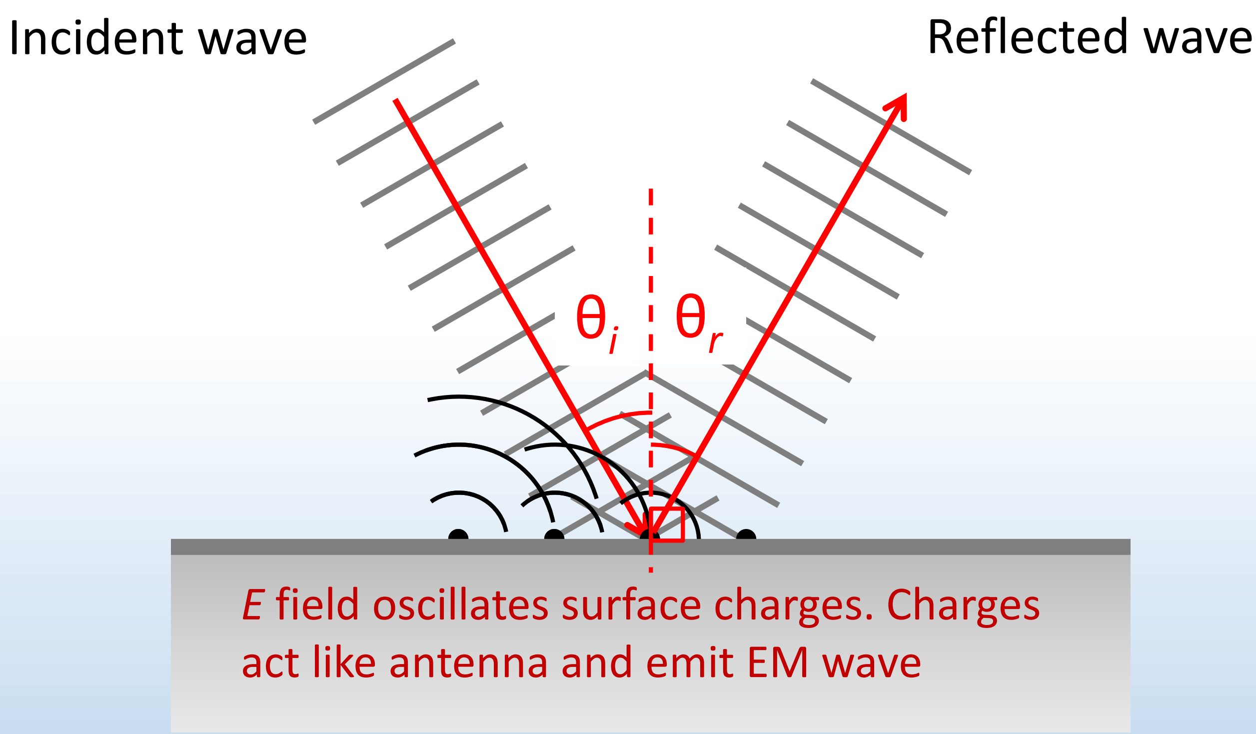
Should you be able to see the light from the laser pointer in the picture below?

A. Yes

B. No

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?

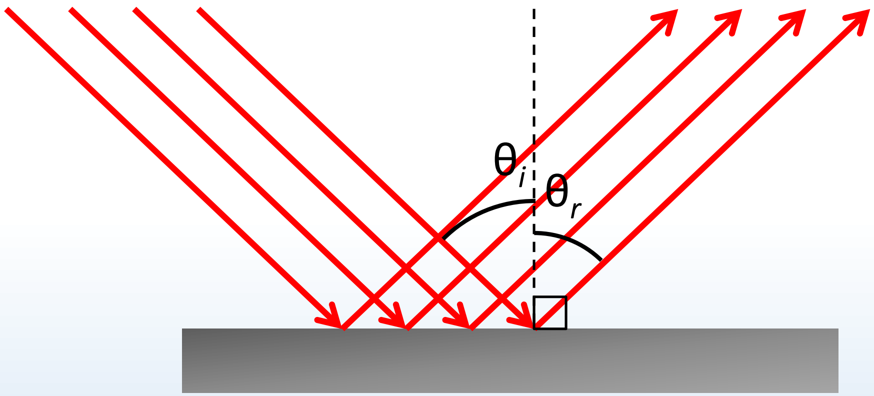
Because:

A. Electrons are free to move in metals
B. Metals can be polished better than insulators
C. The *E* field is zero inside conductors

