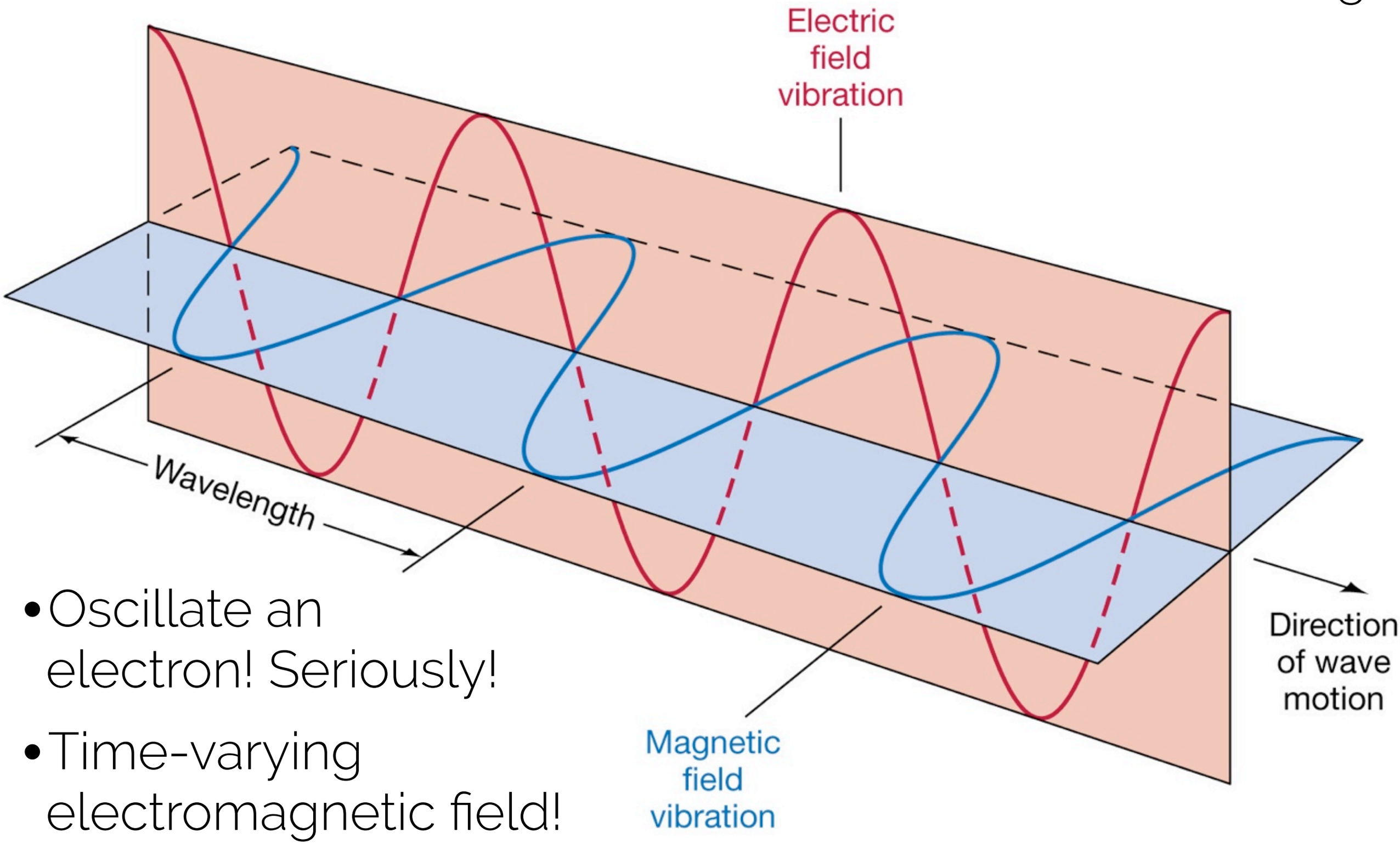
Chapter 07 Light

Section 7.1: Sources of Light

Luminosity

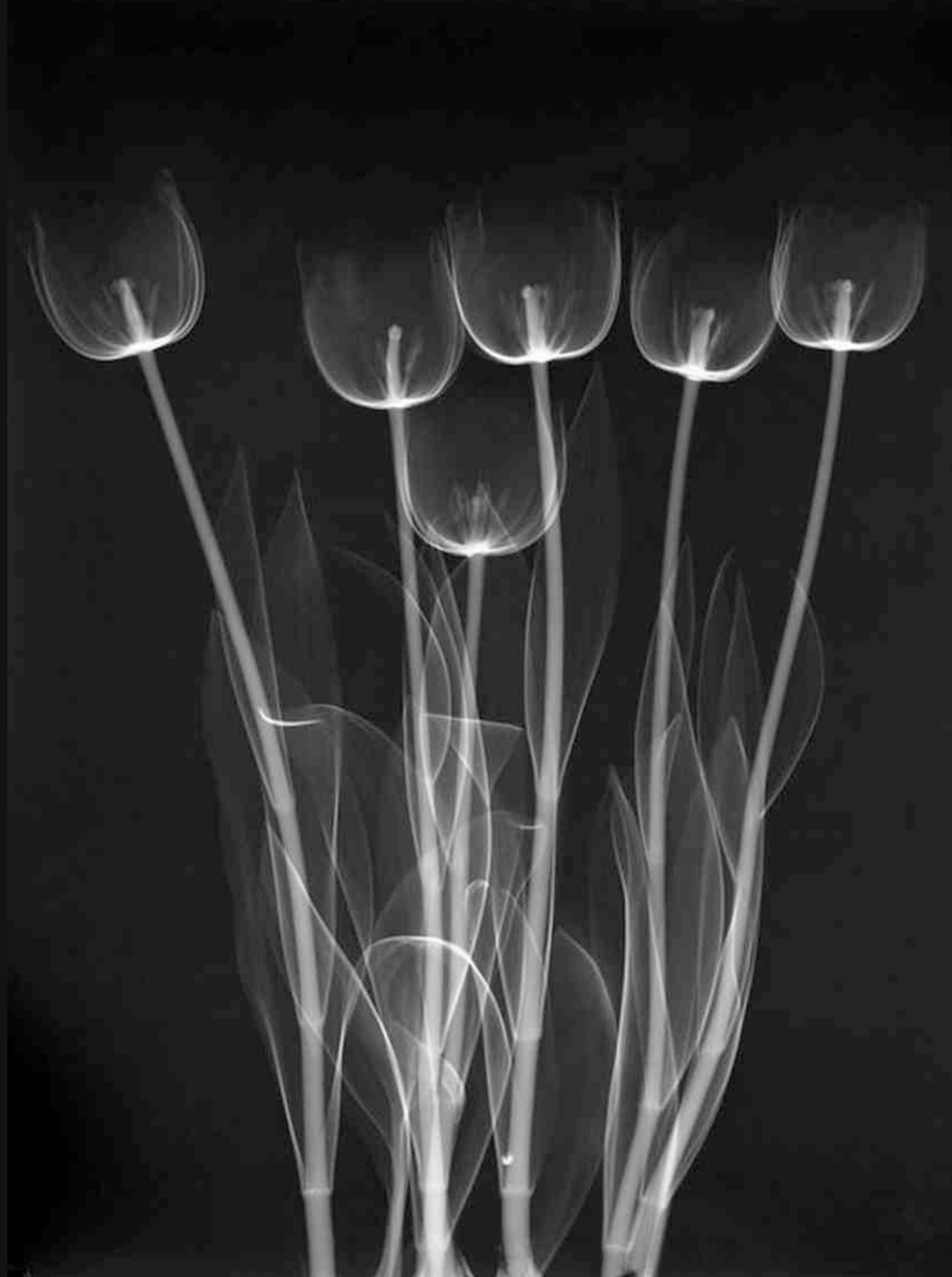
The sun shines, a candle glows, a lightbulb burns: It's all the same thing!



- Oscillate an electron! Seriously!
- Time-varying electromagnetic field!

Q07.01:
True or false:

X-rays are the same physical phenomenon as visible light.



The Electromagnetic Spectrum

- Accelerate an electron: greater acceleration, greater frequency of oscillation
- Visible light = obvious to us, but it's only a tiny part of a greater spectrum
- Radio waves and x-rays are exactly the same thing as visible light–just at a different frequency
- All e·m waves travel at the same speed! $c = 3\times10^8\text{m/s}$

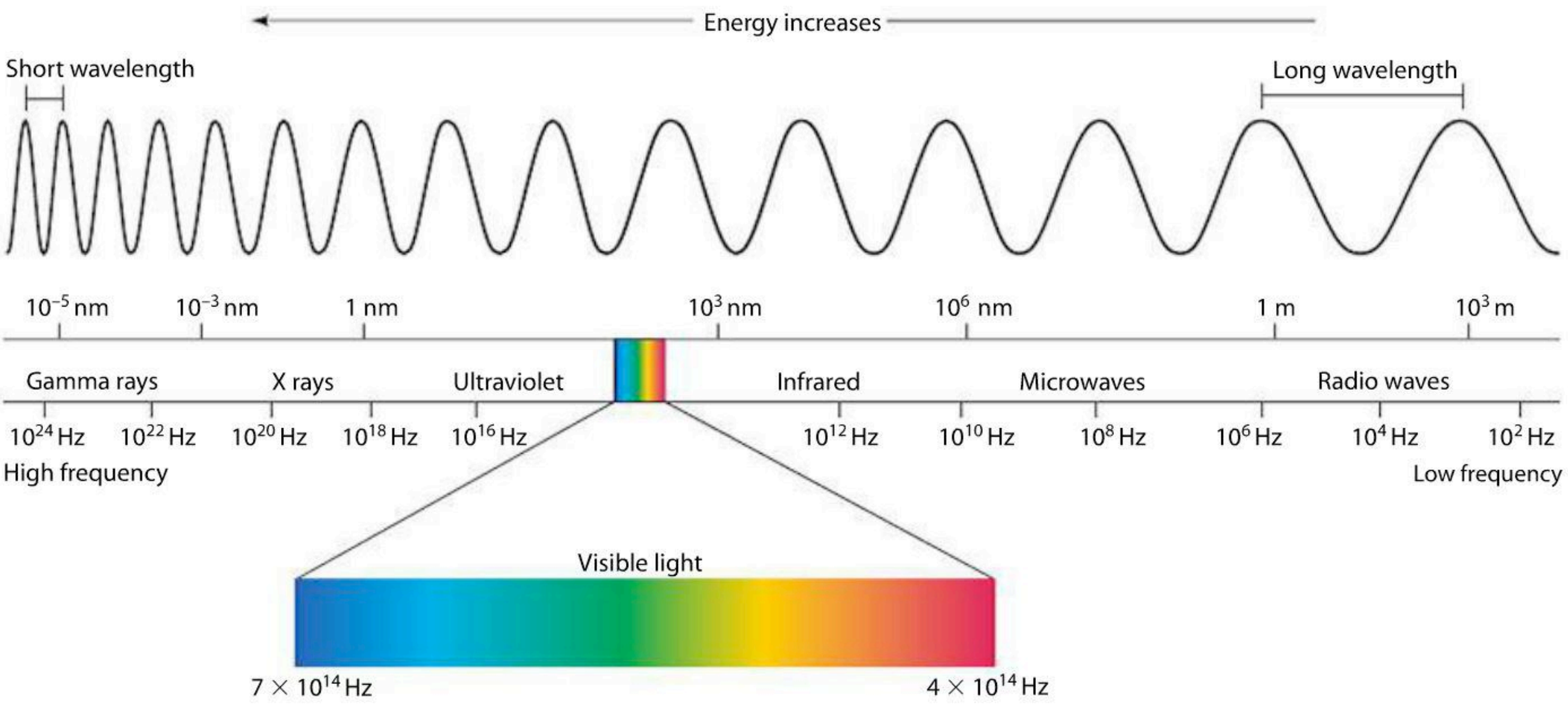
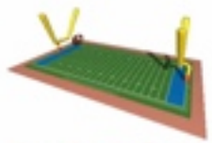


Chart of the Electromagnetic Spectrum

Size reference


football field


man's height


baseball


paperclip thickness


paper thickness


cells


bacteria


viruses


water molecule


atom


subatomic particles →

wavelength λ (m)

1 ft | 1 cm | 1 mm | 1 mil | 1 μ | 1 nm | 1 Å | 1 pm

10^{3} 10^{2} 10 1 10^{-1} 10^{-2} 10^{-3} 10^{-4} 10^{-5} 10^{-6} 10^{-7} 10^{-8} 10^{-9} 10^{-10} 10^{-11} 10^{-12}

wavenumber (cm^{-1})

10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 1 10 10^{2} 10^{3} 10^{4} 10^{5} 10^{6} 10^{7} 10^{8} 10^{9} 10^{10}

electron volt (eV)

10^{-9} 10^{-8} 10^{-7} 10^{-6} 10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 1 10 10^{2} 10^{3} 10^{4} 10^{5} 10^{6}

frequency (Hz)

1 MHz | 1 GHz | 1 THz | 1 PHz | 1 EHz | 1 ZHz

10^{5} 10^{6} 10^{7} 10^{8} 10^{9} 10^{10} 10^{11} 10^{12} 10^{13} 10^{14} 10^{15} 10^{16} 10^{17} 10^{18} 10^{19} 10^{20} 10^{21}

Bands

Radio Spectrum | Terahertz | Infrared | Ultraviolet | X-ray | Gamma

Broadcast and Wireless | Microwave | Far IR | Mid IR | Near IR | Near UV | Extreme UV | Soft X-ray | Hard X-ray

electronics | optics

Visible wavelengths (nm): 700 625 575 540 470 440

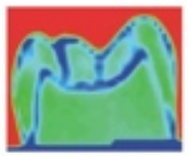
Sources and Uses of Frequency Bands


AM radio
600kHz-1.6MHz


FM radio
88-108 MHz


Mobile Phones
900MHz-2.4GHz


Radar
1-100 GHz


Bio imaging
1-10 THz


Fiber telecom
0.7-1.4 μ


Visible Light
425-750THz
700-400nm


Dental Curing
200-350nm


Medical X-rays
10-0.1 Å


Cosmic ray observations
<<1 Å

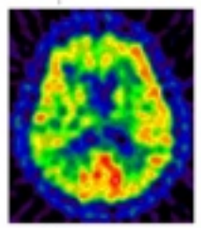
TV Broadcast
54-700 MHz


Wireless Data
~ 2.4 GHz


Screening
0.2-4.0 THz


Remotes
850 nm


Baggage screen
10-1.0 Å


PET imaging
0.1-0.01 Å


Microwave Oven
2.4 GHz

"mm wave"
"sub-mm"


Night Vision
10-0.7 μ


Suntan
400-290nm


Crystallography
2.2-0.7 Å

$\lambda = 3x10^{8}/freq = 1/(wn*100) = 1.24x10^{-6}/eV$

SURA Southeastern Universities Research Association ®

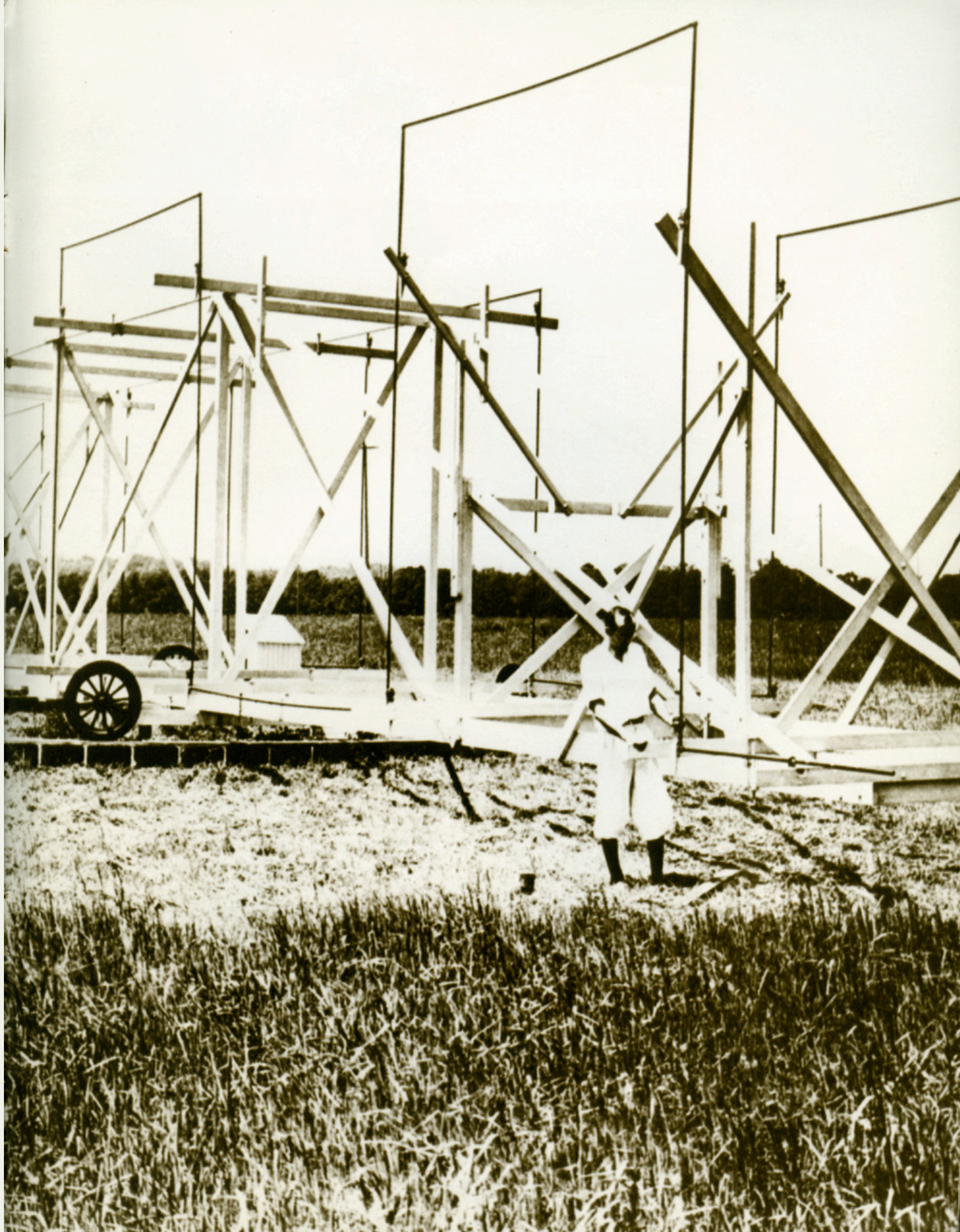
Q07.02: A radio wave traveling through space travels

A) at the speed of light!
$v = 3\times10^8\text{m/s}$.

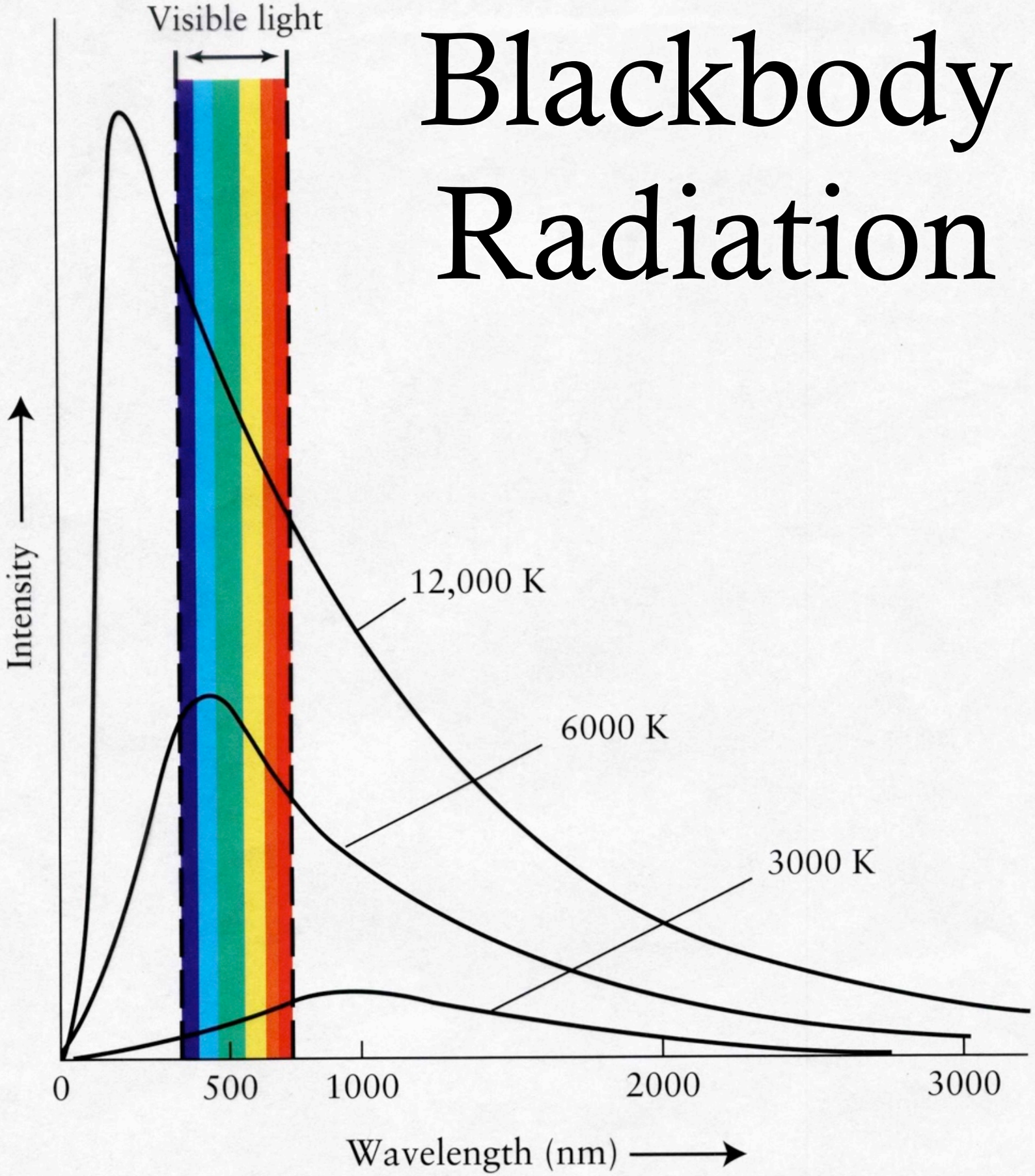
B) slower than light speed
($v < 3\times10^8\text{m/s}$).

