

# PHYS11 CH:15 The Invisible Rainbow

## From Radio Waves to Gamma Rays

Mr. Gullo

December 2025

# Outline

1 Introduction

2 15.1 The Electromagnetic Spectrum

3 15.2 Behavior of EM Radiation

4 Summary

# The Mystery

What if everything you see  
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Visible light is a narrow sliver of electromagnetic radiation.

The universe broadcasts in frequencies we cannot see.

# Seeing the Unseeable



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## The Mental Model

Fish eyes detect visible light. Our instruments detect the rest.

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- **15.1:** Describe the differences and similarities of each section of the EM spectrum
- **15.1:** Explain applications of radiation from each section

## 15.1 The Source: Oscillating Charge

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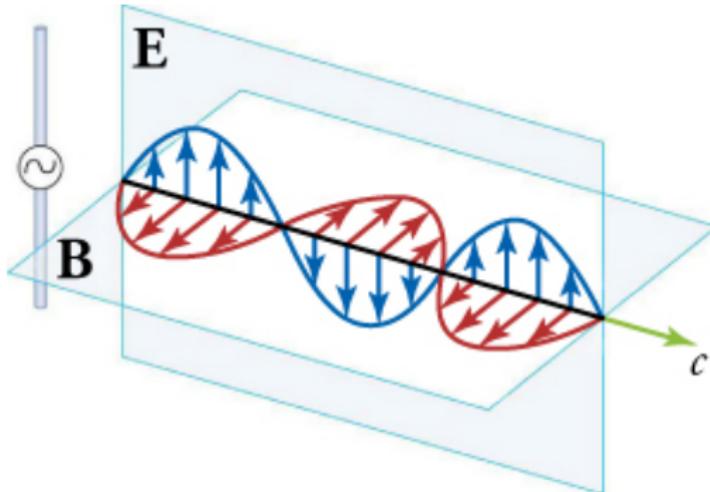
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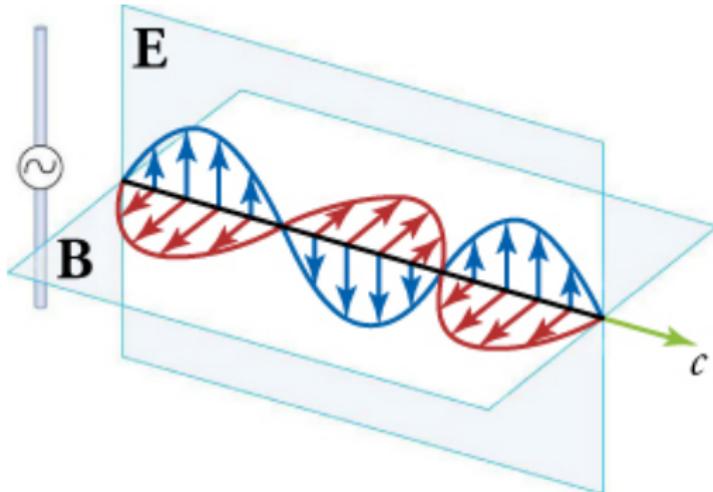
### What makes an EM wave:

- Electric current creates electric field E
- Electric current creates magnetic field B
- E and B perpendicular to each other
- When charge oscillates, wave propagates

## 15.1 Anatomy of an EM Wave



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E and B fields oscillate in phase, perpendicular to each other and to direction of propagation.

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- **Wavelength**  $\lambda$ : Distance between two crests (meters)

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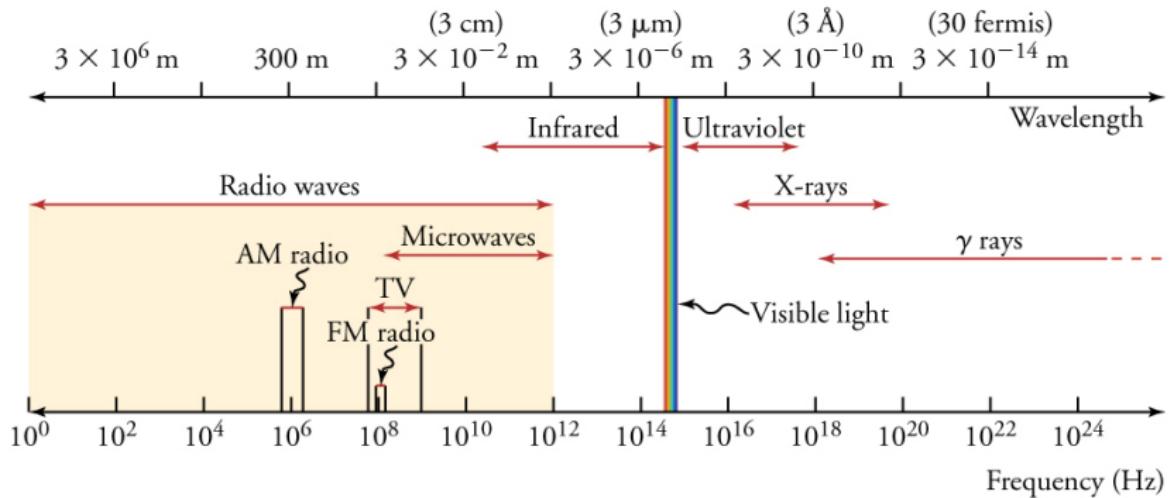
- **Wavelength**  $\lambda$ : Distance between two crests (meters)
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- **Amplitude**: Height of crest above null point

Universal Law: The Speed of Light

$$c = f\lambda$$

Speed equals frequency times wavelength.  $c = 3.00 \times 10^8$  m/s.