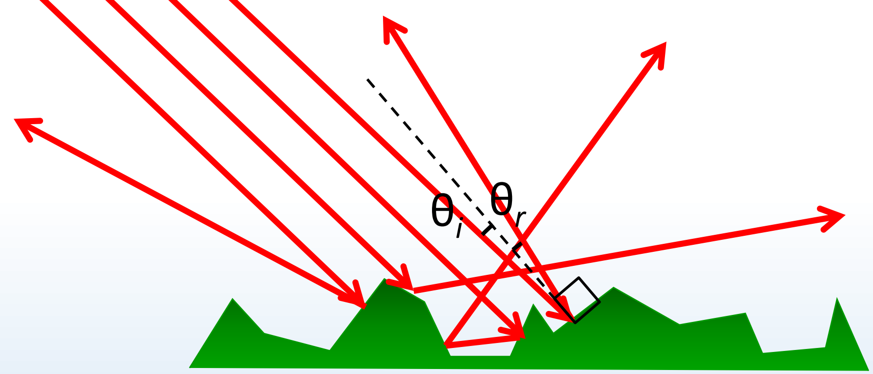
Specular & diffuse reflection

Specular reflection – reflection from a smooth surface

Diffuse reflection – reflection from a rough, irregular surface



Ex: plane mirror

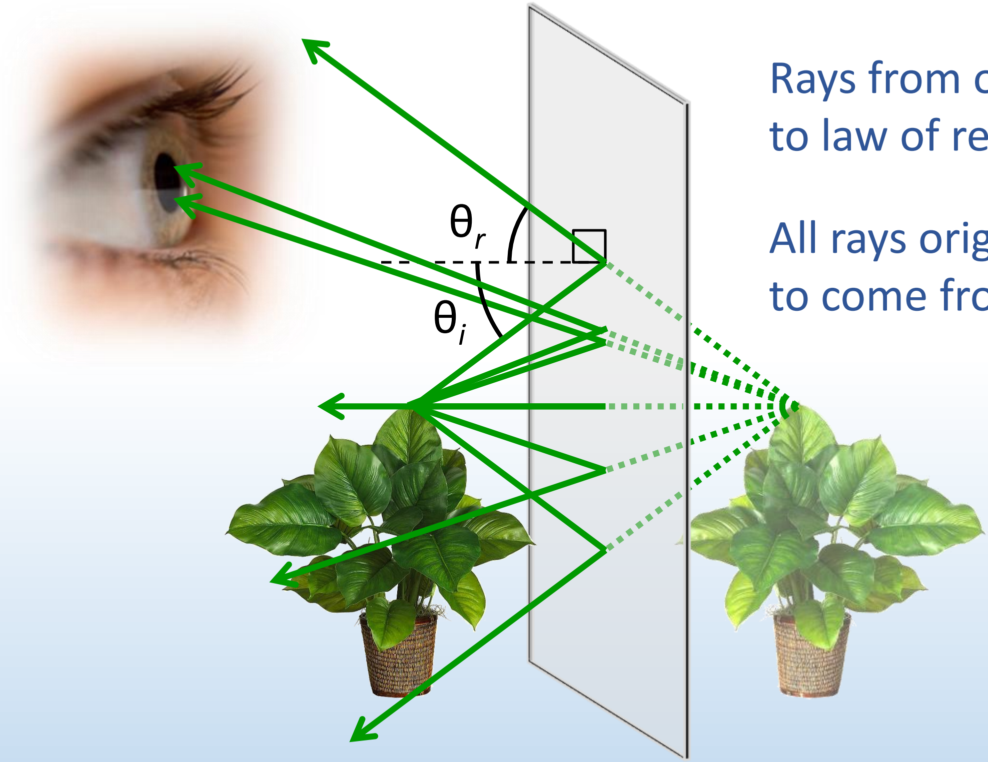


Ex: rough surface

Specular Mixed Diffuse

Reflection & images

How do we see reflected images in a flat mirrors?



Object Image

"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!