C) faster than the speed of light
($v > 3\times10^8\text{m/s}$).

D) at $\mathbf{0\ m/s}$. Radio waves cannot travel through space!



Blackbody Radiation



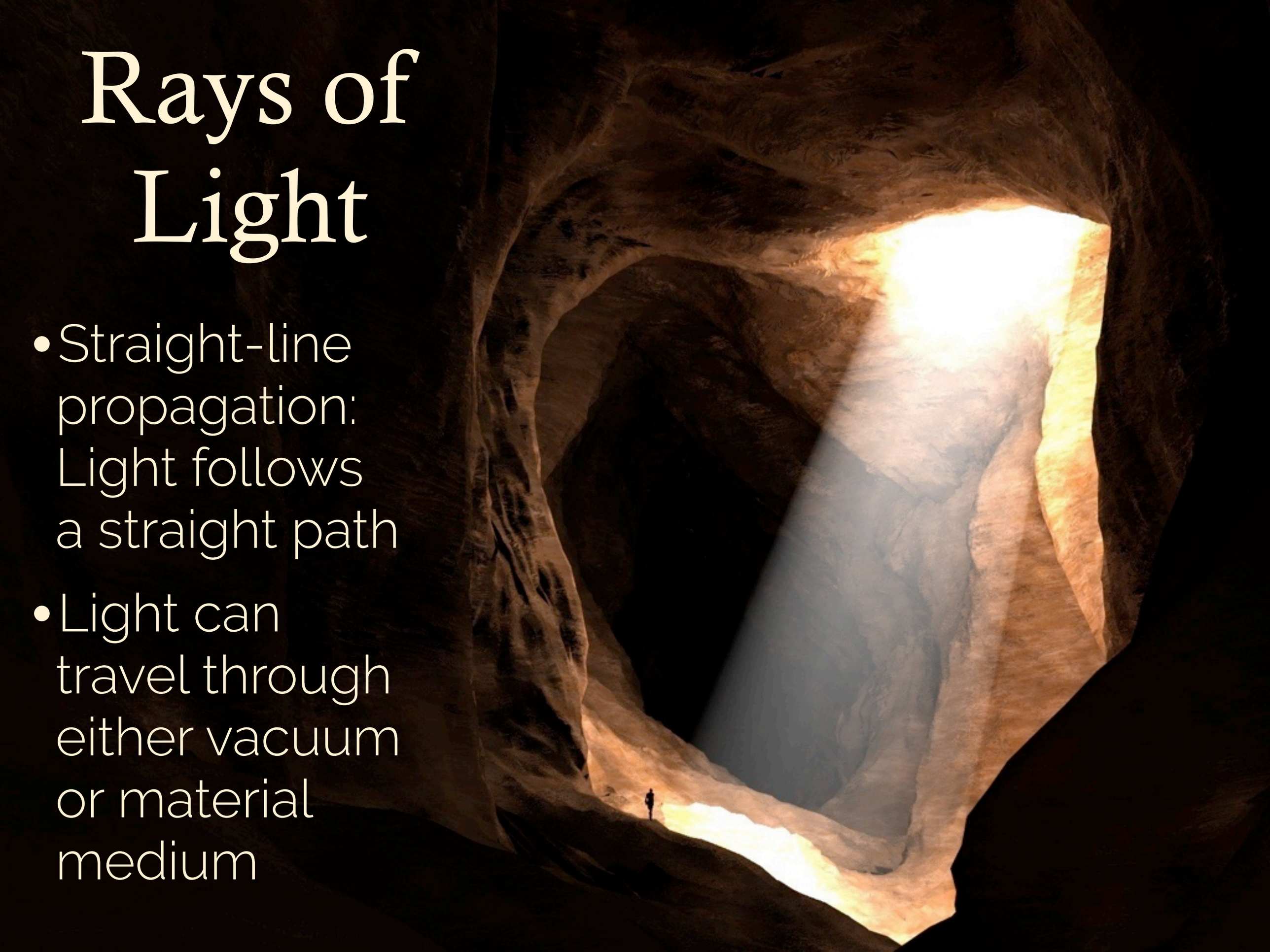
- Everything radiates: It's creepy, but it's true
- Everything that is a thing is made of matter containing moving electrons
- Higher temperature, higher frequency: You are radiating in the infrared (about 300K), but the sun radiates in the visible (about 6000K)

Section 7.2:

Properties of Light

Rays of Light

- Straight-line propagation: Light follows a straight path
- Light can travel through either vacuum or material medium



Q07.03: Light Strikes A Boundary: Now What?

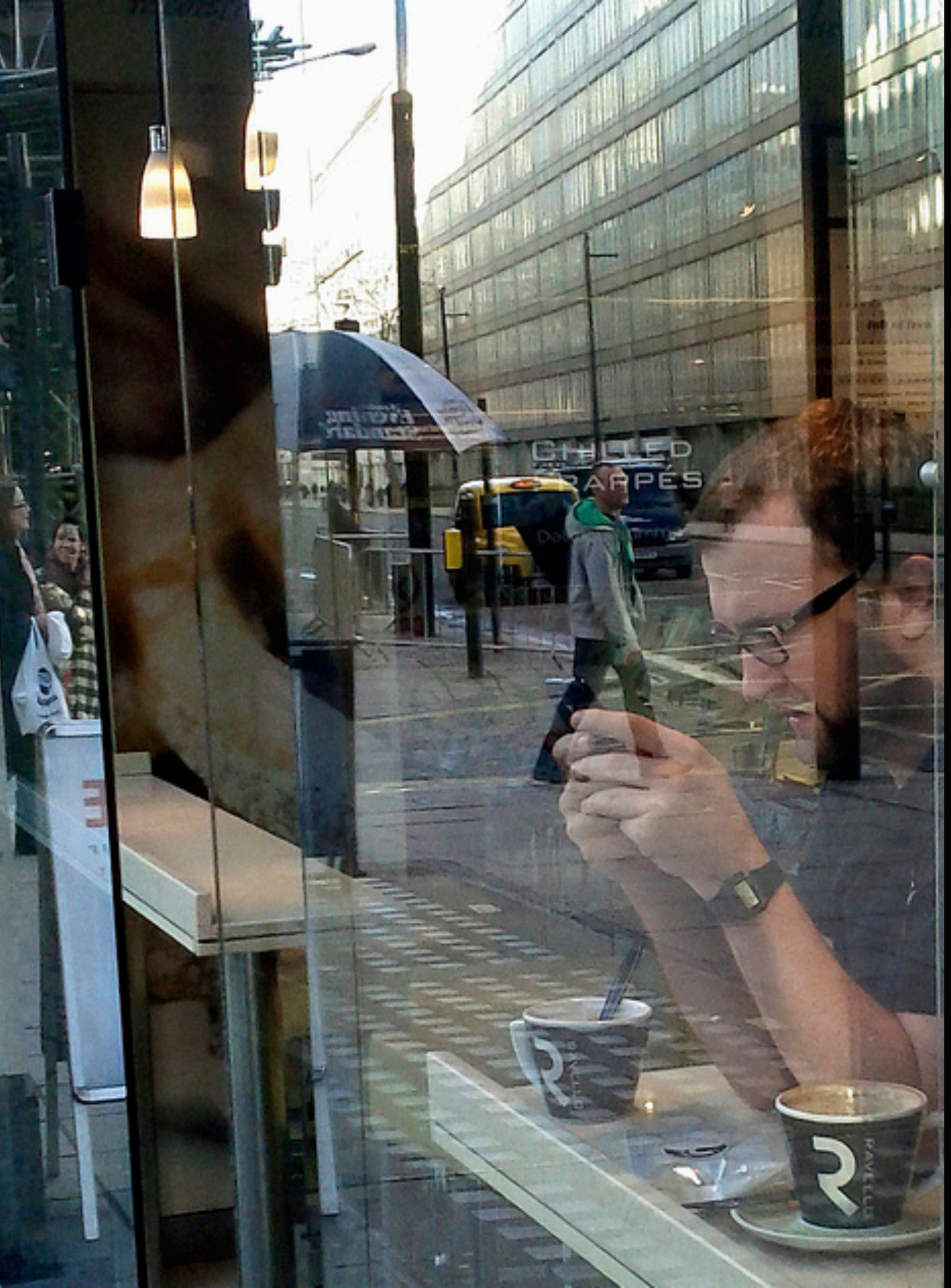
A) Transmission: light strikes a new medium, passes through

B) Absorption: light enters medium, but does not emerge out the other side

C) Reflection: light strikes, cannot pass through; bounces off the surface

D) Depending on the surface, the light might do any or all of the above, in some combination.

E) Now What? Now nothing. When light strikes a surface, nothing happens.

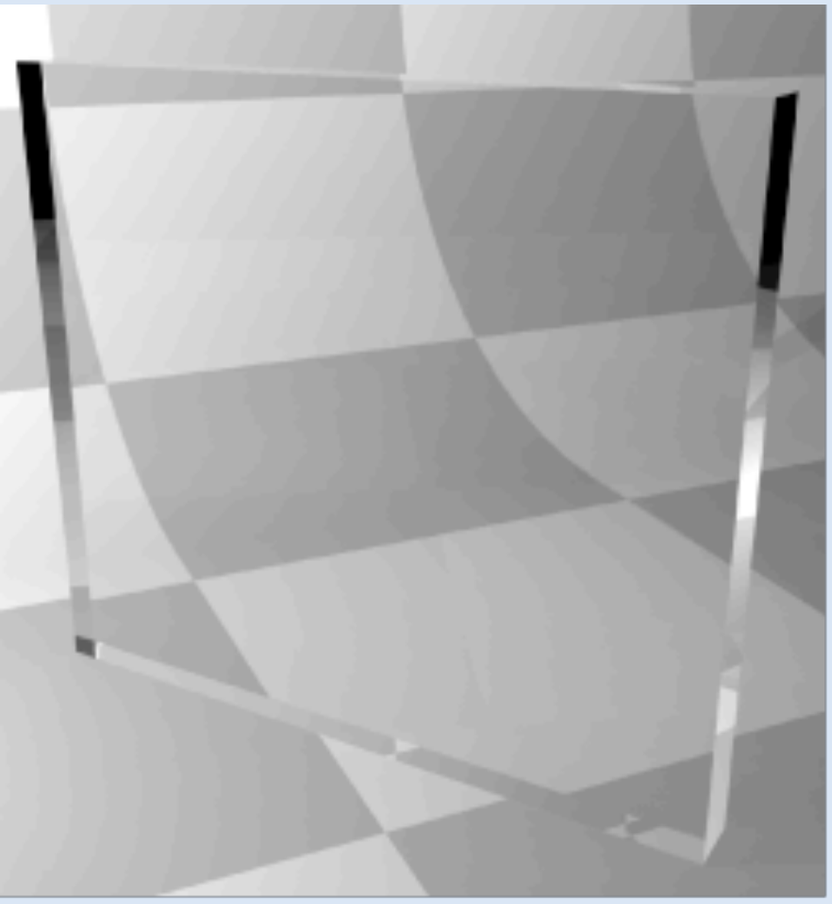


Light Interacts With Matter

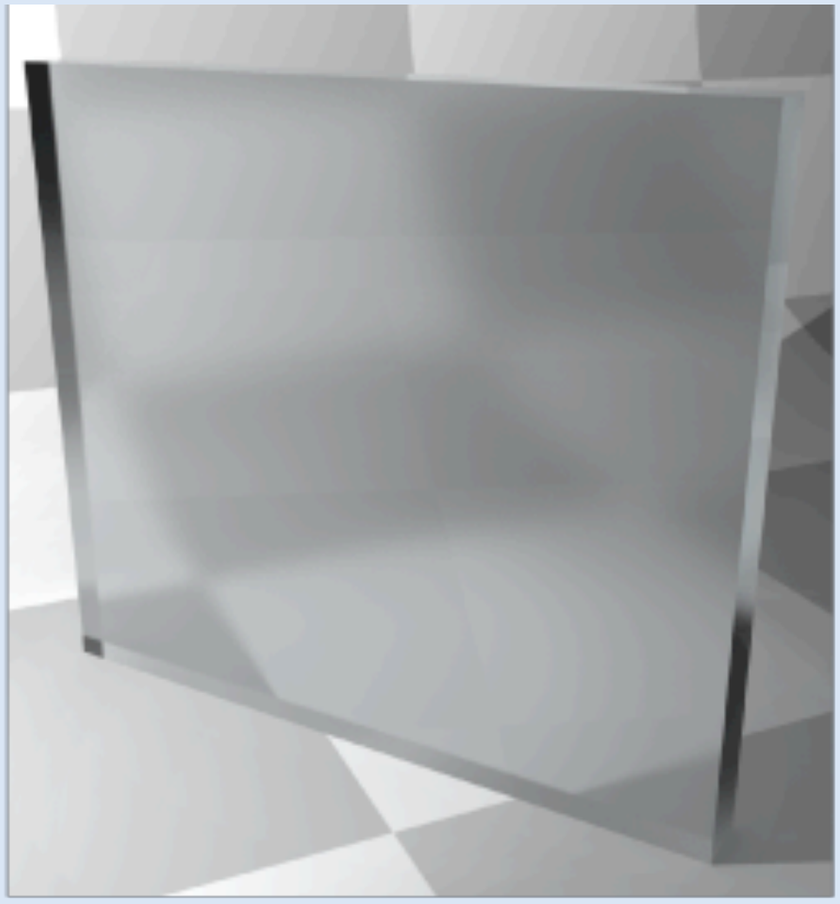
- What happened when light runs into an obstruction? Or a change in medium?
- Three possibilities:
  Reflection
  Absorption
  Transmission
- Sometimes all three at once!

The Material Makes a Difference

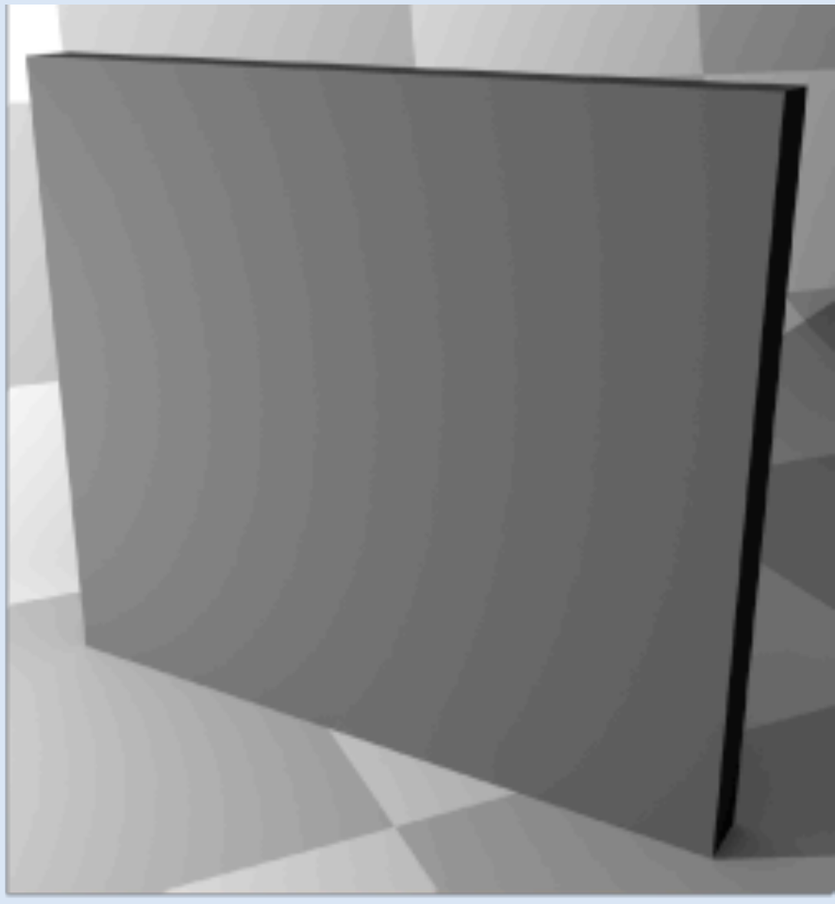
- Transparent: Material permits light to pass through (glass, water)
- Not all materials permit all frequencies to pass through!
- Opaque: Material either reflects or absorbs (or both!)