CheckPoints 1 & 2

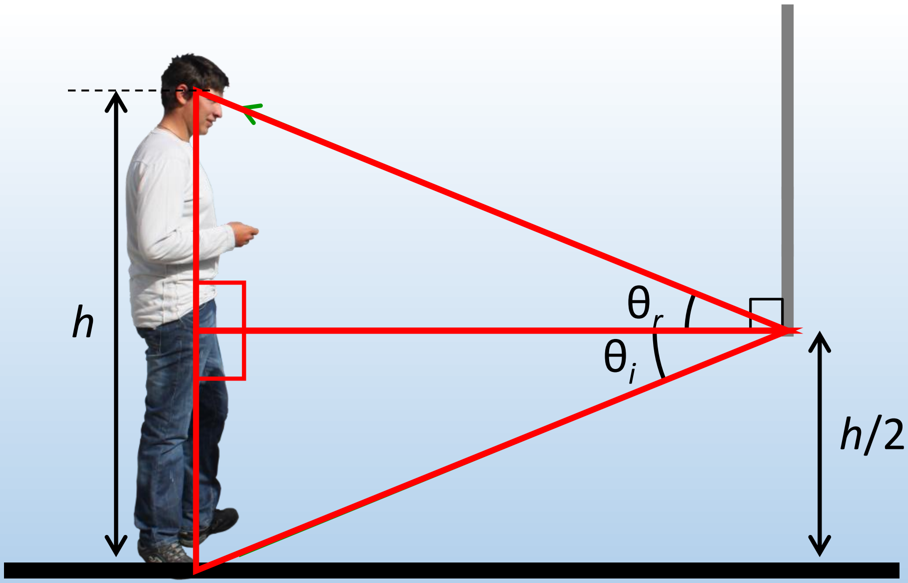
Why is the word "AMBULANCE" written *backwards* on the front hood of all ambulances?

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

Calculation: Plane Mirror

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?



ACT: Plane mirror

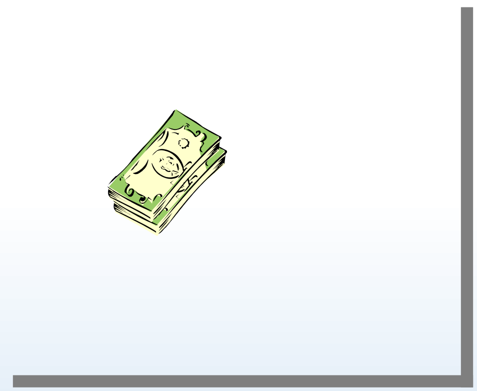
The man is standing in front of a short flat mirror that is placed too high, so he can only see down to his knees

To see his shoes, he must move:

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

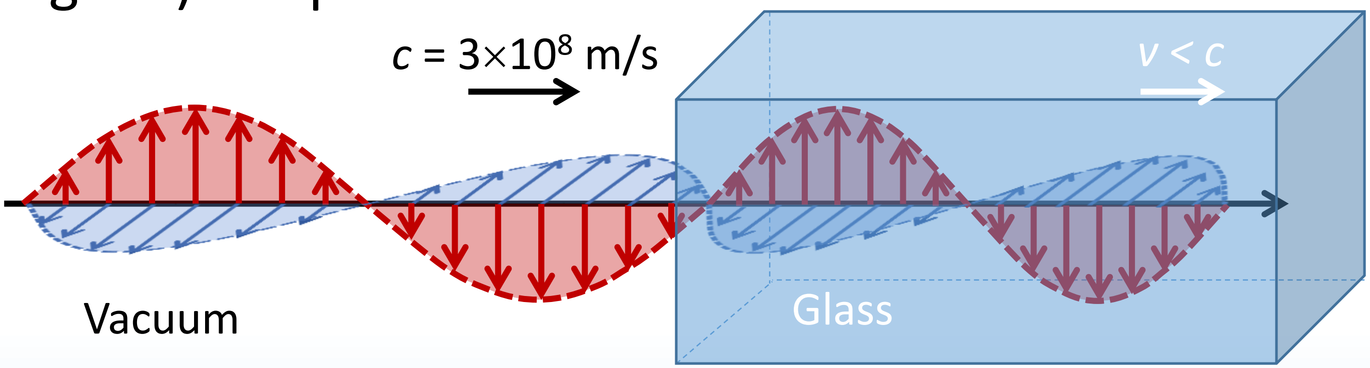


How many images will there be (not including the actual object)?