Transparent

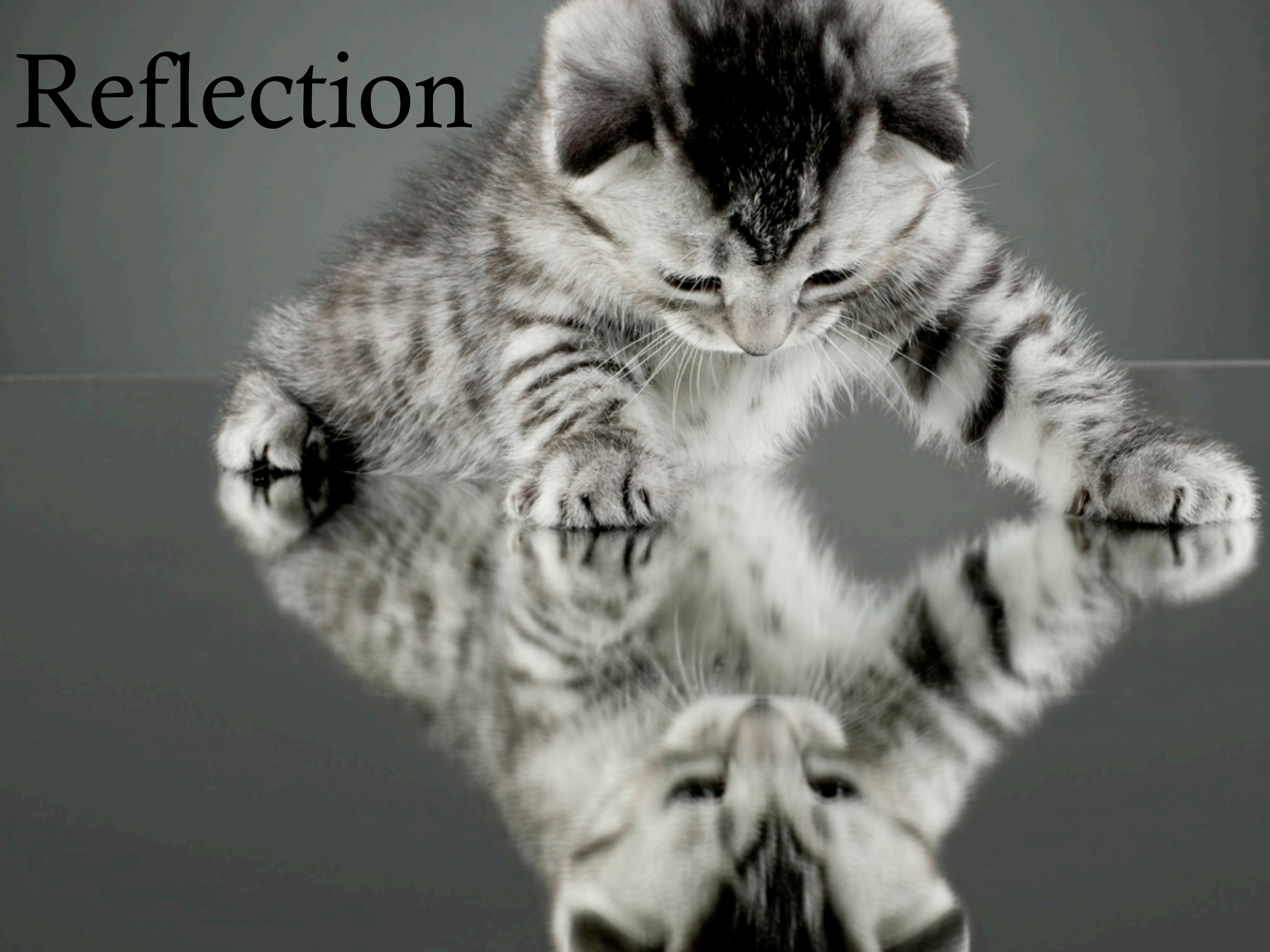


Translucent

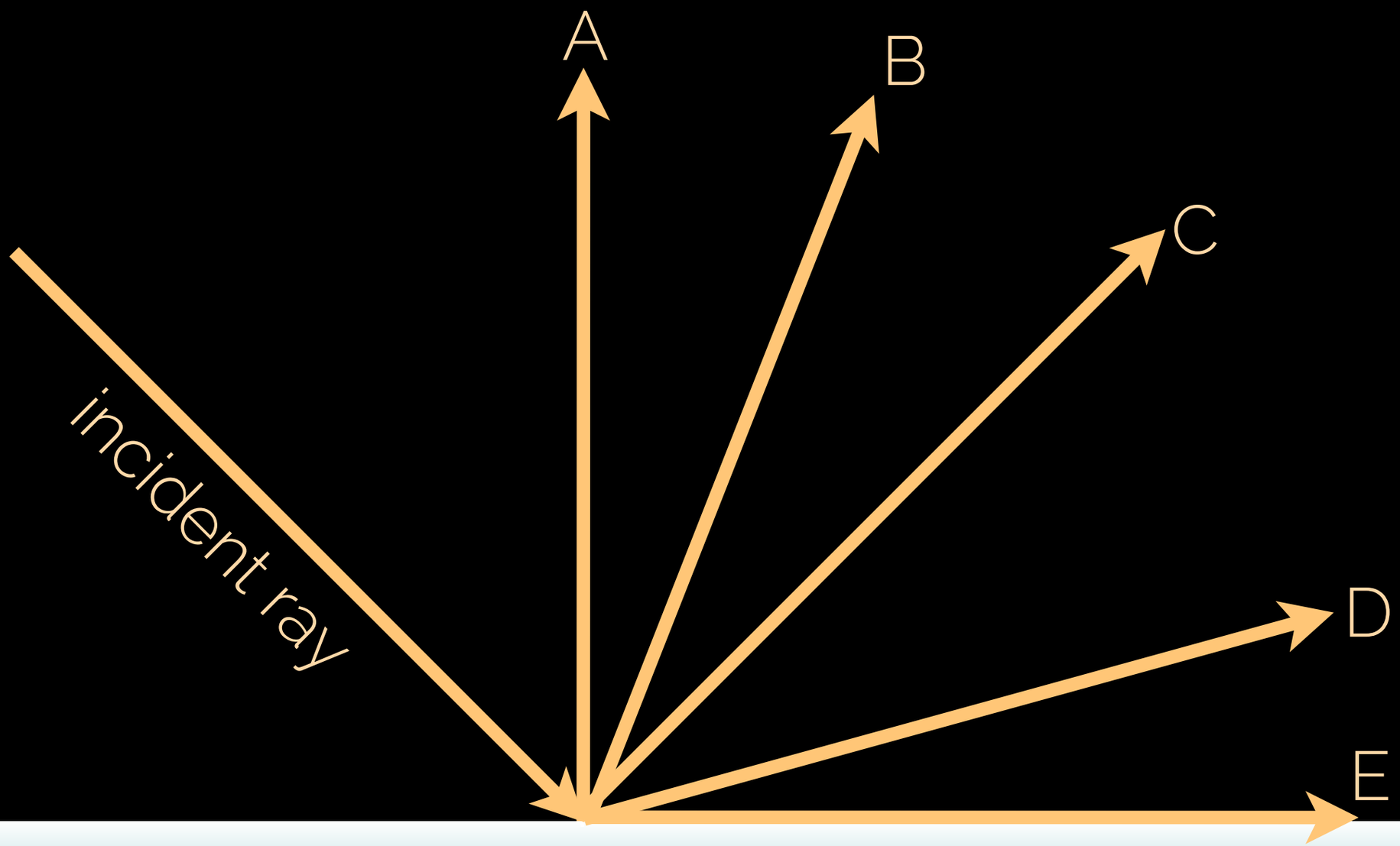


Opaque

Reflection

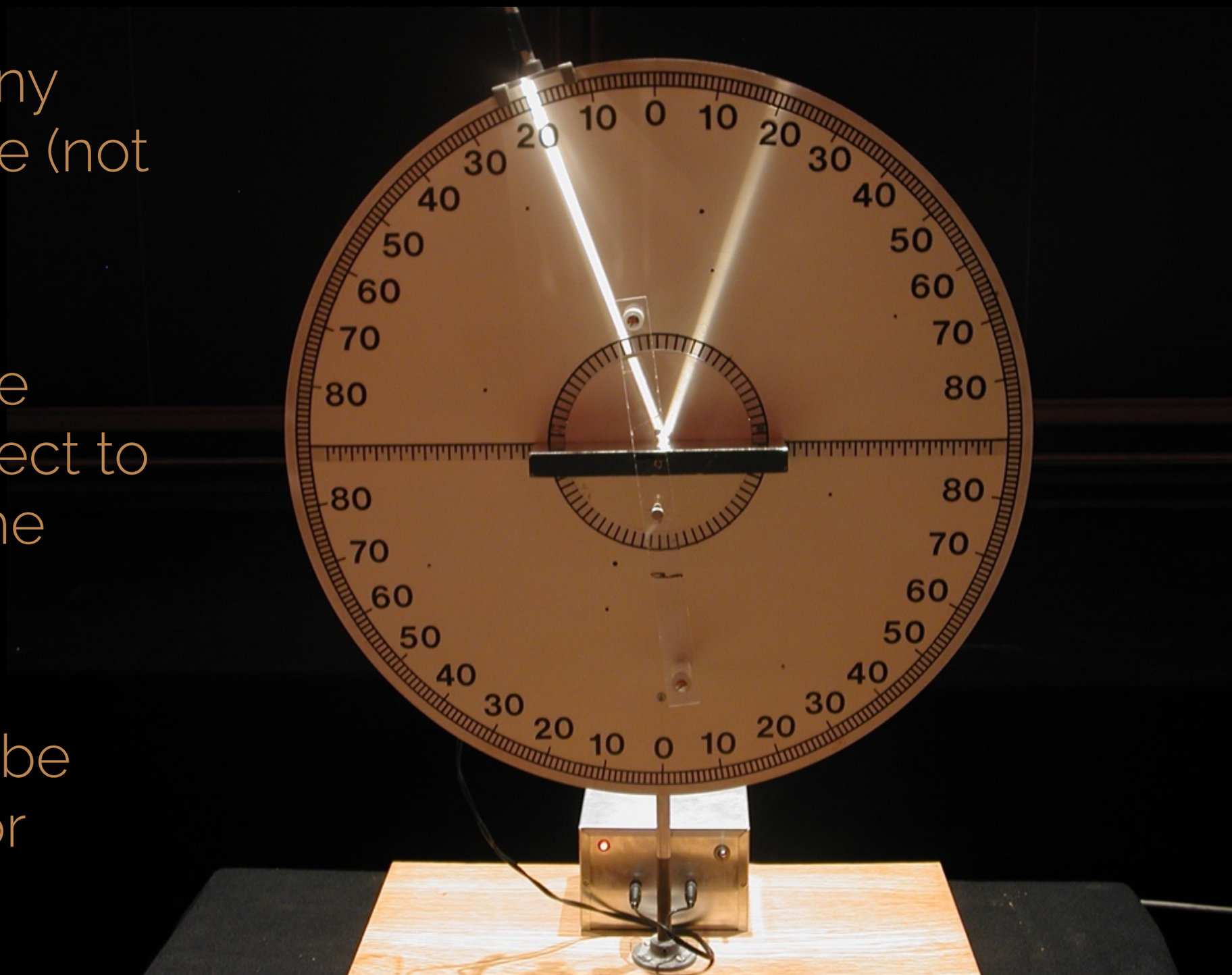


Q07.04: Which ray is the reflected ray?

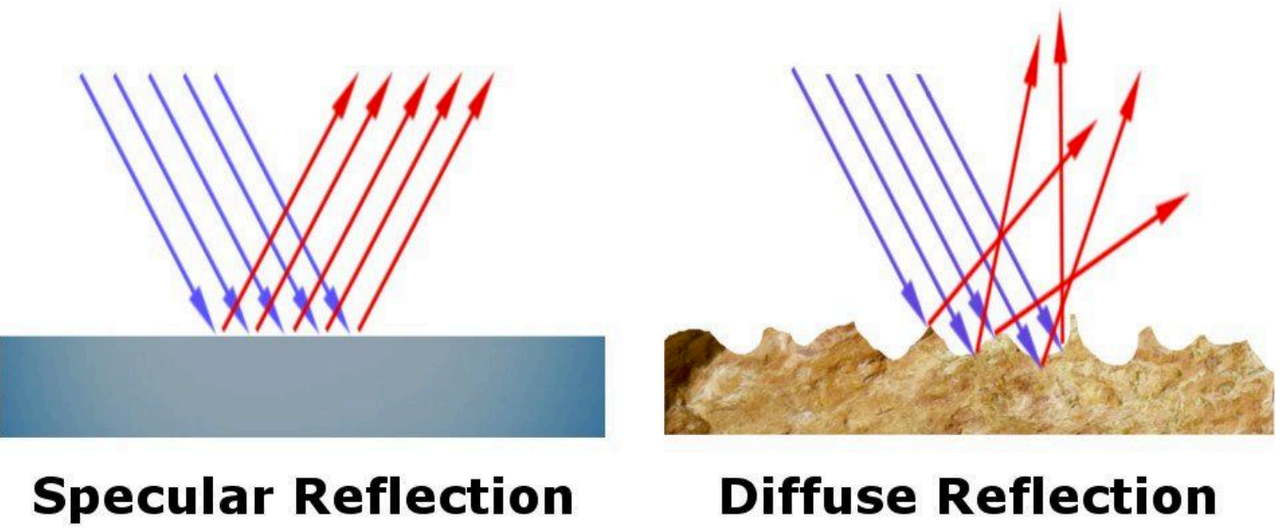


Law of Reflection

- One rule only: $\theta_i = \theta_r$
- This holds for any kind of wave (not just light)
- This holds for any shape of surface (not just smooth flat planes)
- Always measure angle with respect to the normal to the surface
- Why? Because surface my not be flat or smooth or regular



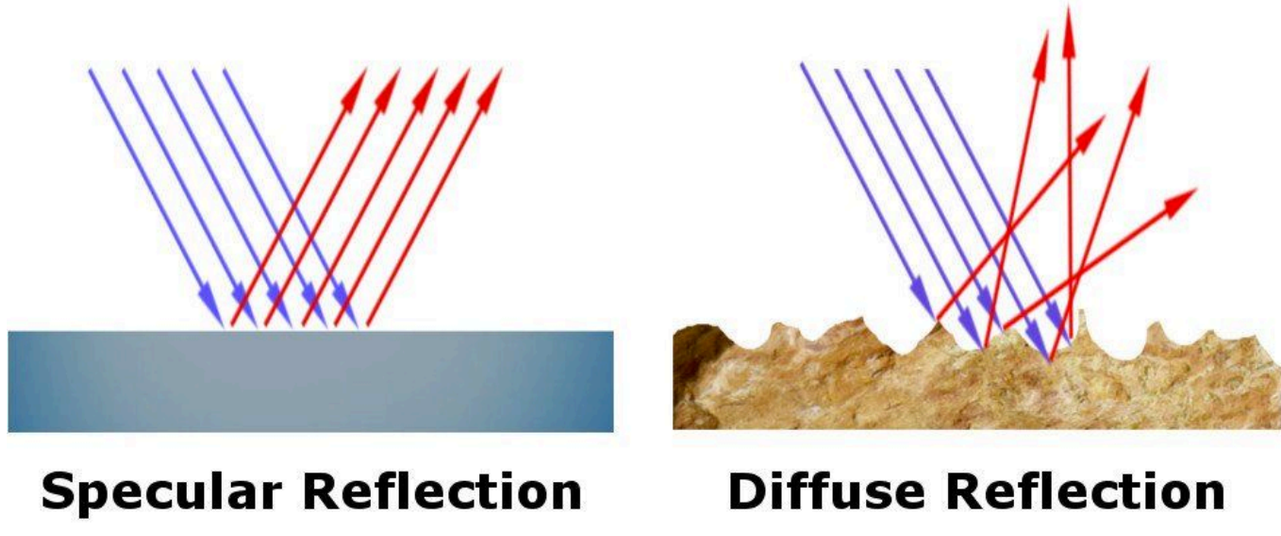
Specular Reflection



- Sharp, clear reflection that you see when you look in the bathroom mirror
- Parallel rays are reflected off a smooth surface: reflected rays are parallel as well
- Image formed is crisp, clear: in focus

Diffuse Reflection

- Blurry, low-resolution reflection seen when you look at yourself in the brushed steel refrigerator door
- Surface is not smooth or regular, so parallel incoming rays are not all reflected in the same direction
- Difficult to form a coherent image



Q07.05: True or False:

The law of reflection is only valid for plane mirrors.
It is not valid for curved or irregular surfaces.

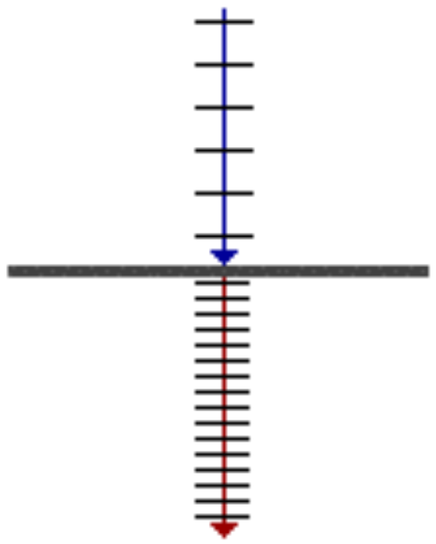
Image Formation

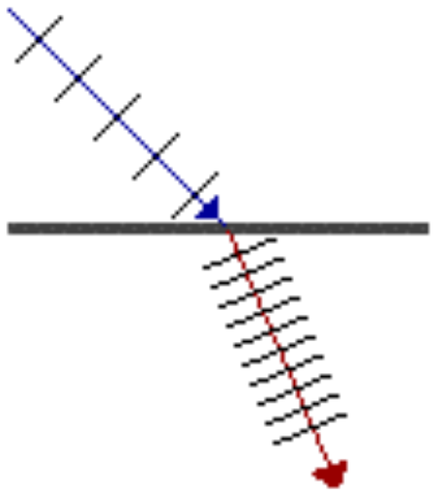
- Virtual image: Upright (right side up, might be magnified or "minified"
- Real Image: Inverted (upside down), might be magnified or "minified"
- Plane mirror: Virtual image is the same size as real object
- Concave mirror: Can form either real or virtual images!
- Convex mirror: Virtual images only (objects in mirror are closer than they appear!)

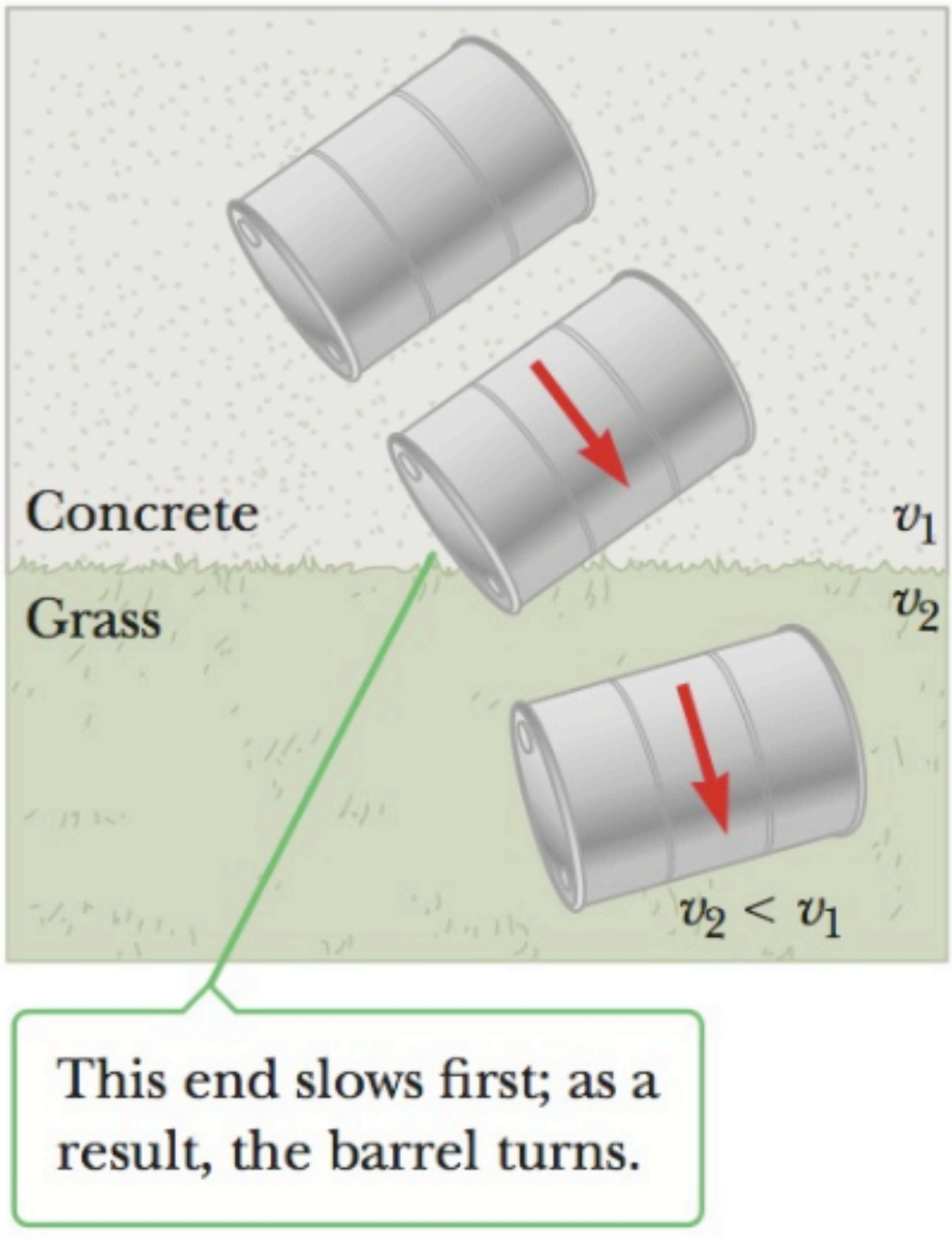
Refraction

Refraction

- Change in medium means change in speed
- Change in speed means change in direction
- Light ray bends towards the slower medium



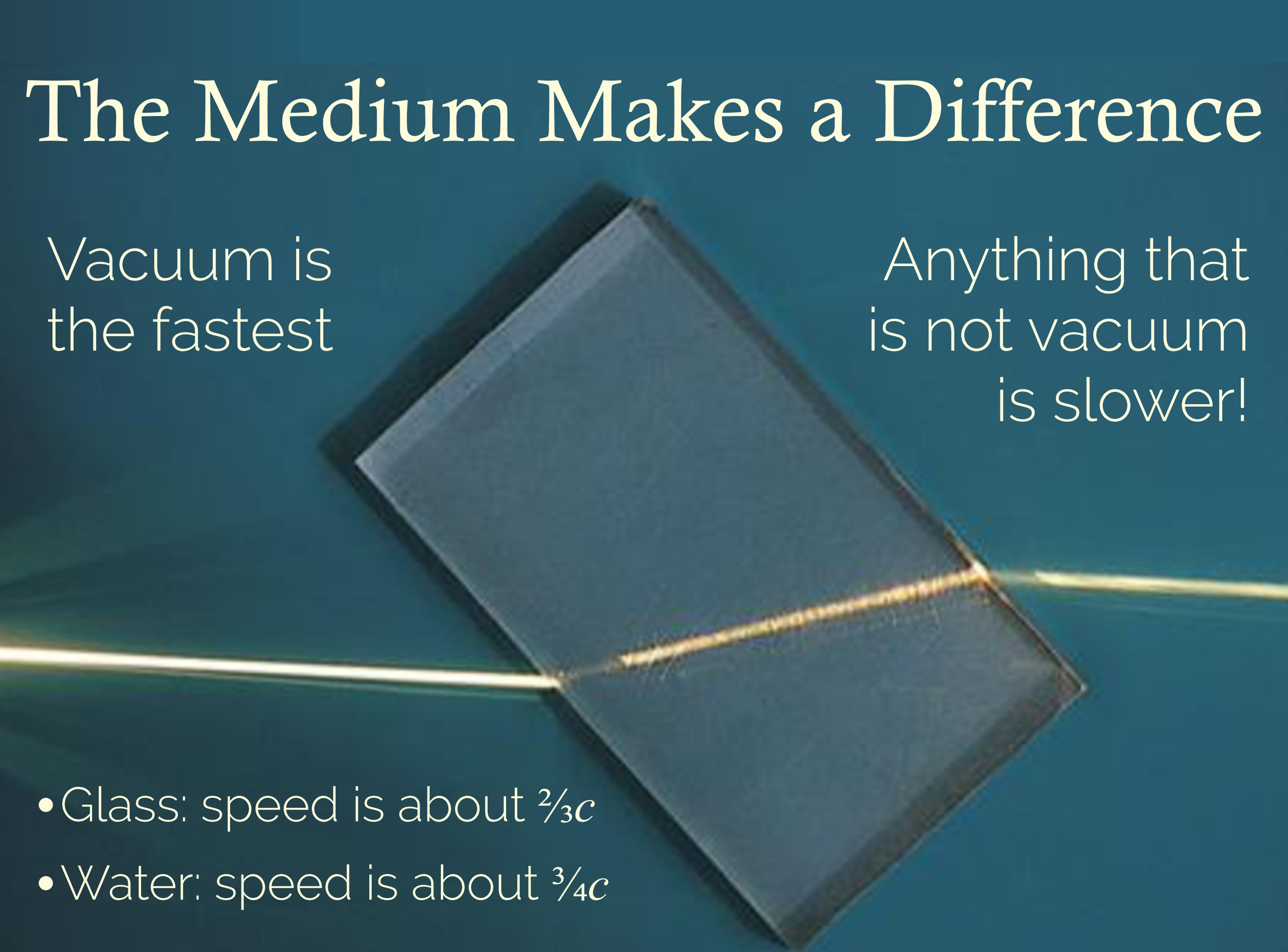




The Medium Makes a Difference

Vacuum is
the fastest

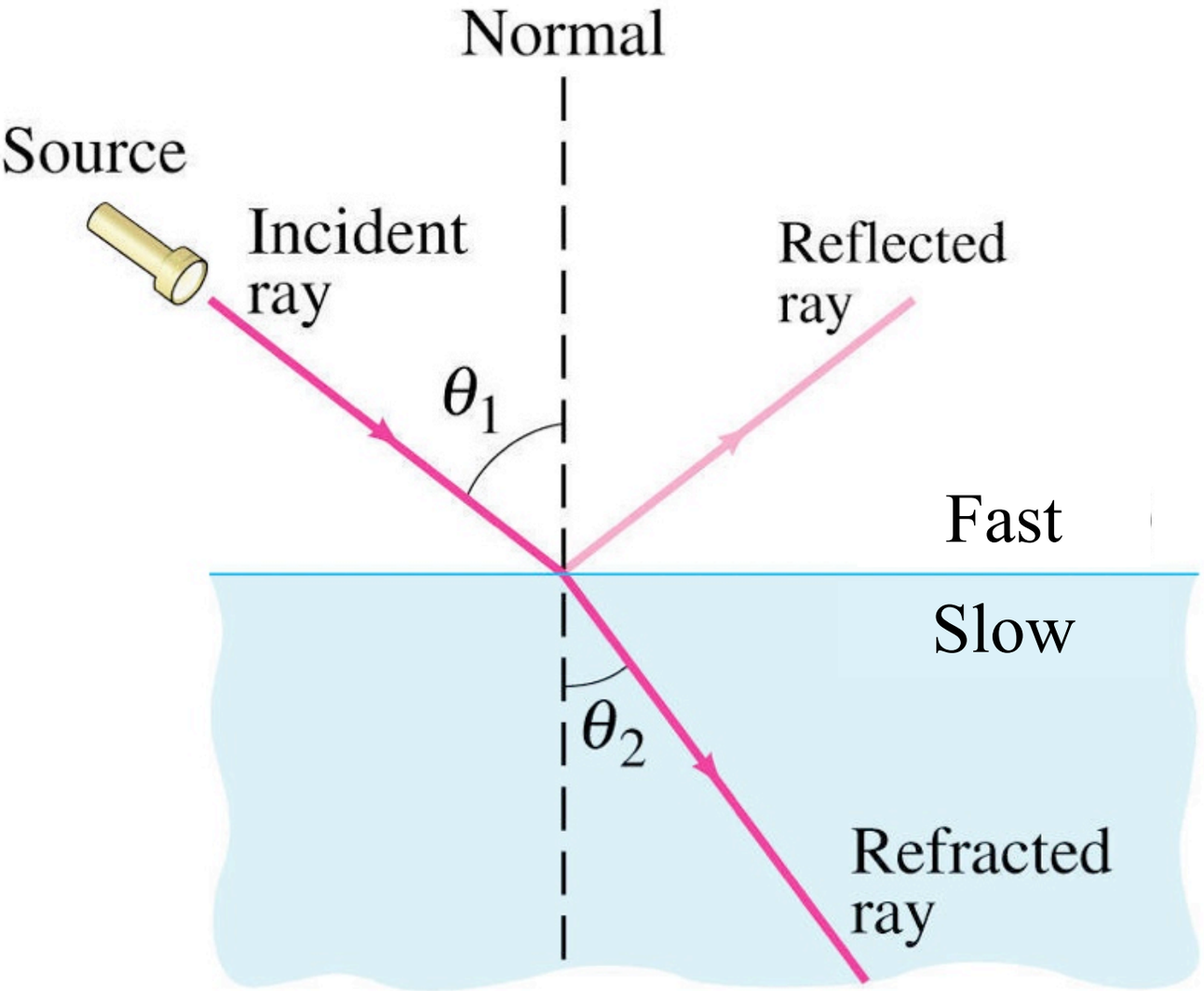
Anything that
is not vacuum
is slower!

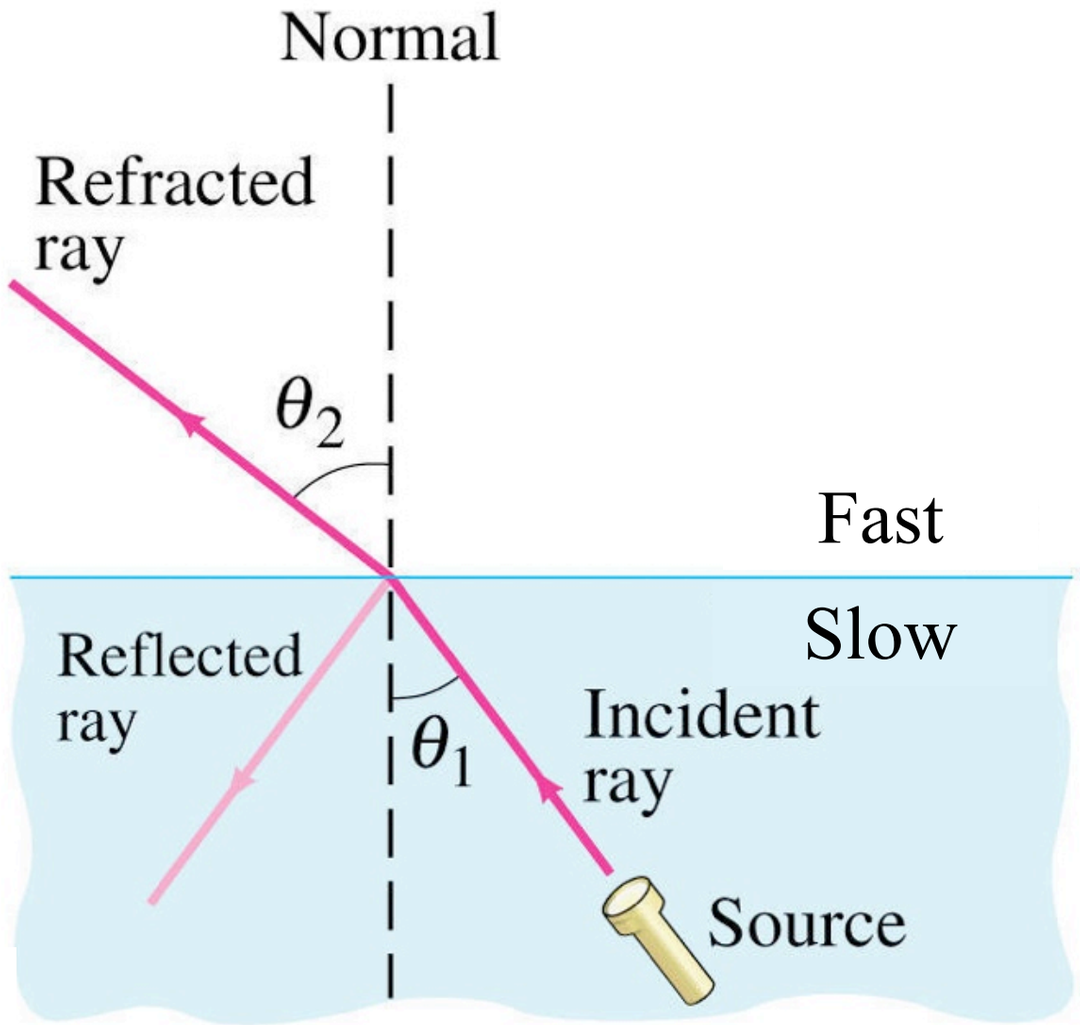


- Glass: speed is about $\frac{2}{3}c$
- Water: speed is about $\frac{3}{4}c$

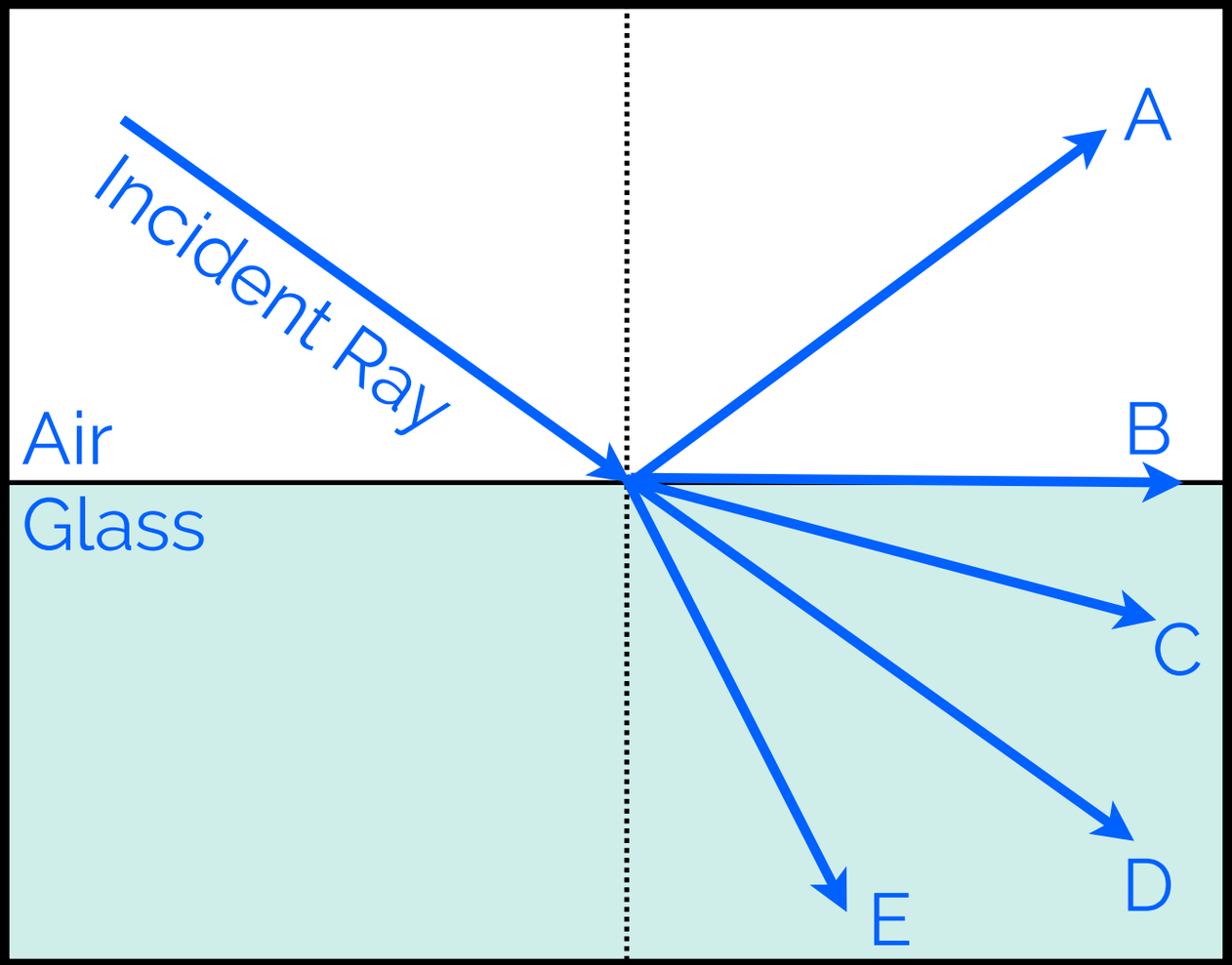
The Angle Makes a Difference

- Always measure angle with respect to the normal!
- Light incoming along normal: no refraction
- Greater angle of incidence, greater amount of refraction

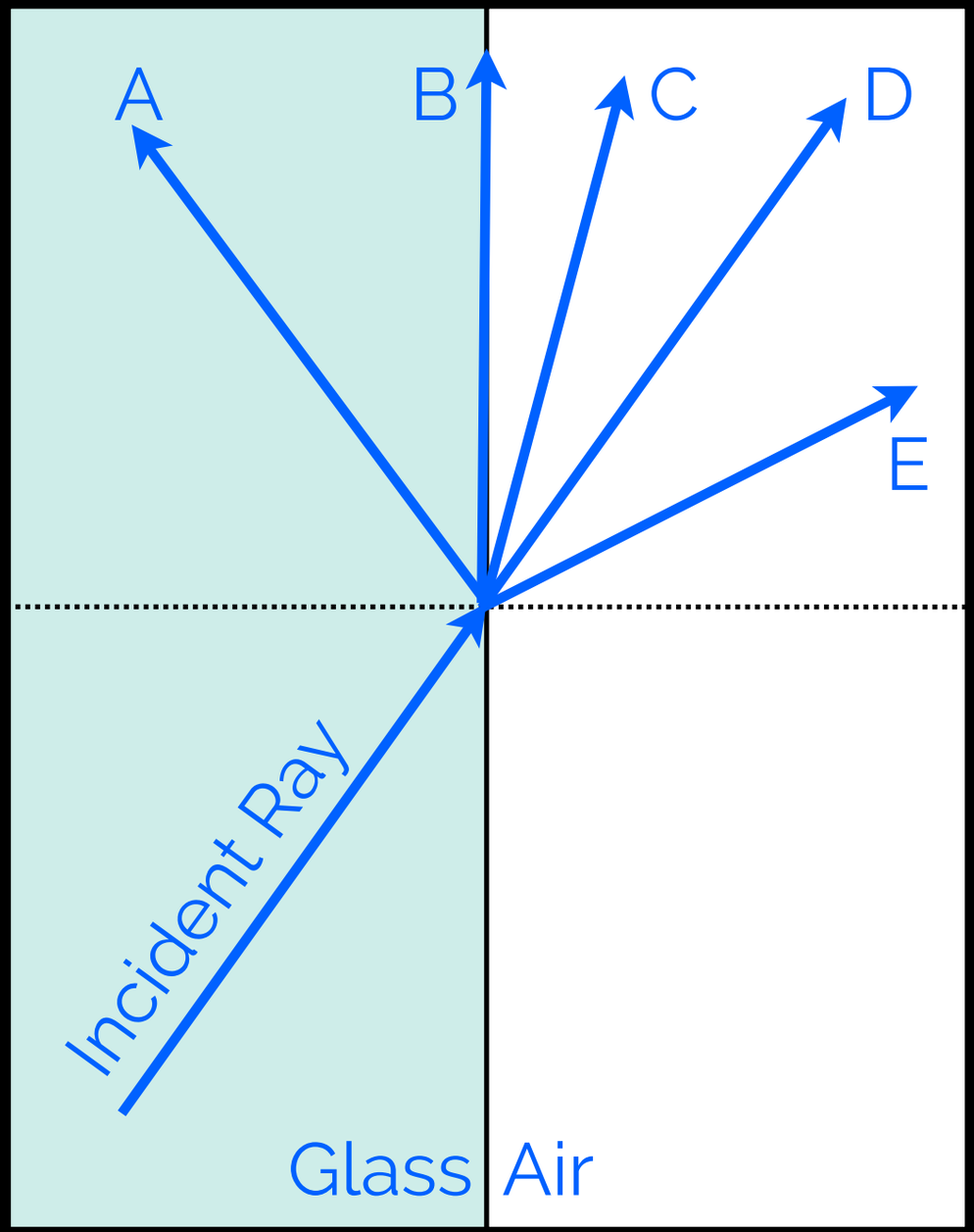


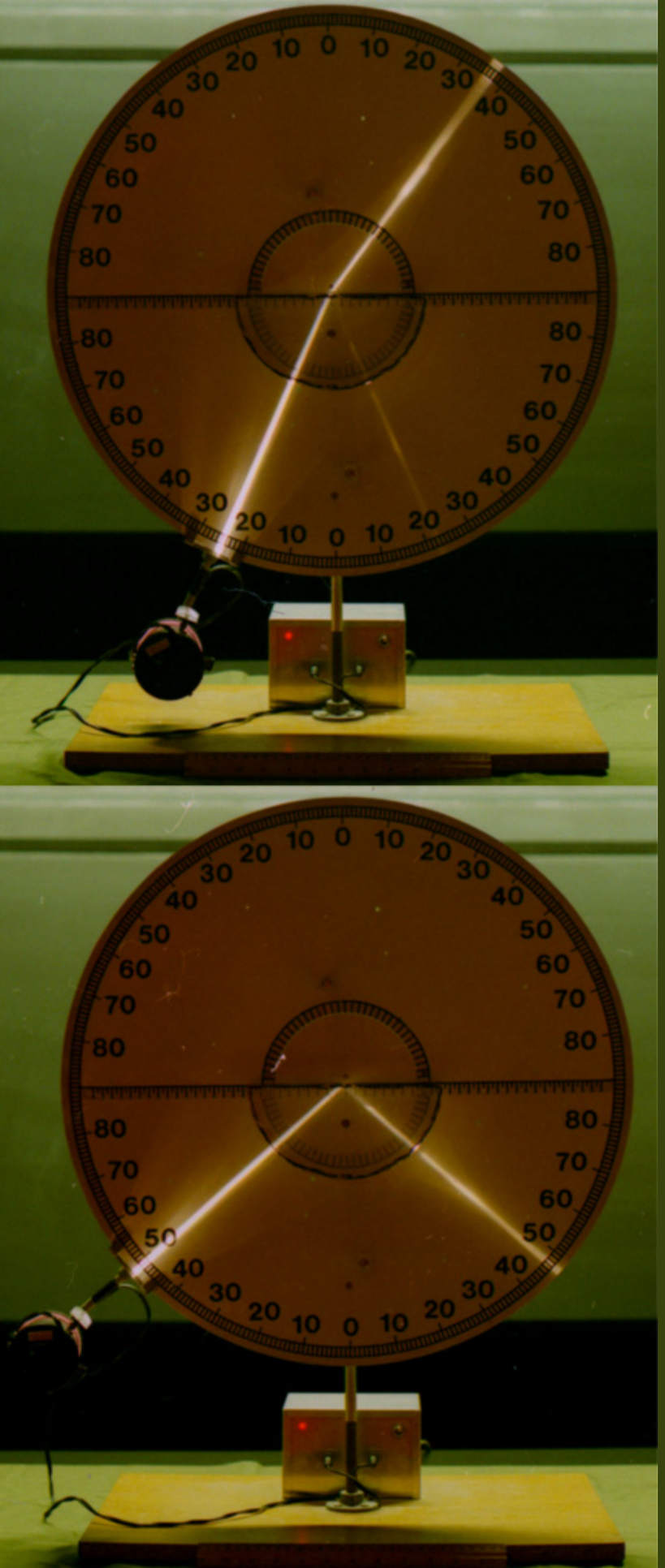


Q07.06: Which is the refracted ray?



Q07.07: Which is the refracted ray?





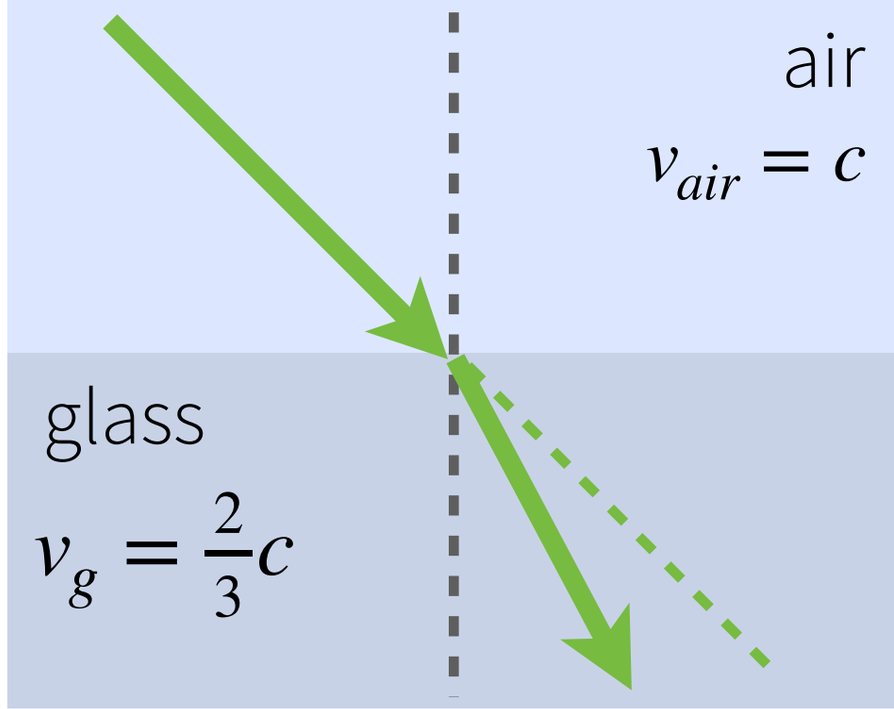
Snell's Law

$$n_i \sin\theta_i = n_r \sin\theta_r$$

- n = index of refraction
- Index of refraction = ratio of speeds: $n = c/v$
- $n = 1$ for vacuum, anything else (slower), $n > 1$

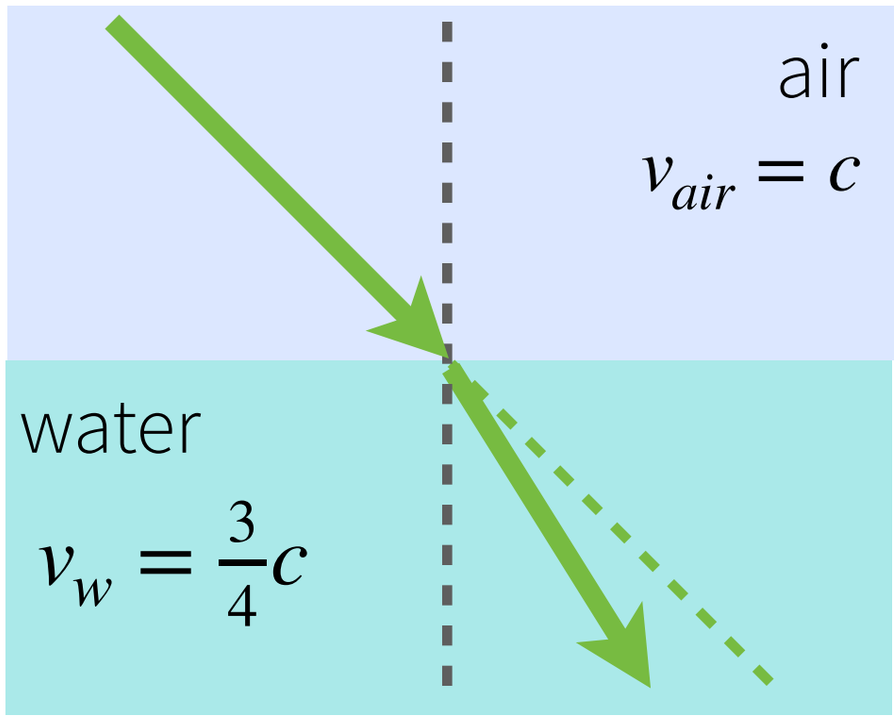
Index of Refraction

- Compare speed of light through a specific medium to speed through vacuum
- Light travels more slowly through water than air
- Light travels more slowly through glass than water
- The larger the index of refraction, the slower the medium



$$n_g = \frac{c}{v_g} = \frac{c}{\frac{2}{3}c} = \frac{3}{2} = 1.5$$

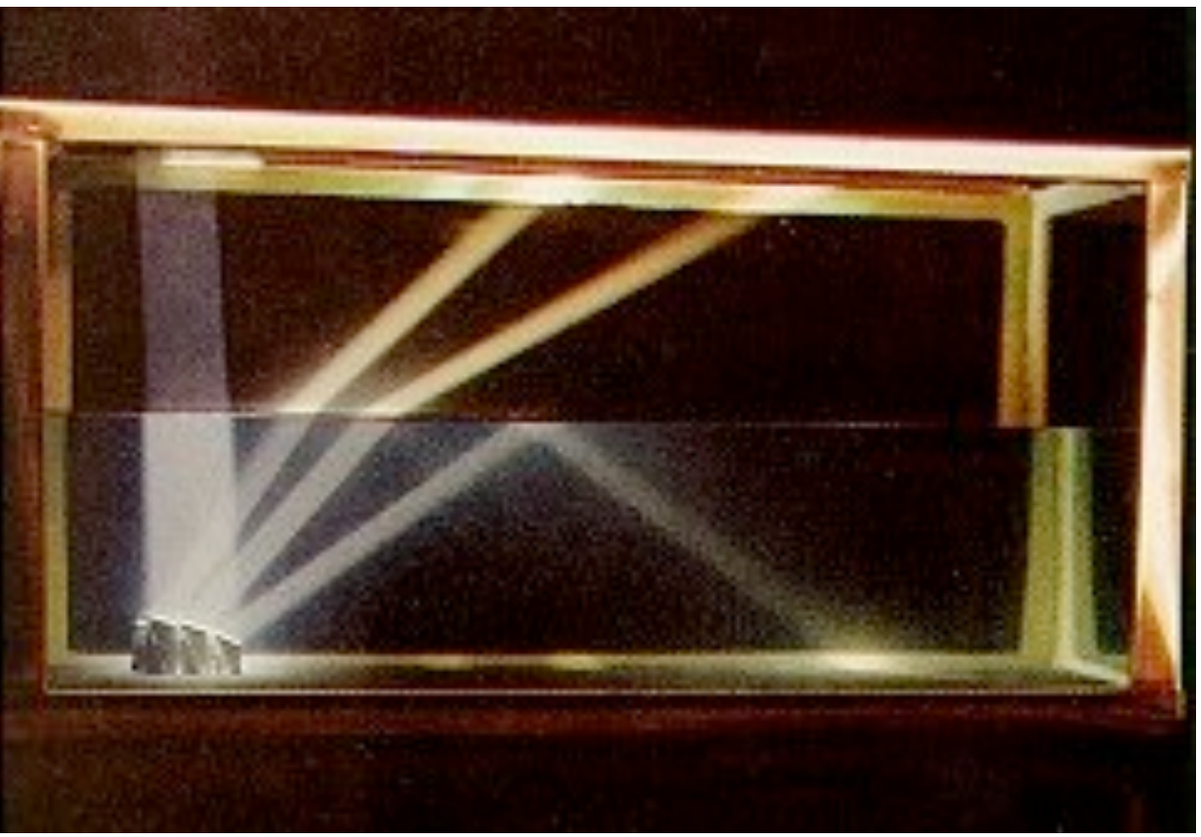
$$n_w = \frac{c}{v_w} = \frac{c}{\frac{3}{4}c} = \frac{4}{3} = 1.33$$