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

Index of refraction

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



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

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

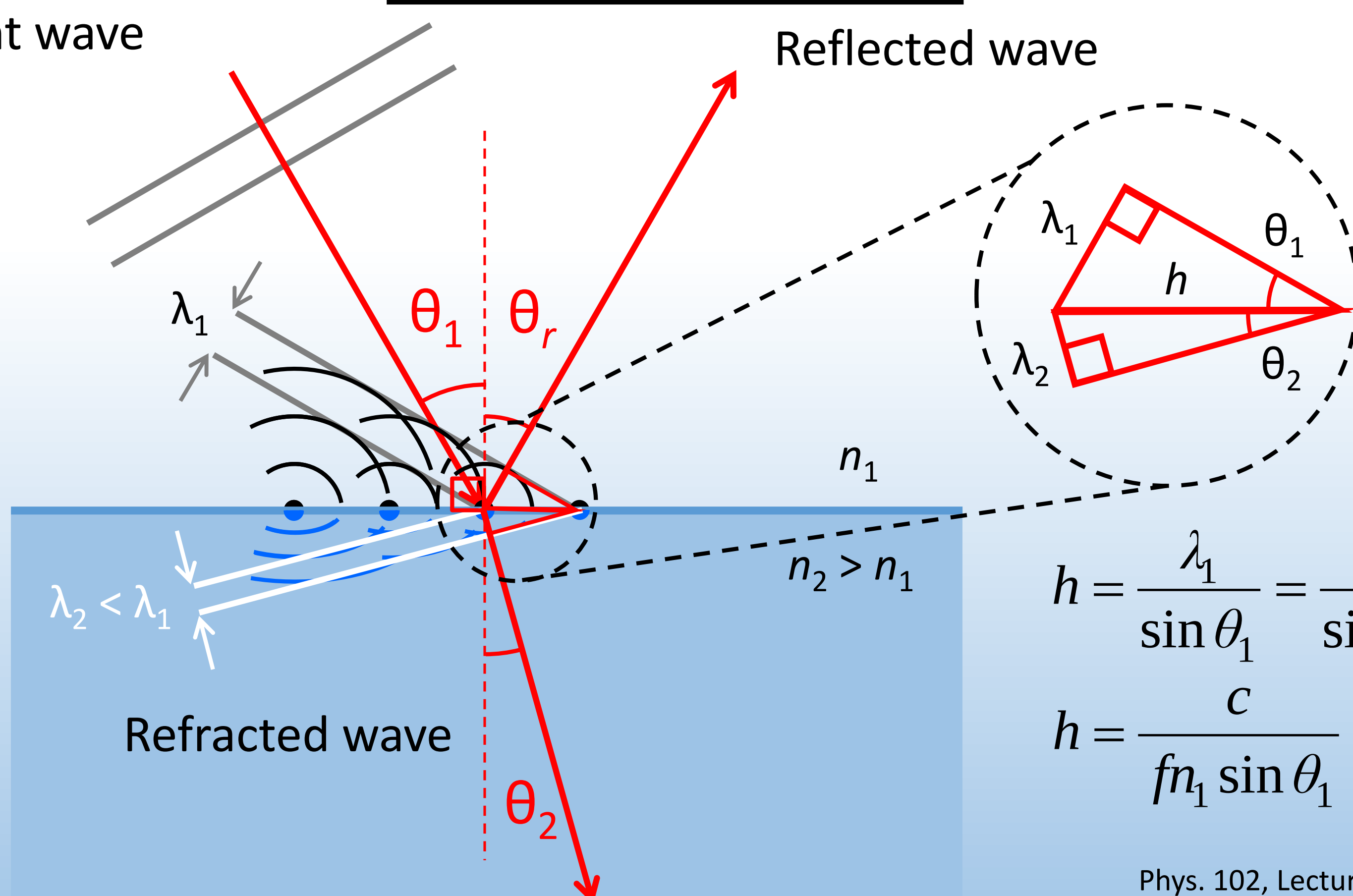
Refractive index

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*

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



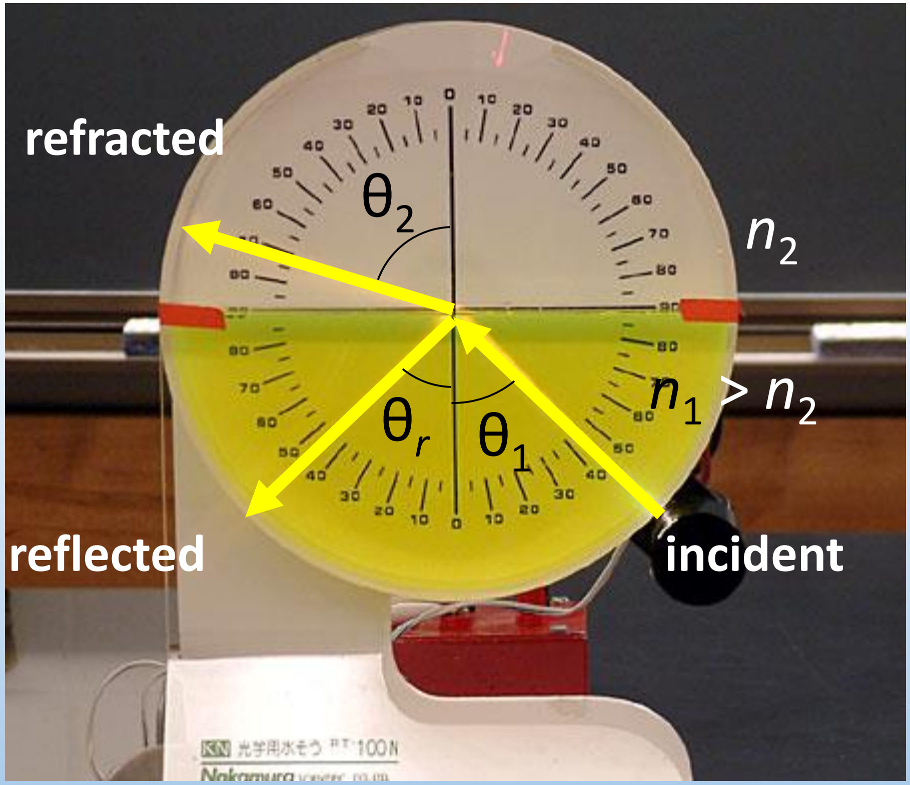
$$\lambda = \frac{c}{nf}$$

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

$$h = \frac{c}{fn_1 \sin\theta_1} = \frac{c}{fn_2 \sin\theta_2}$$

Calculation: Snell's law

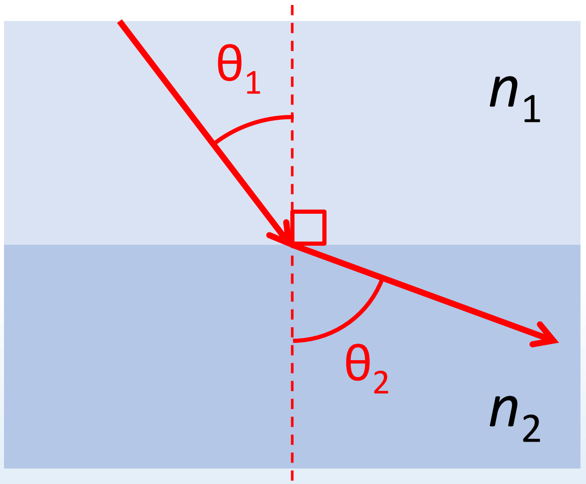