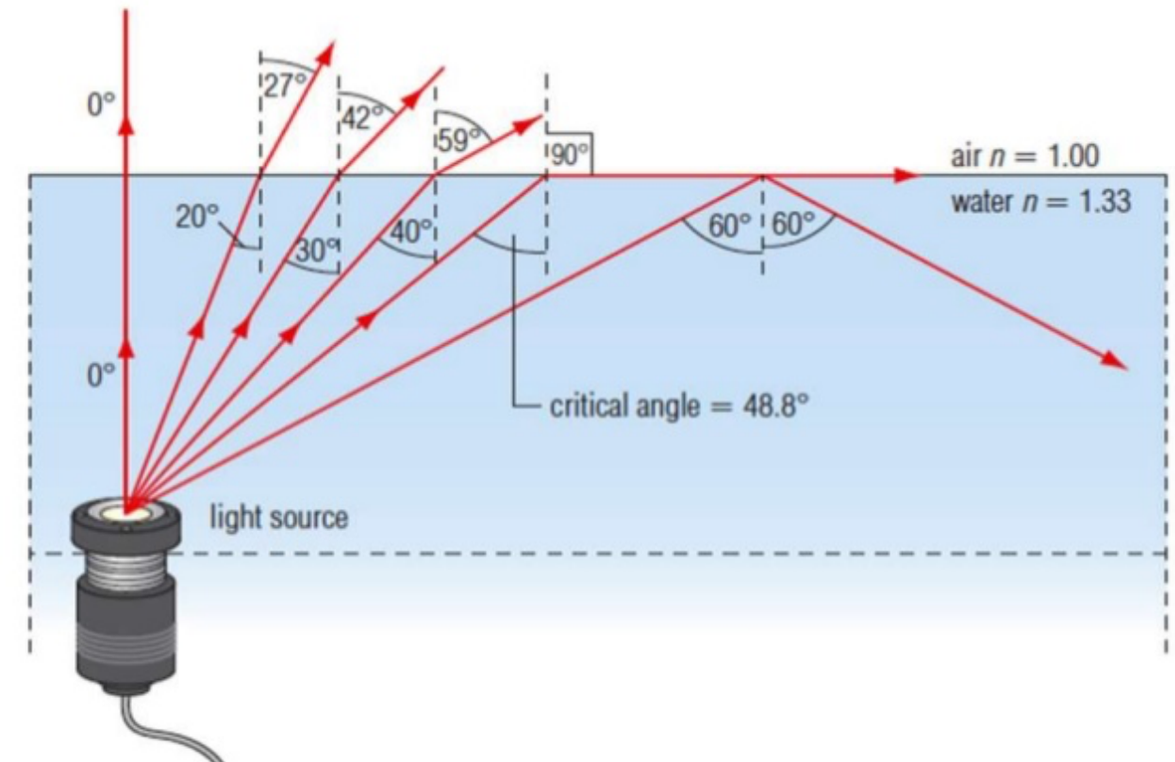


Total Internal Reflection

- Only happens when light travels from slower to faster medium (water to air, for example)
- As angle of incidence increases, more and more light reflects instead of transmits
- Critical angle: All of the light is reflected back, none is transmitted

The Medium Makes a Difference





- Use Snell's Law to show:

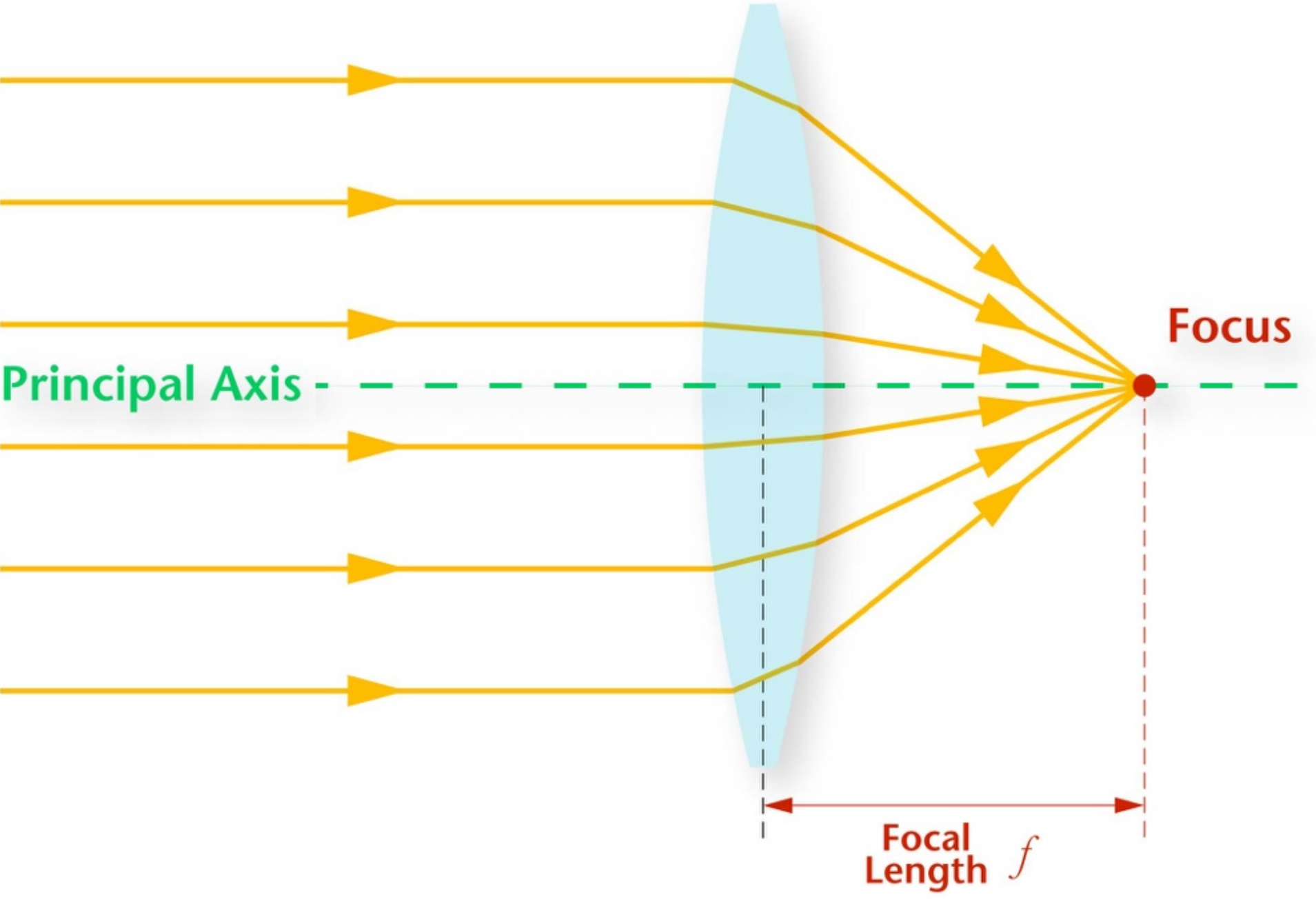
$$\sin\theta_c = \frac{n_2}{n_1}$$

- Critical angle will depend on which media you use
- You only get TIR when the refractive medium is a faster medium than incident medium: $n_2 < n_1$
- No TIR if light transitions from fast to slow: $n_2 > n_1$ not possible ($\sin\theta \leq 1$!)

Lenses

- Curve a piece of glass (or plastic) to control the refraction
- Convex lens: Curved outward
- Concave Lens: Curved inward

Convex (Converging) Lenses



- Can form either real (magnified or "mini-fied") or virtual ("minified") images
- Type of lens in the human eye
- Corrects far-sightedness (hyperopia)

A) a converging (convex) lens.

B) a diverging (concave) lens.

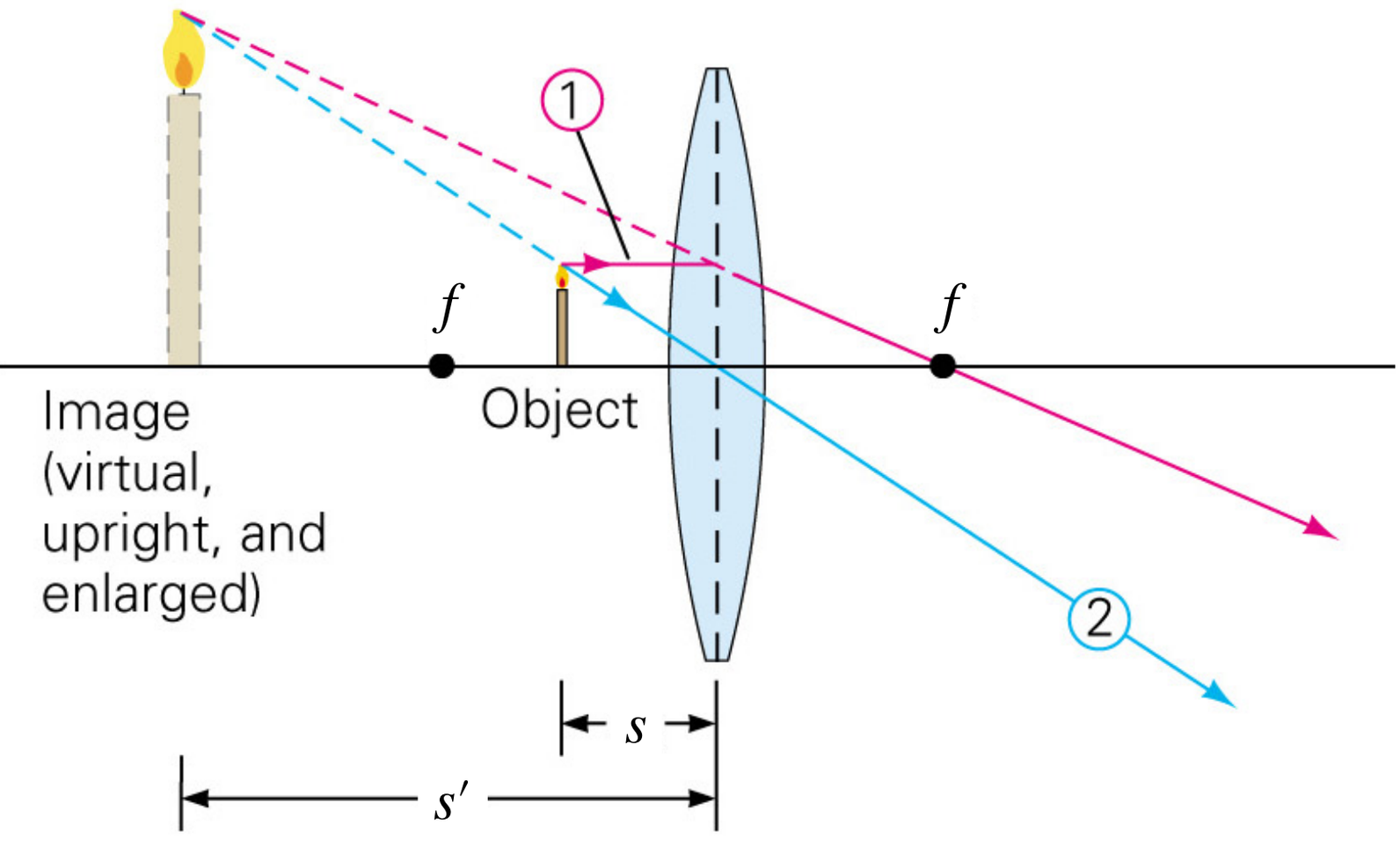
C) a flat piece of glass or plastic.

D) a very famous film director.

Q07.08: This is

Image = virtual, magnified

Virtual Image Formed By a Converging Lens



- Object distance must be less than focal length:

$$s < f$$

- Object distance: $s > 0$
- Image distance: $s' < 0$
- Object height: $h > 0$
- Image height: $h' > 0$
- Magnification: $M \geq +1$
- Image is magnified (this is a magnifying glass)

Q07.09: This is

Image = real, minified

A) a converging (convex) lens.

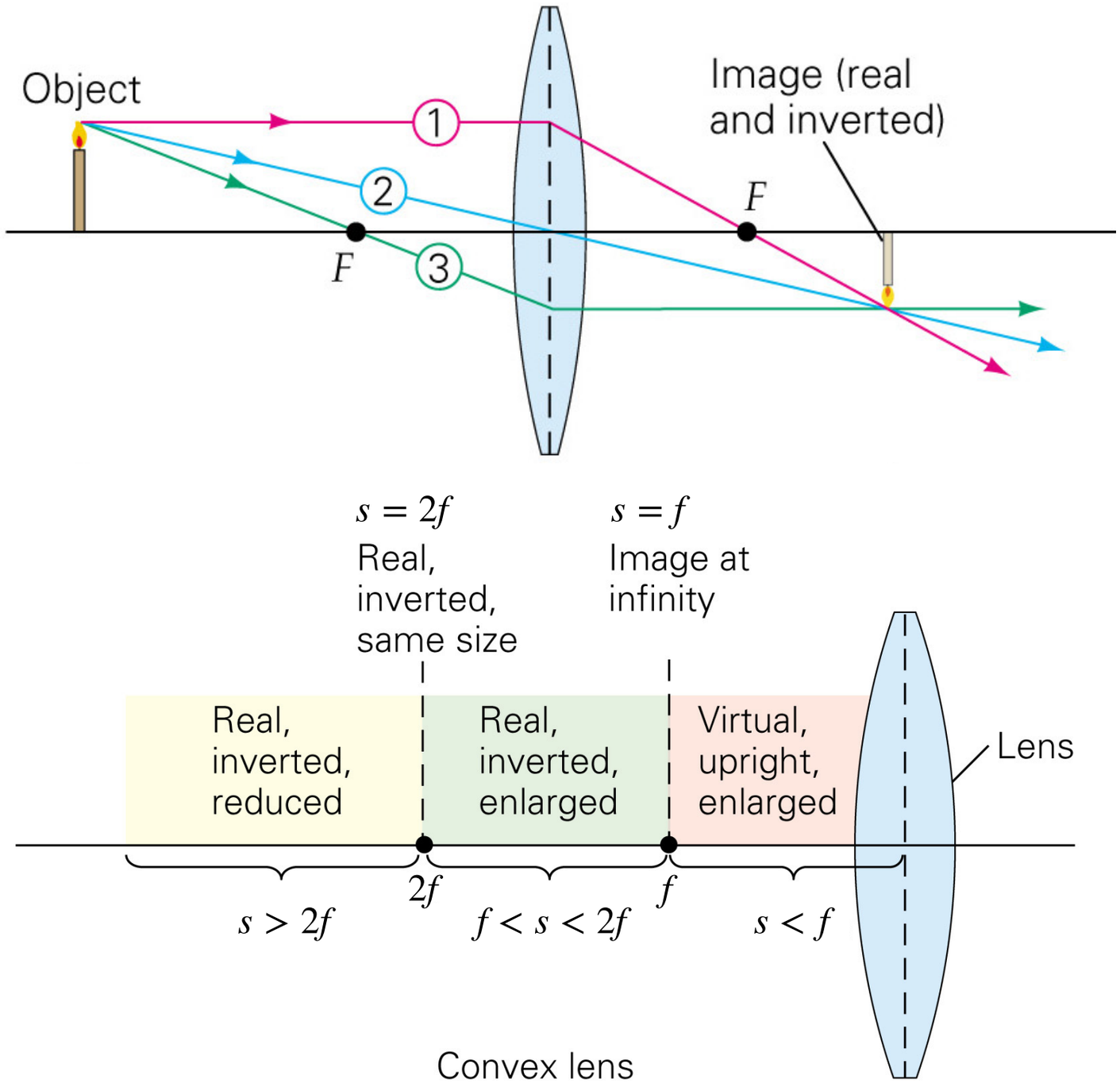
B) a diverging (concave) lens.

C) a flat piece of glass or plastic.

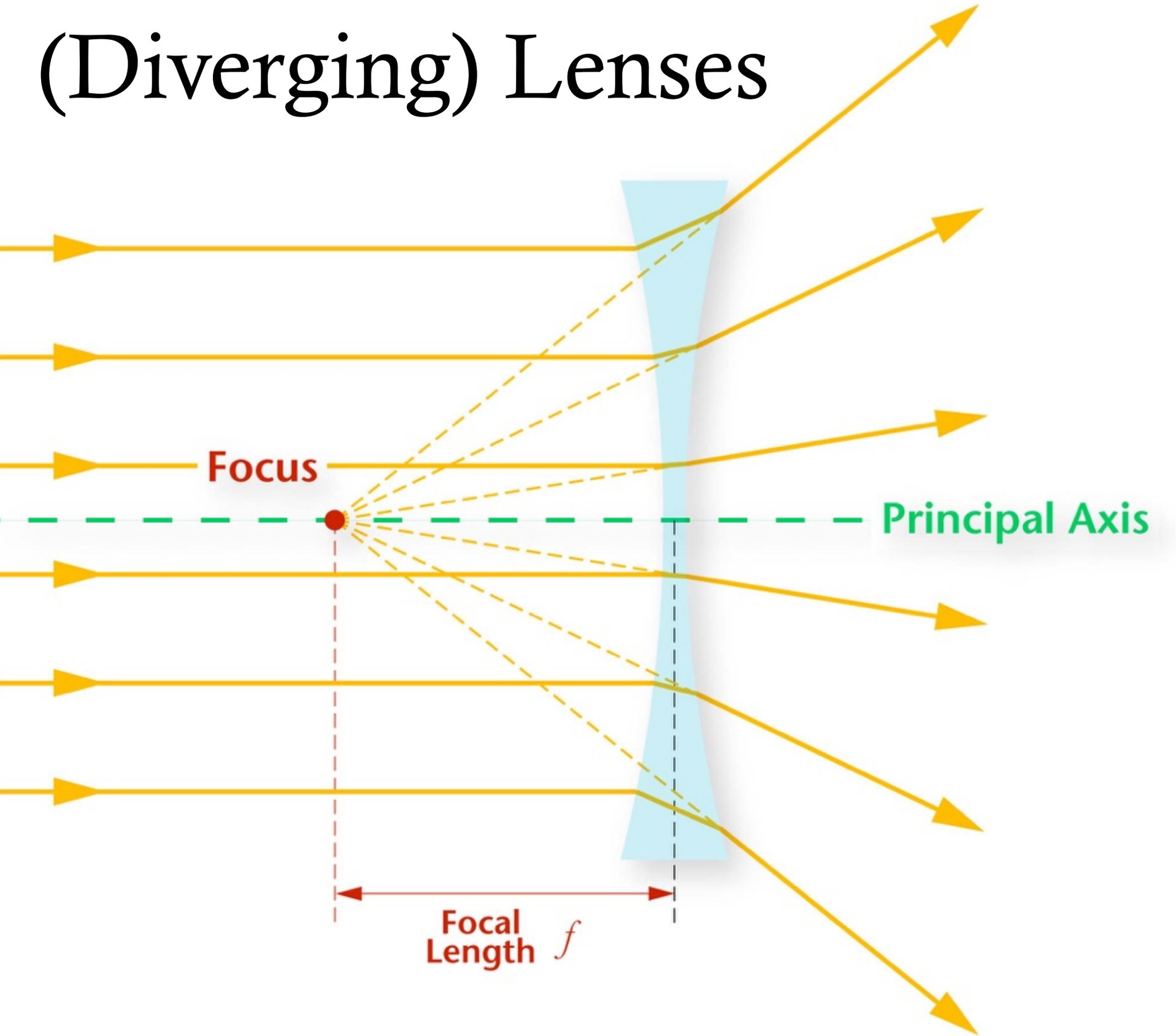
D) a very famous film director.

Real Image Formed By a Converging Lens

- Object distance must be greater than focal length:
  $s > f$
- $f < s < 2f$: image is magnified
- $s = 2f$: image height = object height
- $s > 2f$: image is minified



Concave (Diverging) Lenses



- Can only form virtual images that are "mini-fied"
- Corrects near-sightedness (myopia)

Q07.10: This is

A) a converging (convex) lens.

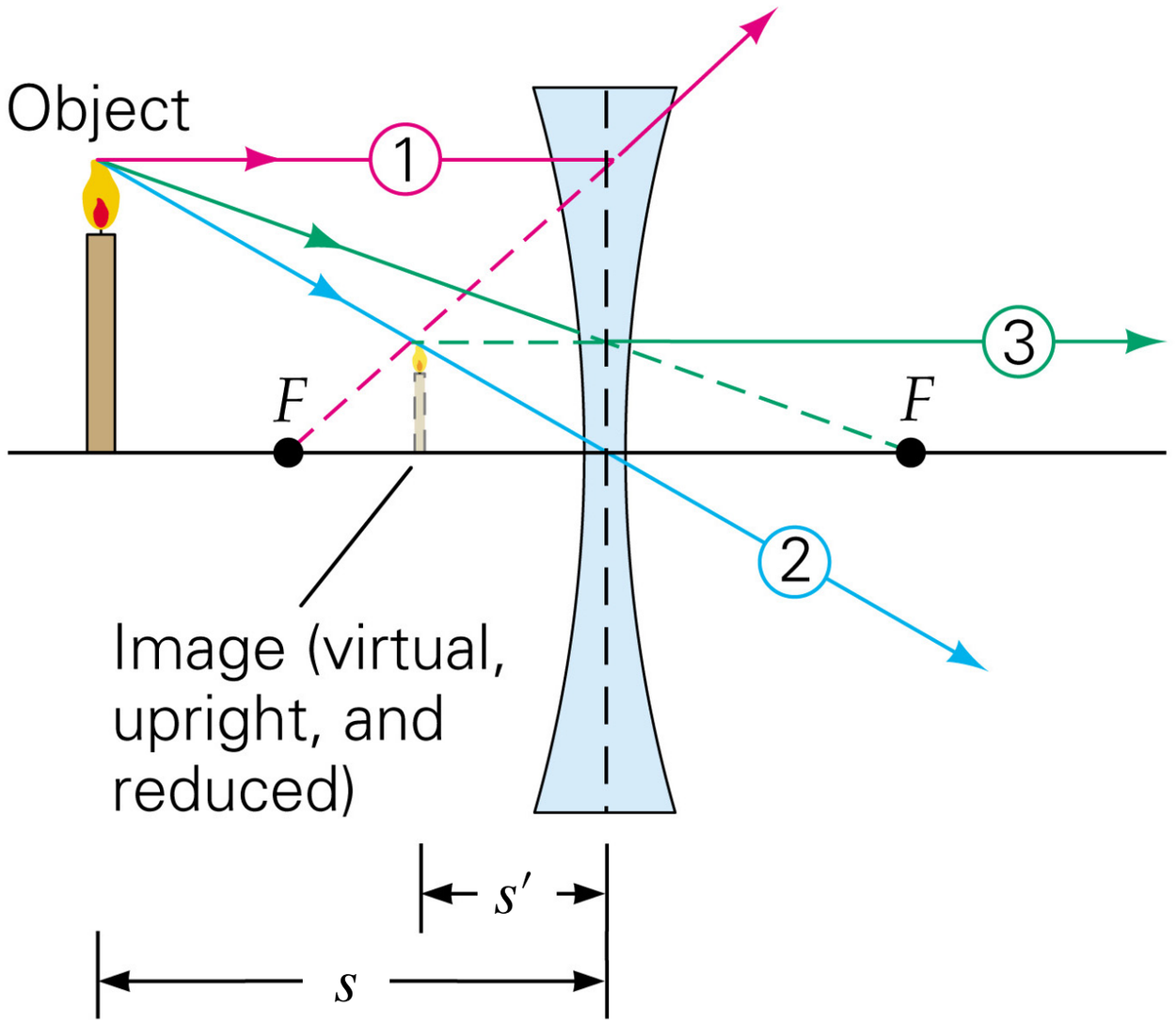
B) a diverging (concave) lens.

C) a flat piece of glass or plastic.

D) a very famous film director.

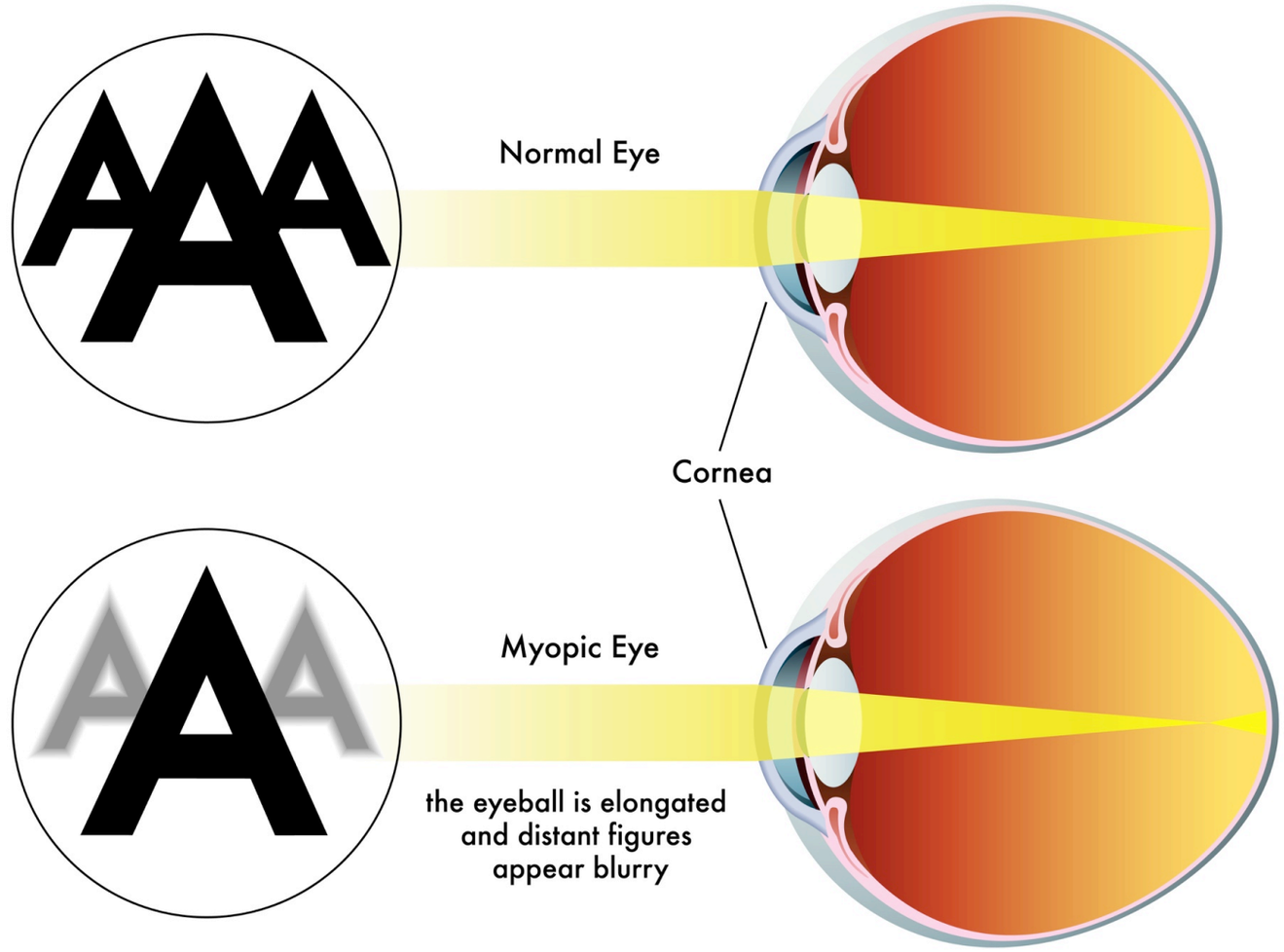
Virtual Images Formed By A Concave Lens

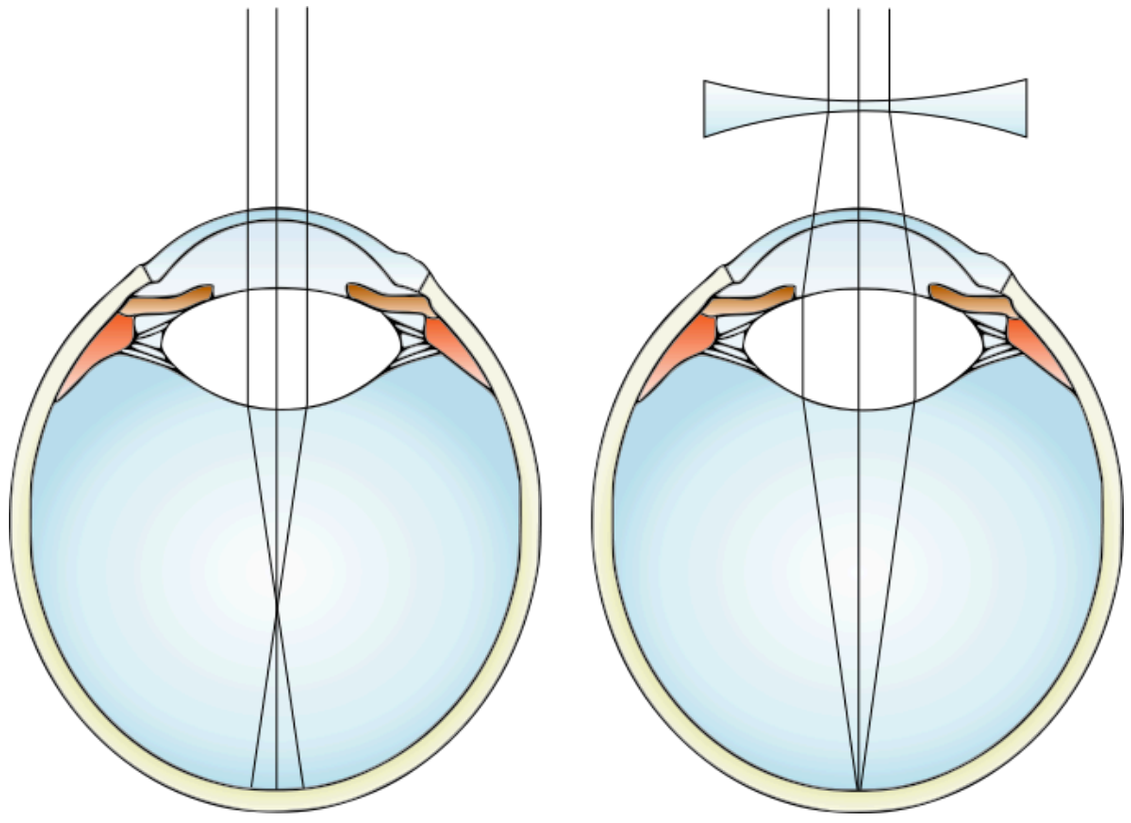
- Diverging lens cannot form a real image for any object at any distance
- Object distance: $s > 0$
- Image distance: $s' < 0$
- Object height: $h > 0$
- Image height: $h' > 0$
- Magnification: $0 < M < 1$
- Image is always minified; s does not matter

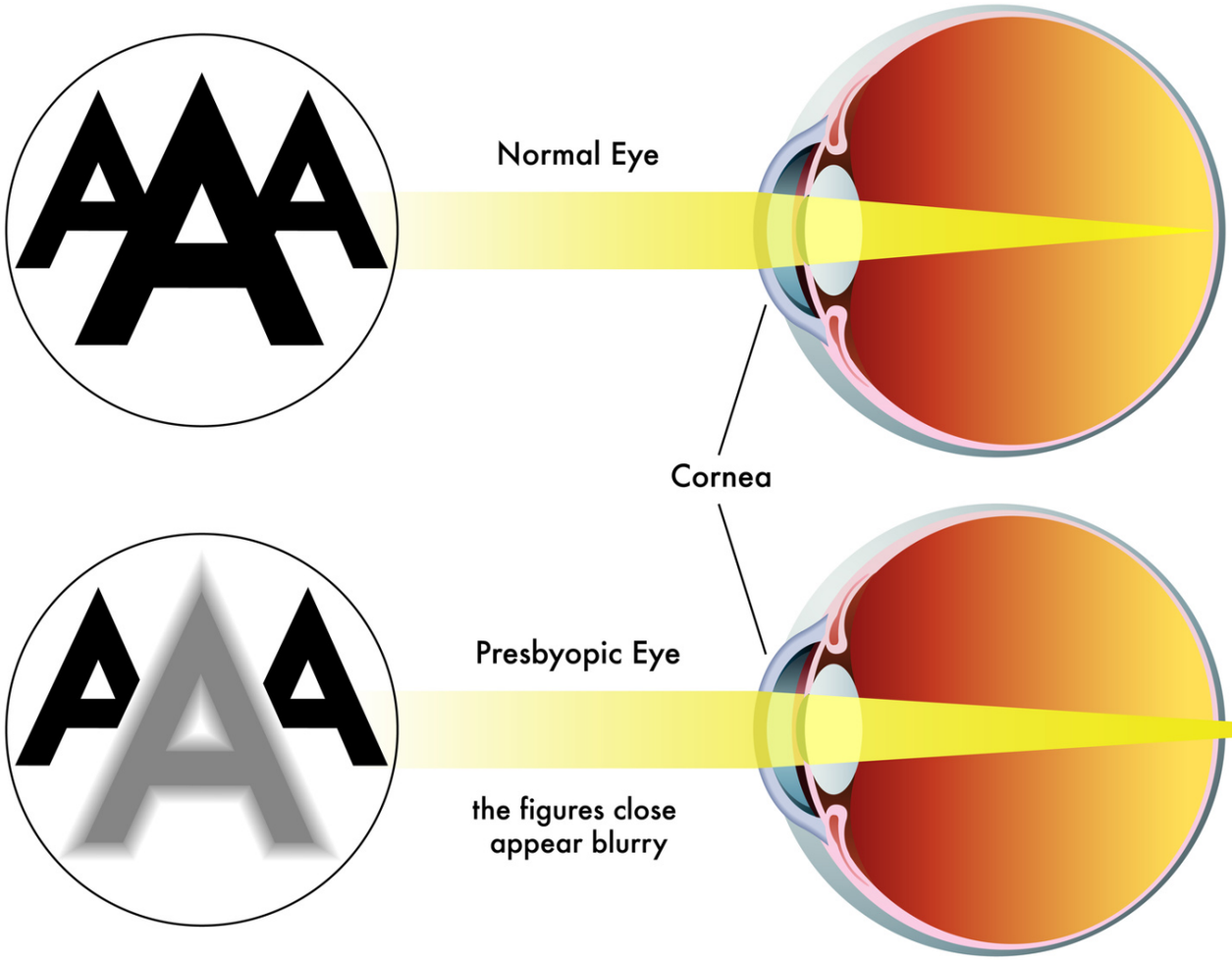


Myopia: Near-Sightedness

- If you wear corrective lenses, you are probably near-sighted
- Distant objects are blurry, objects must be brought close to focus
- Typically results when your eyeball is slightly elongated and image focuses in front of the retina

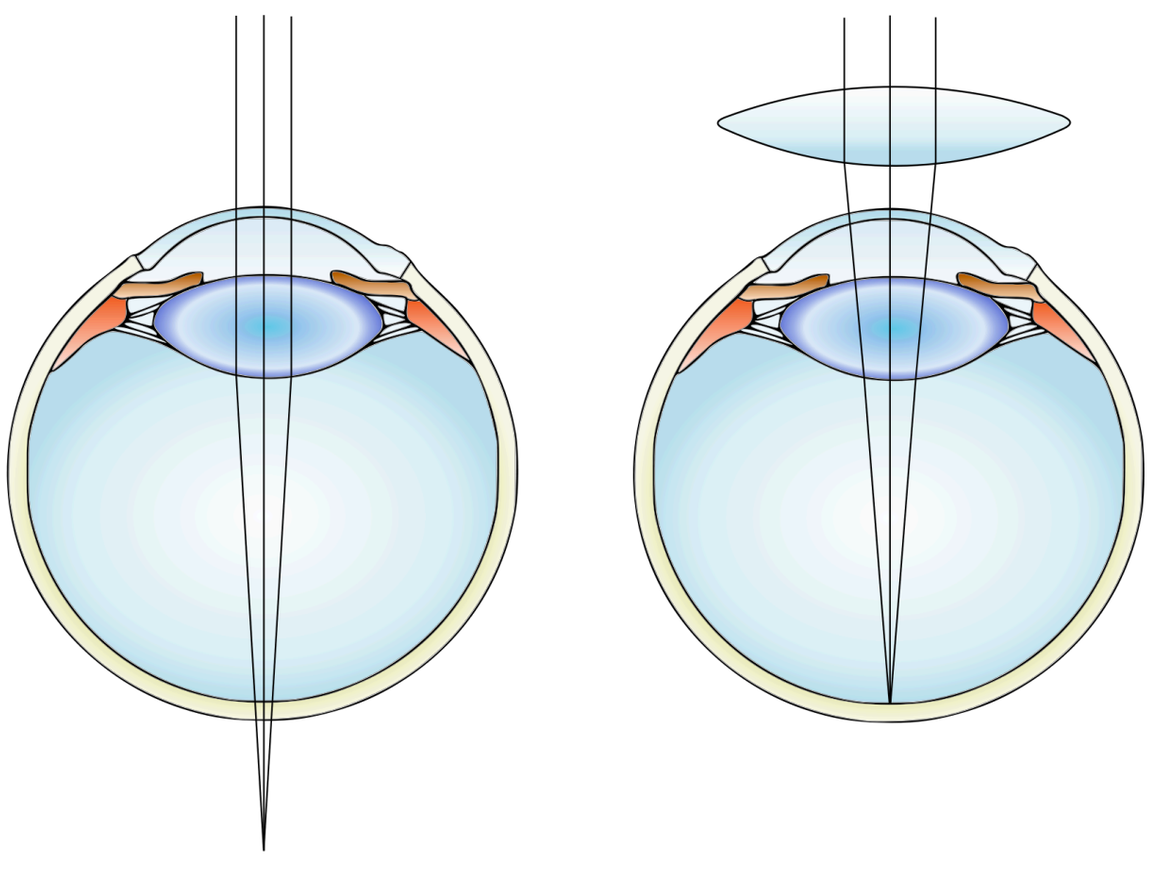






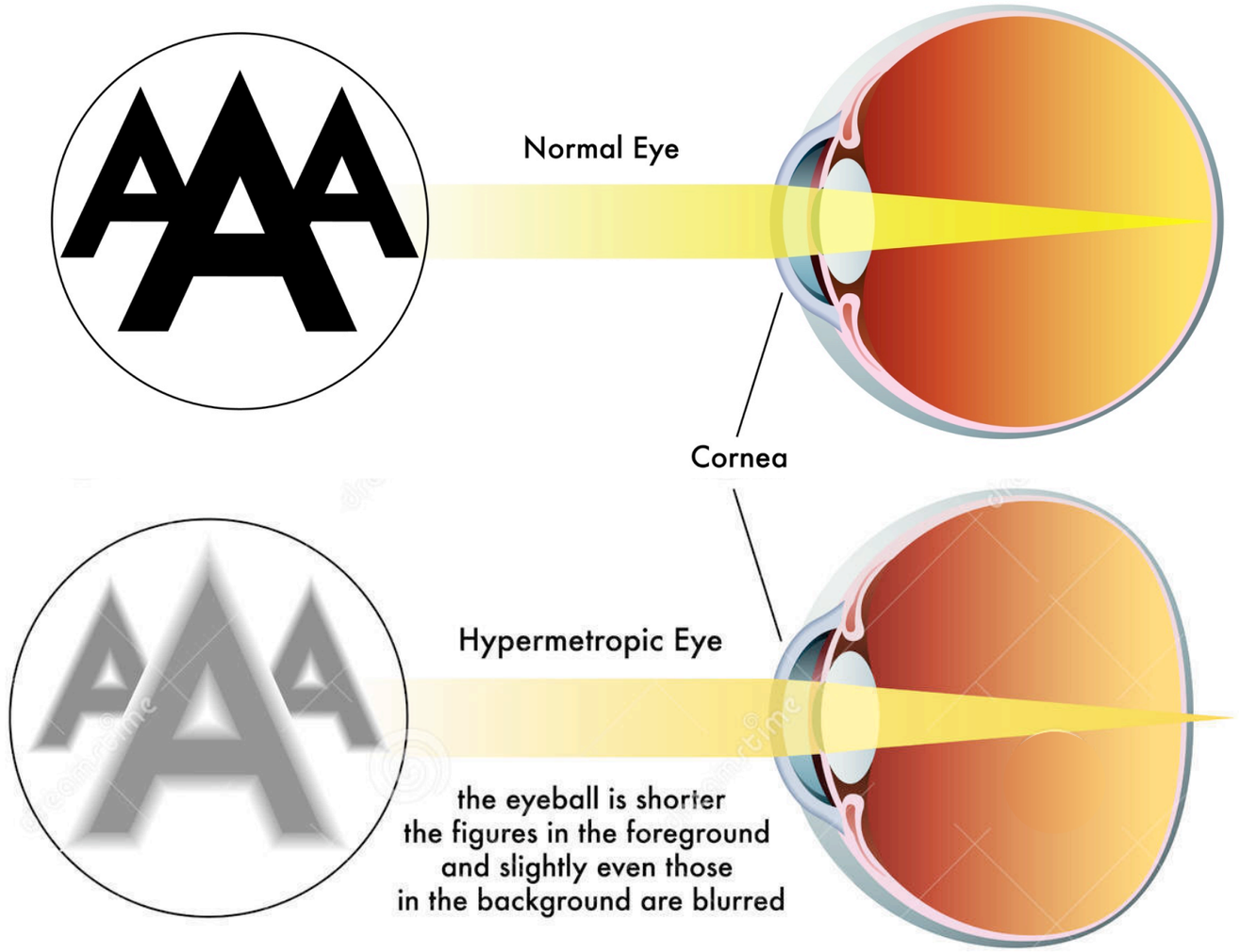
Presbyopia: Probably Not Your Problem (Yet)