A ray of light traveling through the water (n = 1.33) is incident on air (n = 1.0). Part of the beam is *reflected* at an angle θ_r = 45°. The other part of the beam is *refracted*. What is θ_2?



Reflection	Refraction
$\theta_1 = \theta_r$	$n_1 \sin\theta_1 = n_2 \sin\theta_2$

ACT: CheckPoint 3

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



Compare the index of refraction of the two materials:

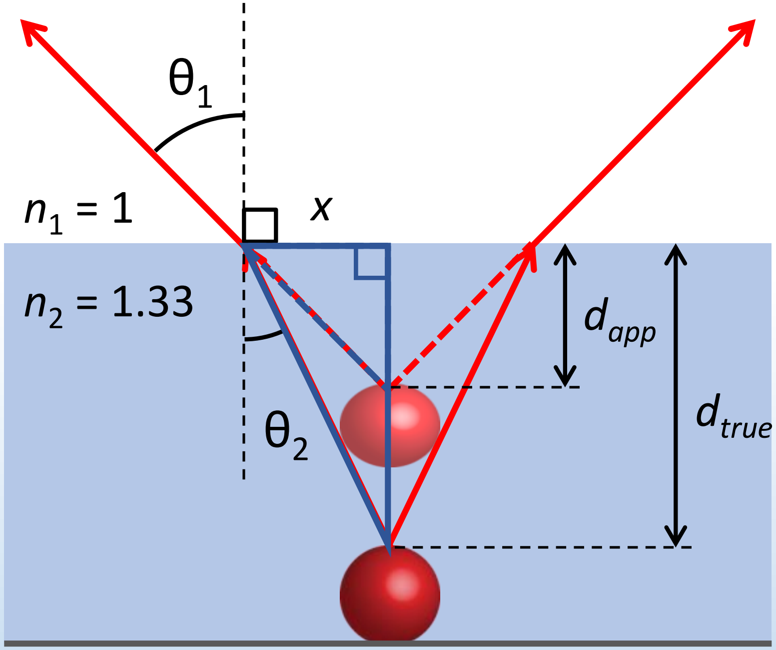
A. $n_1 > n_2$

B. $n_1 = n_2$

C. $n_1 < n_2$

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?



Note: Angles are exaggerated

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

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

$$d_{app} \approx d_{true} \frac{n_1}{n_2}$$

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

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