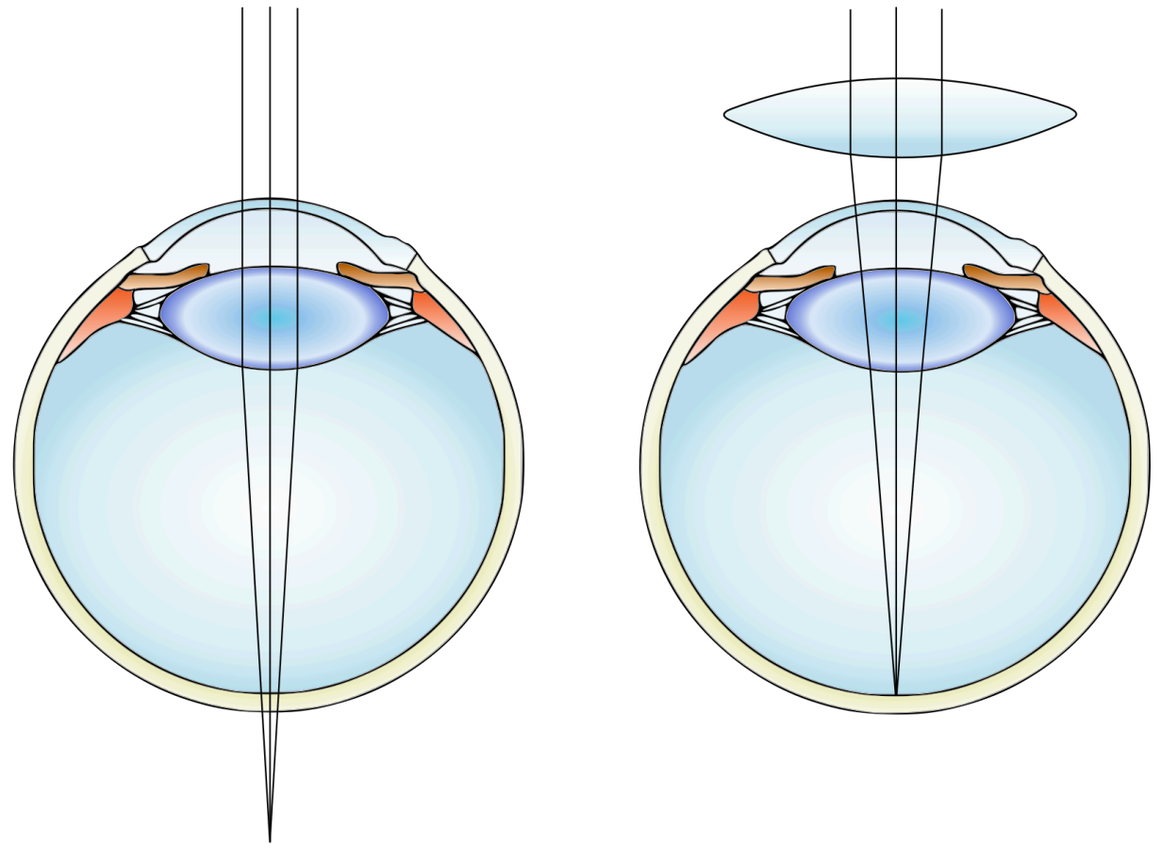
- As you get older, your lens loses some flexibility and the supporting muscles weaken
- You will start to lose the ability to focus on close objects
- This is why your mom has a pair of reading glasses in every room of the house



Hyperopia: Far-Sightedness

- This is much less common, but sometimes occurs in very small children
- Near objects are blurry, farther objects are clear
- Typically results when your eyeball is slightly squashed and image focuses behind the retina





Dispersion and Color

- Wavelength is related to frequency
- All frequencies have same speed, so higher frequency = shorter wavelength
- Shorter wavelengths are dispersed (bent) more than longer wavelengths

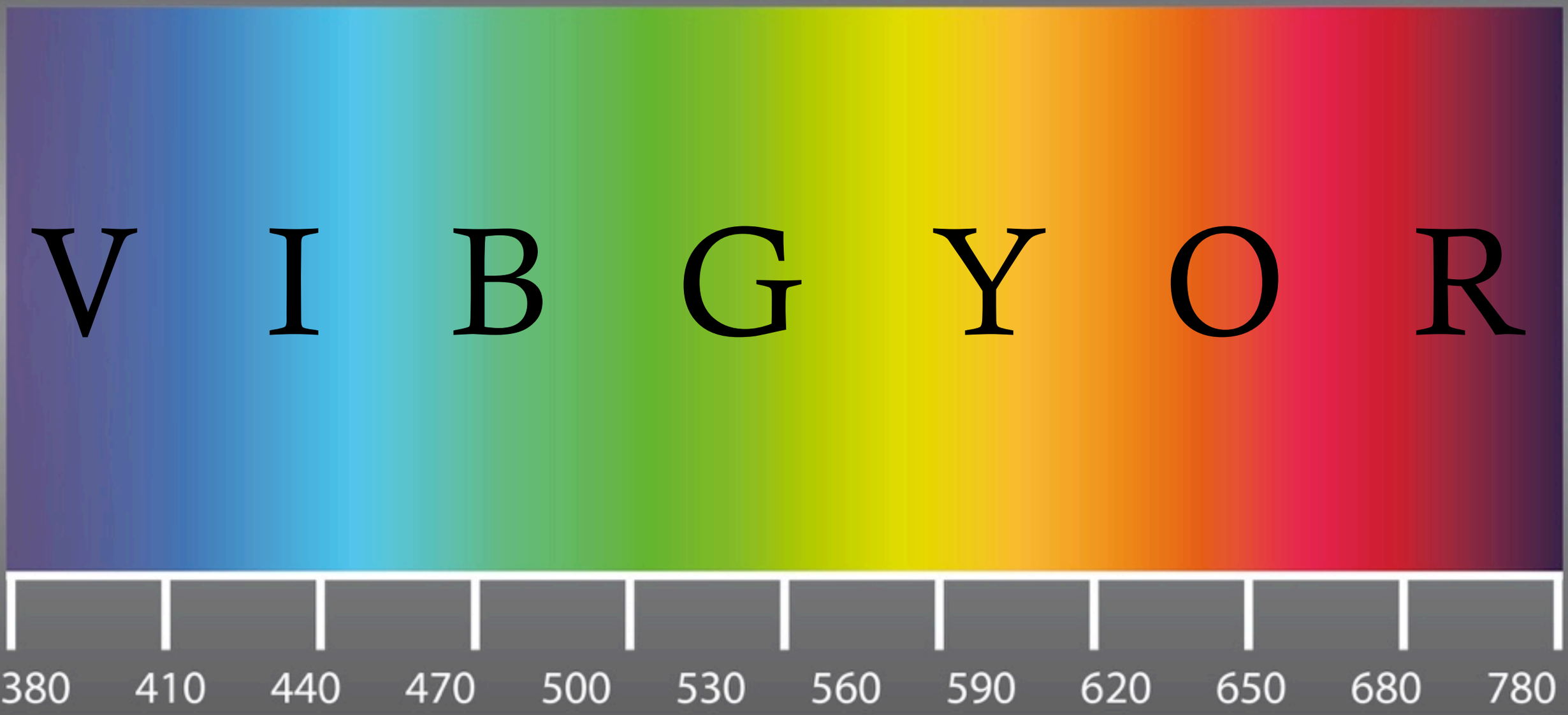
Q07.11

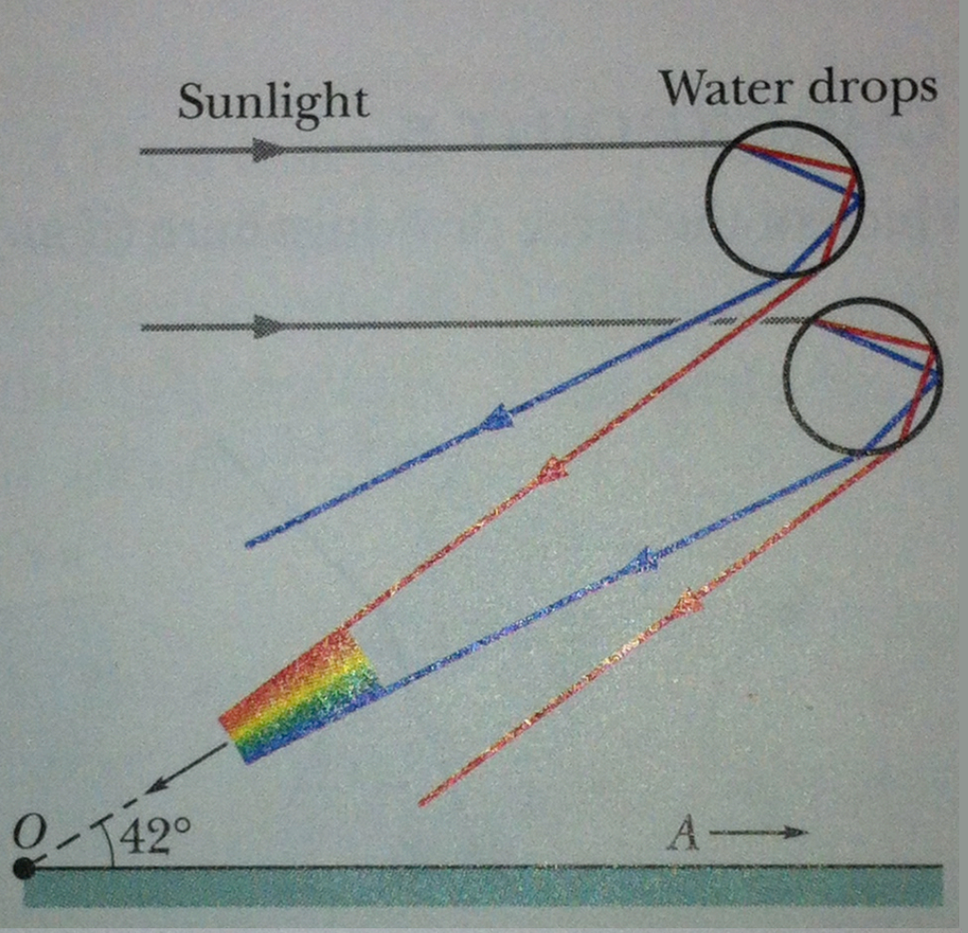
A) This is ***never*** what a real rainbow looks like.

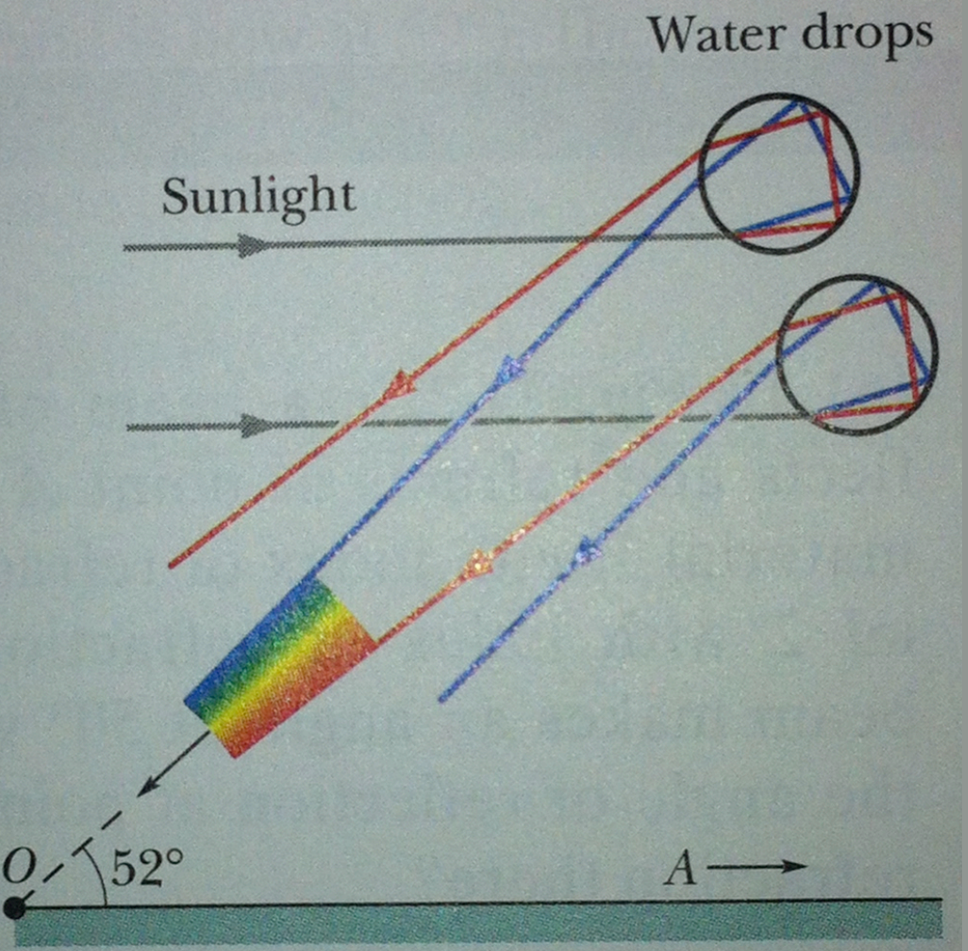
B) This is ***always*** what a real rainbow looks like.

C) This ***may*** or ***may not*** be how a real rainbow appears.

- White light can be separated into colors according to wavelength (frequency)
- The spectrum of colors is always ROY G BIV, never VIB GORY (or IVY B GRO, or any other anagram combination)
- Red = low frequency, long wavelength
- Violet = high frequency, short wavelength







Rainbows!

- The geometry is very particular: That's why you don't see them all the time!
- Spherical droplets: Refract, reflect, refract
- Double rainbow: Refract, reflect, reflect, refract

Q07.12: Which one's the real double?

A) This one on the left.

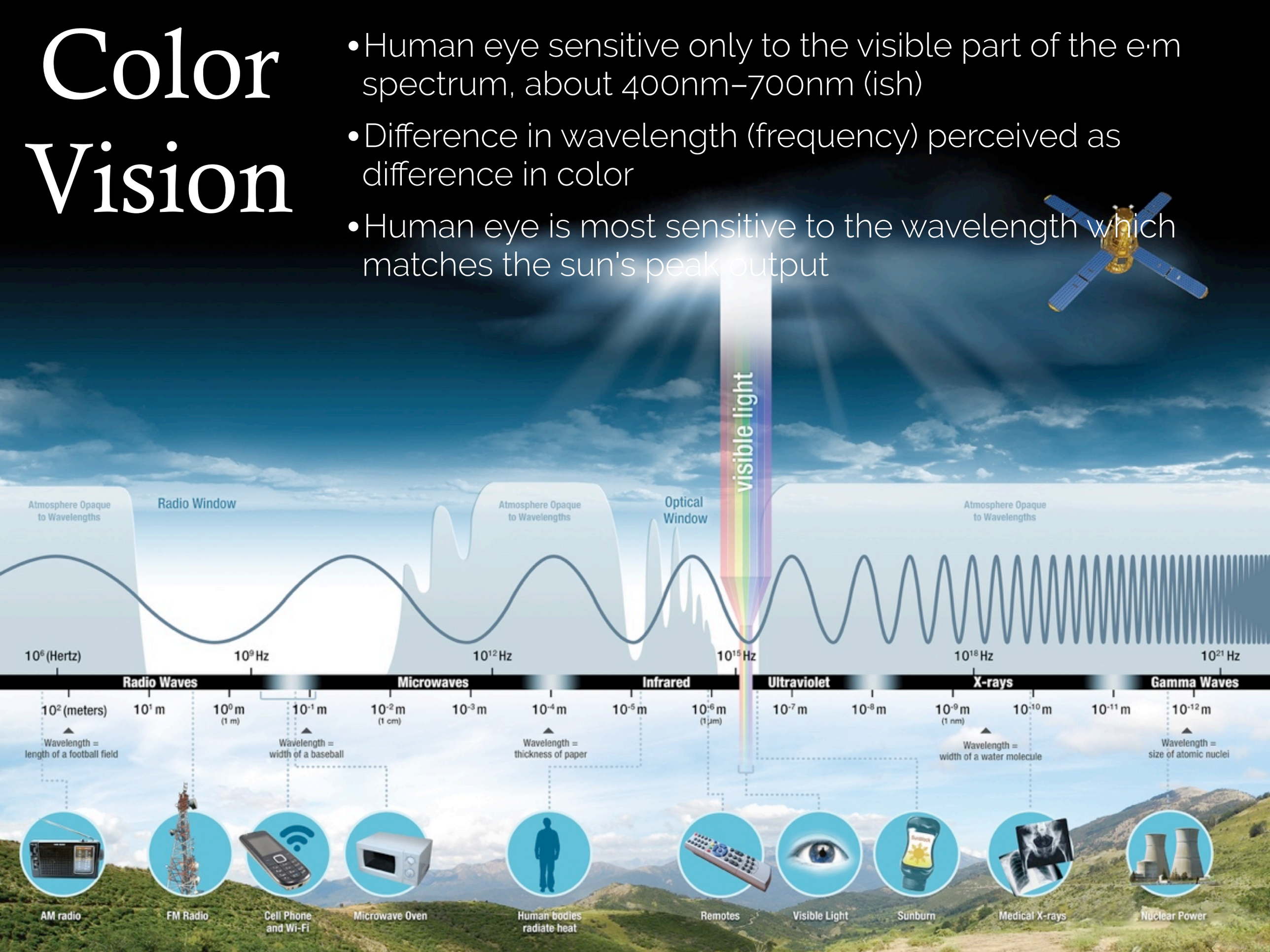
B) Neither one.

C) This one on the right.

D) Both of them.

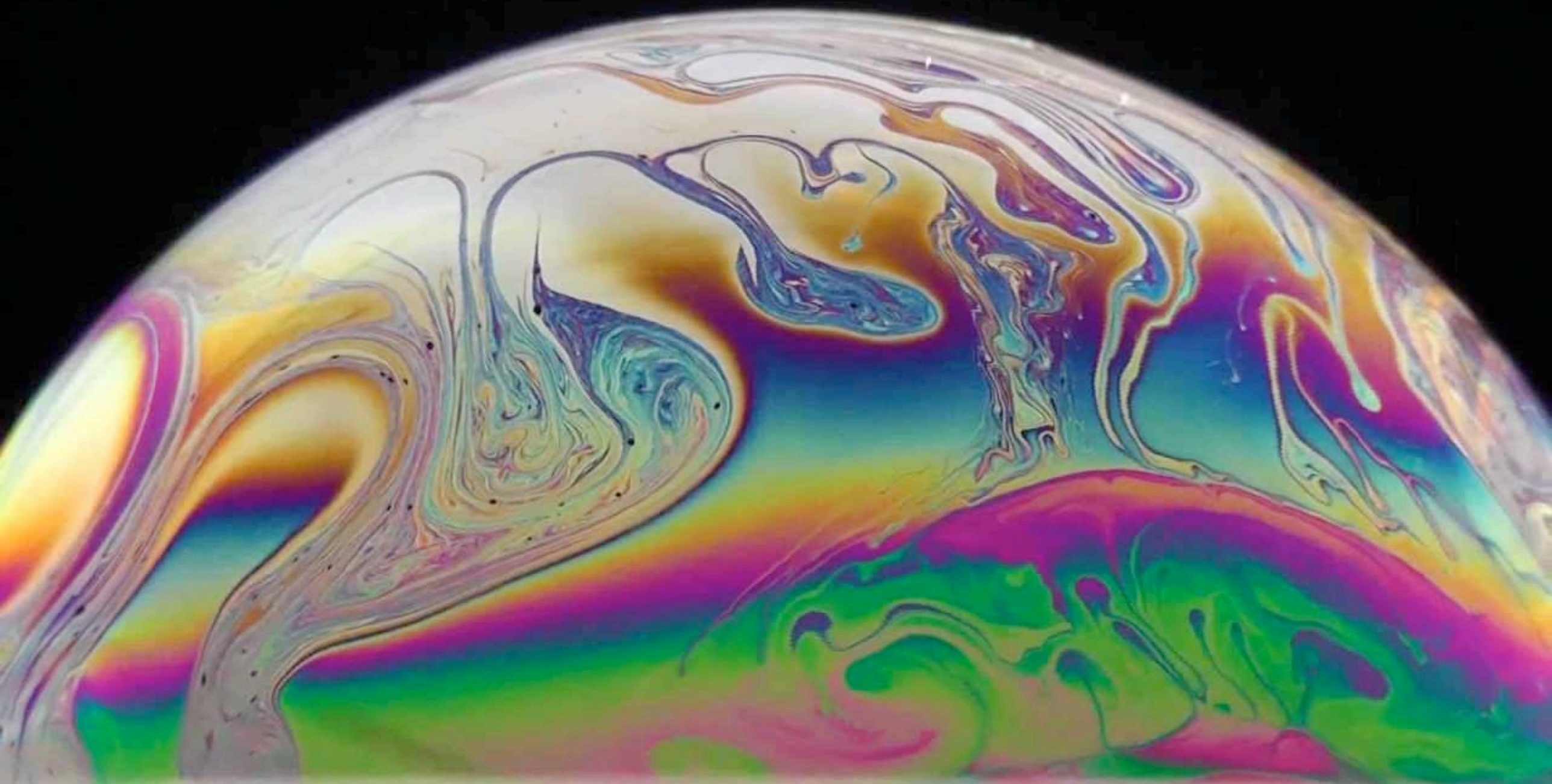
Color Vision

- Human eye sensitive only to the visible part of the e·m spectrum, about 400nm–700nm (ish)
- Difference in wavelength (frequency) perceived as difference in color
- Human eye is most sensitive to the wavelength which matches the sun's peak output



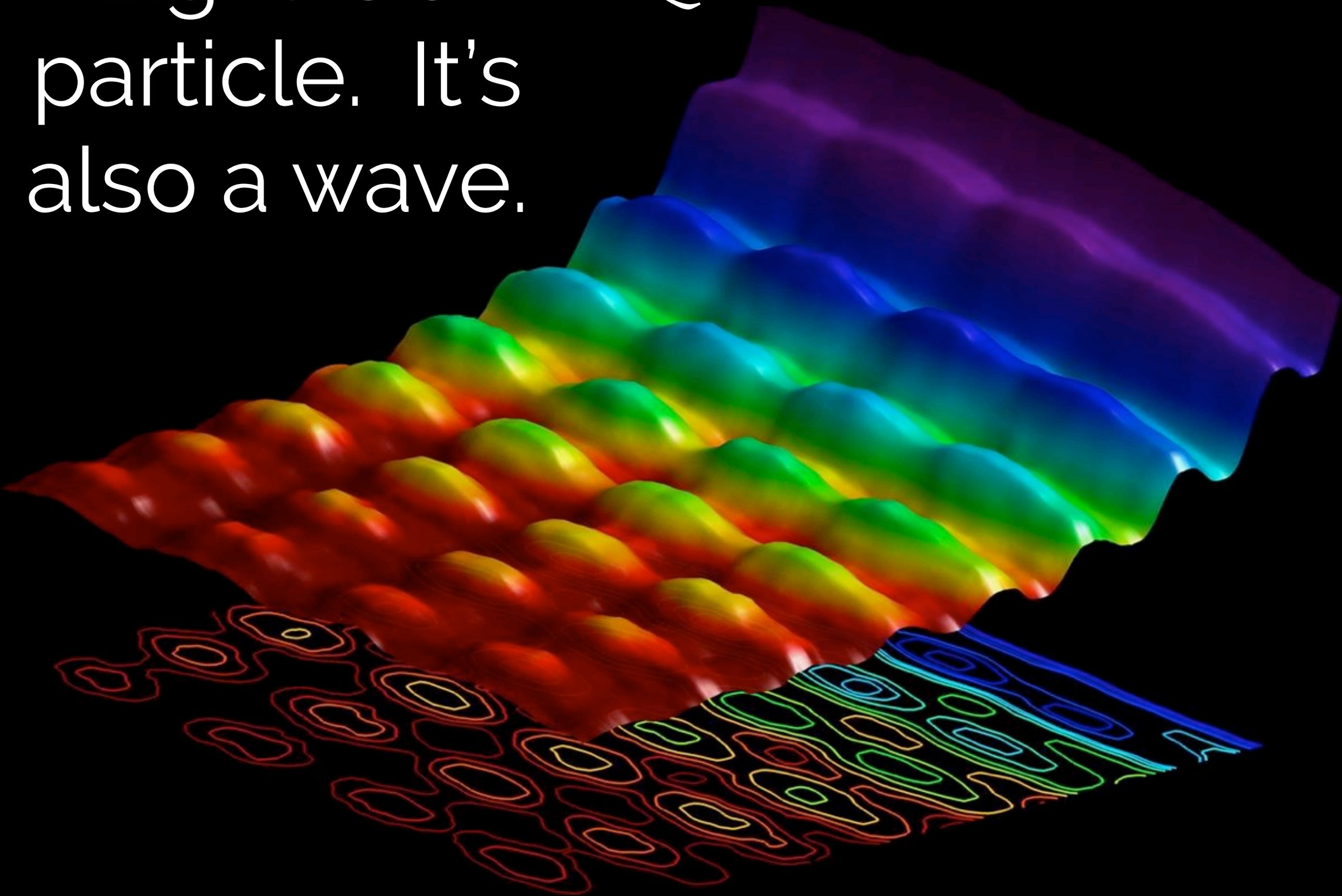
Section 7.3

Evidence for Waves



Q07.13: True or false?

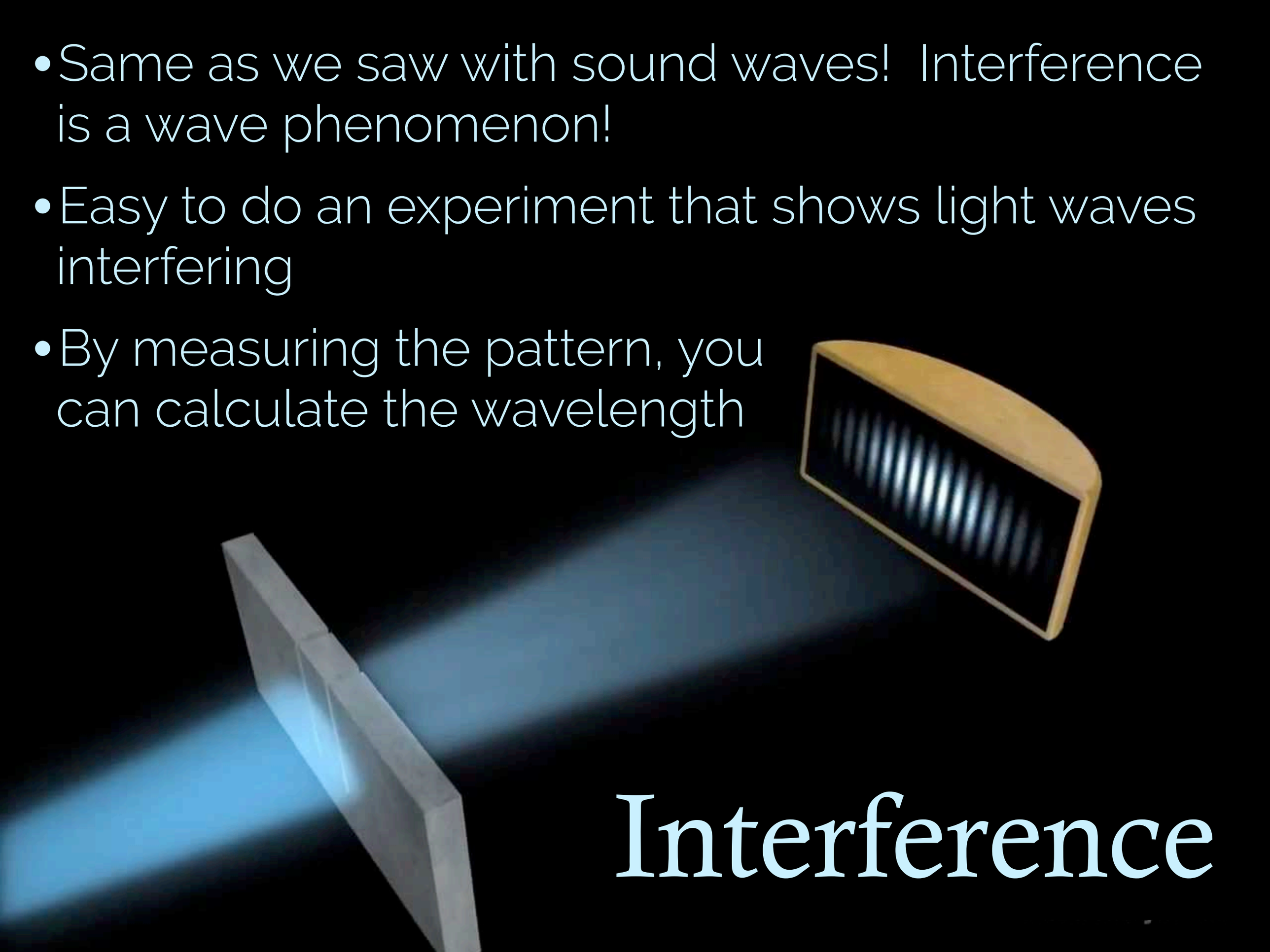
Light is a particle. It's also a wave.



Particle or Wave?

- In the late 1600s, Newton was convinced light was a particle
- At the same time, Christiaan Huygens was convinced it was a wave
- Who was right? Turns out they both were

- Same as we saw with sound waves! Interference is a wave phenomenon!
- Easy to do an experiment that shows light waves interfering
- By measuring the pattern, you can calculate the wavelength



Interference

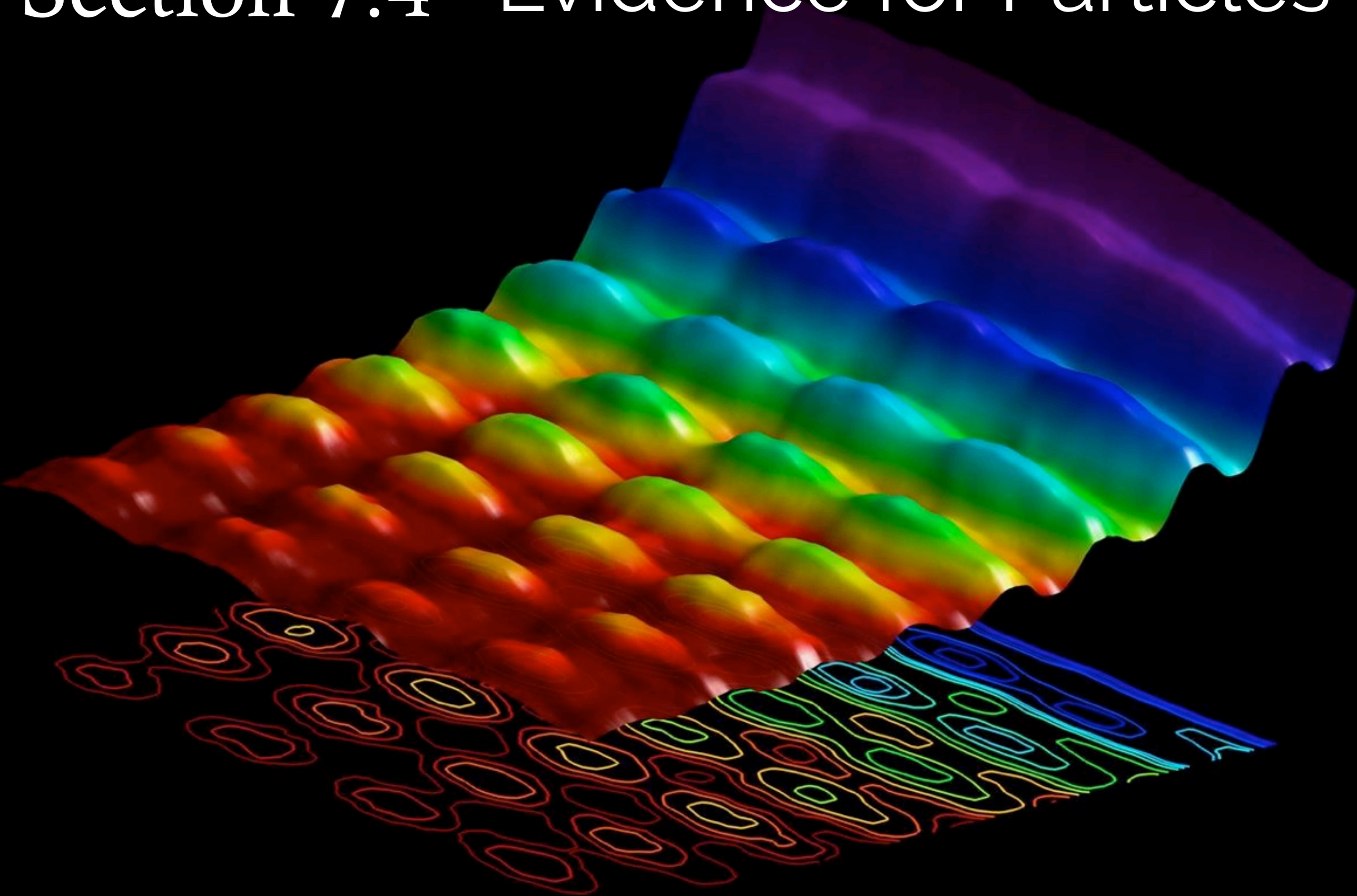
True or false:

Polarized sunglasses are a scam! They can't do anything that regular sunglasses don't already do!

Polarization

- Demonstrates that light is a transverse (not longitudinal) wave
- Sunlight, light bulb: Unpolarized light (oscillations in many random directions)
- Polarized sunglasses: Allow only one direction of vibration to pass through

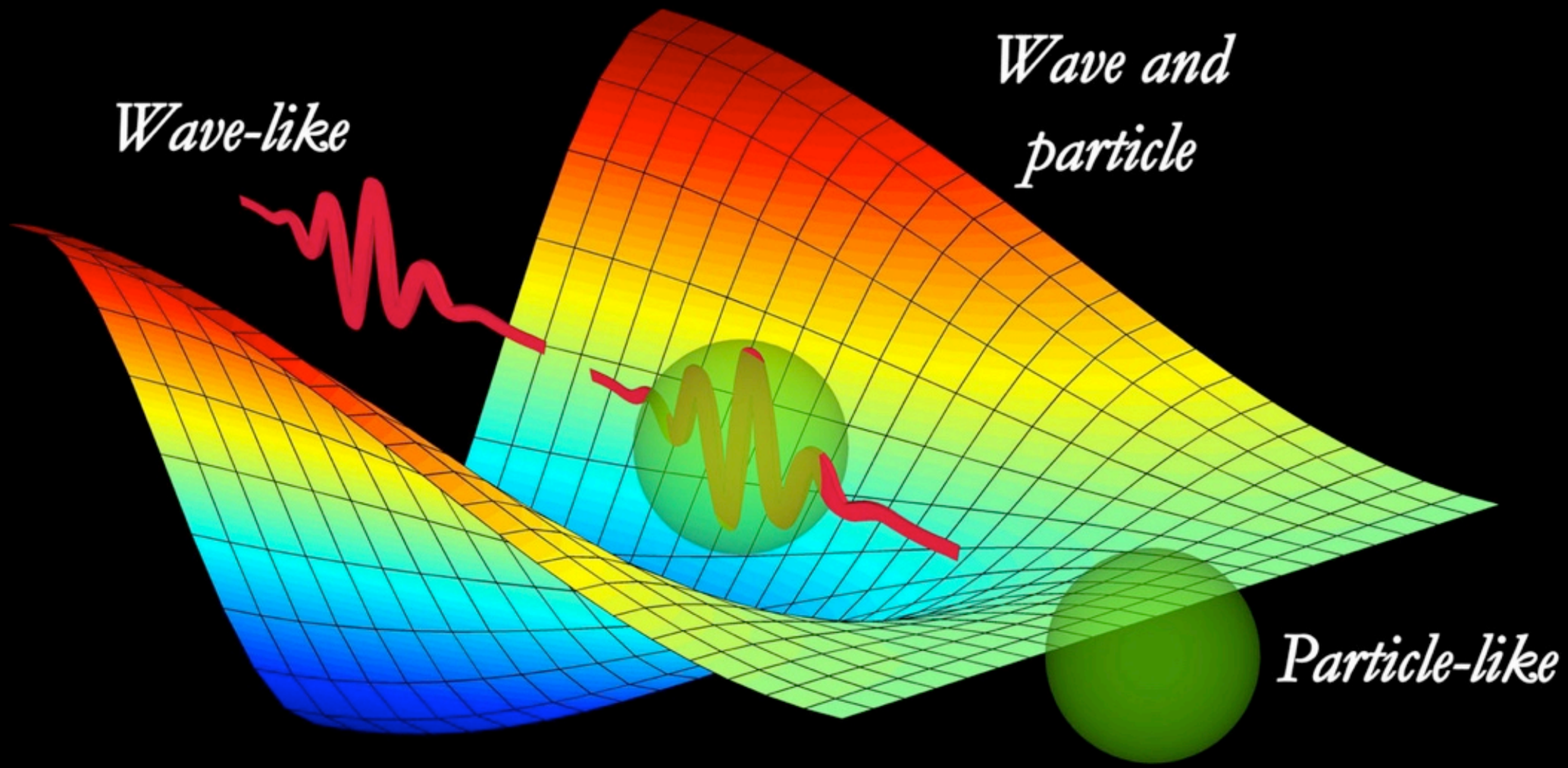
Section 7.4 Evidence for Particles



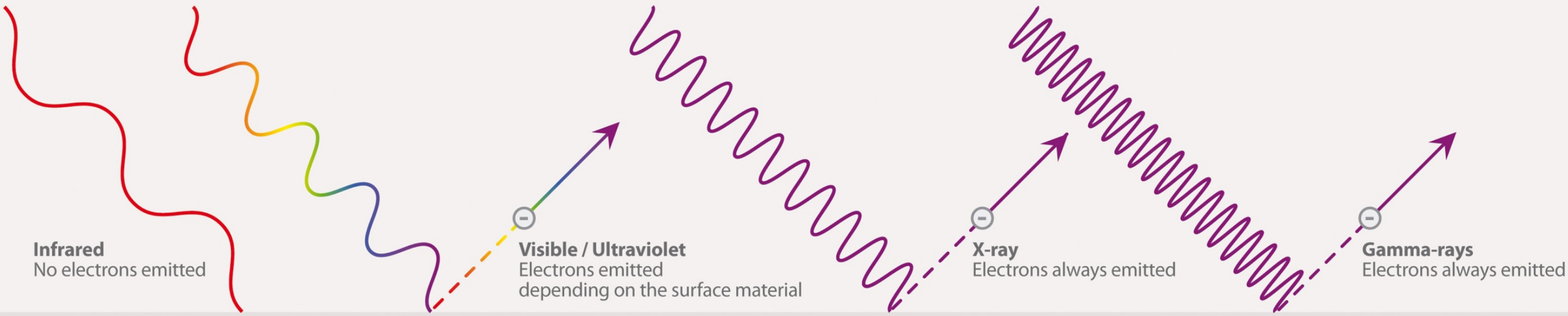
Q07.14: Why Would Light Be a Particle?

A) It wouldn't. Actually, it isn't.

B) Light exhibits behavior that cannot be explained by a wave, but can easily be explained by a particle.



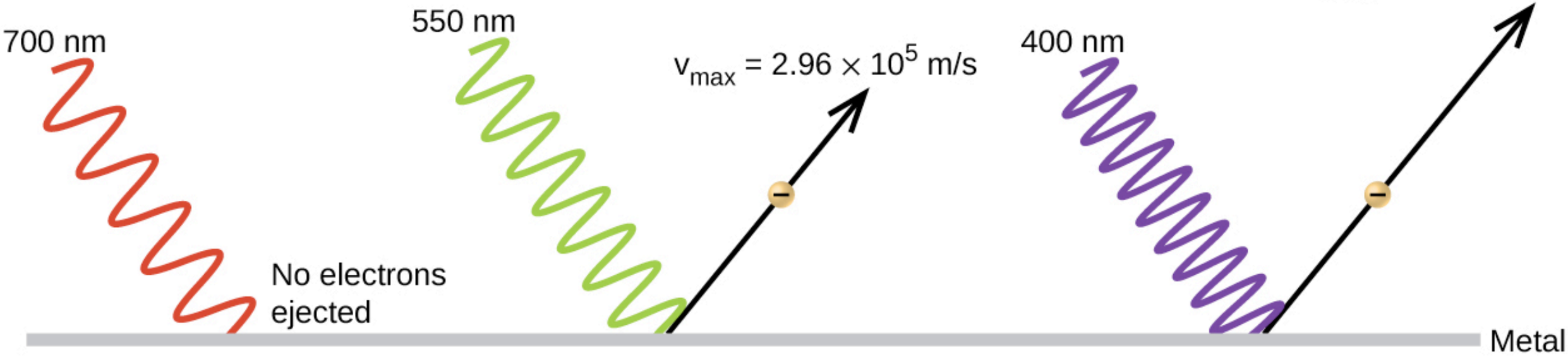
Photoelectric Effect



- You can use light to bounce electrons off a surface
- Specific material requires a specific wavelength (frequency); other colors don't work
- Lower intensity light, fewer e^- ejected (higher intensity, more ejected)
- Ejected e^- have the same KE no matter the intensity of the light

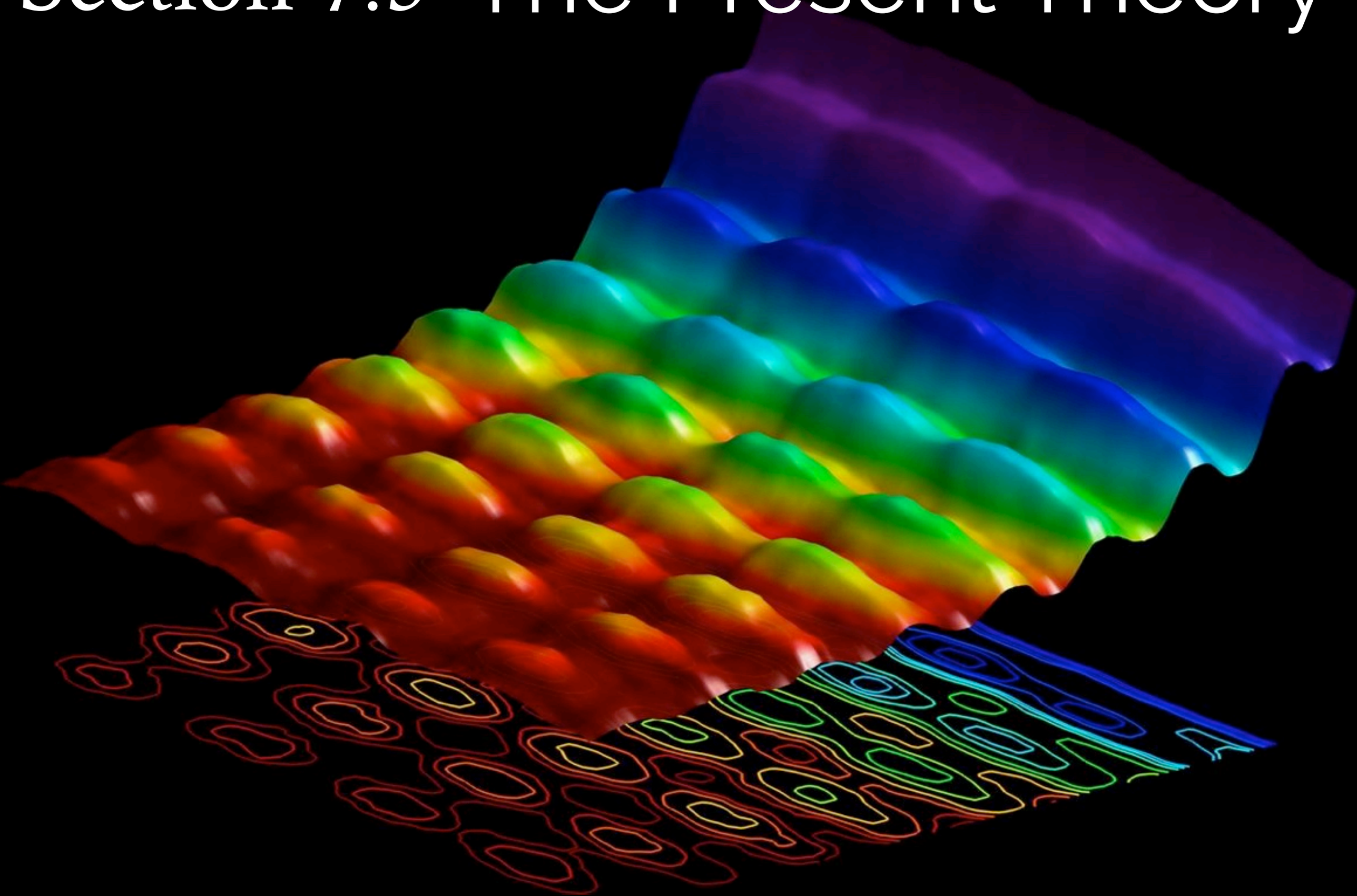
Quantization of Energy

$$E = hf$$



- Photon = particle of light (massless), or packet of energy
- Just like charge is quantized, photons are as well
- Each photon with the same frequency has the same energy

Section 7.5 The Present Theory



Wave-Particle Duality

	Can a wave do this?	Can a particle do this?
Reflection	yep	yep
Refraction	yep	yep
Interference	yep	nope
Diffraction	yep	nope
Polarization	yep	nope
Photoelectric Effect	nope	yep

- Light exhibits both traits, but never at the same time
- If it's behaving like a wave, no particle properties
- If it's behaving like a particle, no wave traits