# 15.1 The Full Spectrum



## 15.1 Decoding the Spectrum

### **Low Frequency (IR):**

- Radio waves
  - Microwaves
  - Infrared (heat)

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- Gamma rays

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- X-rays
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## The Mental Model

IR = below red. UV = beyond violet. Visible light in the middle.

## 15.1 The Intuition Trap

## What Your Brain Gets Wrong

**Misconception:** Visible light is somehow different from other EM radiation.

**Reality:** All EM radiation is identical except for frequency and wavelength.

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### What Your Brain Gets Wrong

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### Why we see visible light:

- Our eyes evolved to detect 400-700 nm wavelengths
- This is the frequency range that penetrates atmosphere
- Has nothing to do with the radiation itself

# 15.1 Radio Waves

## Real-World: Broadcasting

- AM/FM radio, TV signals
- Cell phones, Wi-Fi
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## AM vs FM:

- AM: Amplitude Modulation (varies amplitude)
- FM: Frequency Modulation (varies frequency)

## 15.1 Microwaves

## Real-World: Cooking and Radar

- Microwave ovens: frequency  $2.45 \times 10^9$  Hz
  - Cause polar molecules (water) to rotate
  - Rotational energy becomes heat
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**Doppler radar:** Measures speed using frequency shift of reflected waves.

# 15.1 Infrared Radiation

## Real-World: Heat

- What we feel as radiant heat
- Night-vision goggles detect body heat
- Remote controls use IR signals

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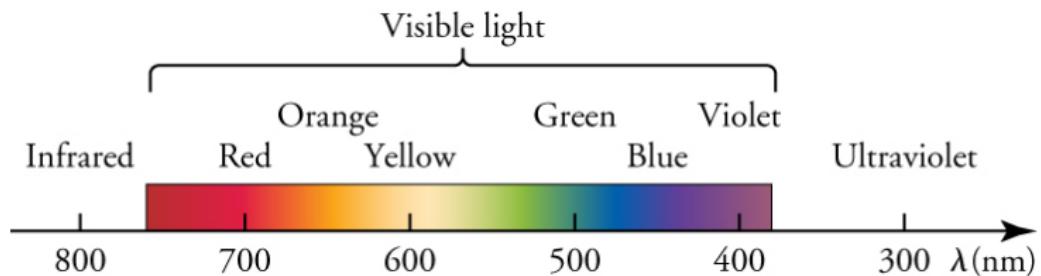
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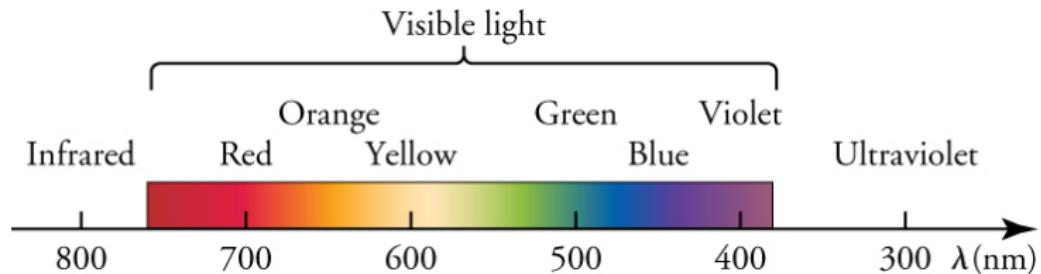
## Misconception Alert

Heat waves are no different from other EM waves. We feel them as heat because their frequency interacts with our bodies to create thermal energy.

## 15.1 Visible Light



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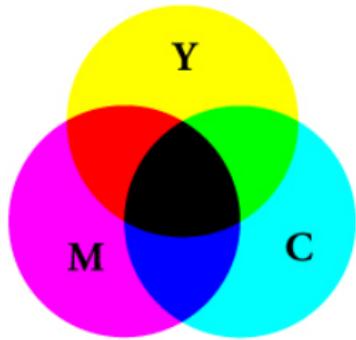


**Wavelengths:** 400-700 nm

**Frequencies:**  $4.0 \times 10^{14}$  to  $7.9 \times 10^{14}$  Hz

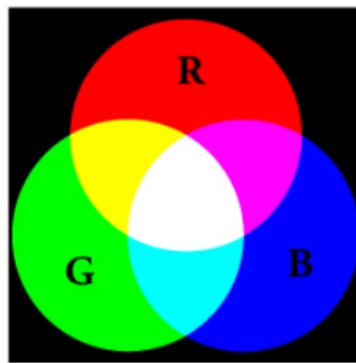
## 15.1 The Color Wheels

Pigment



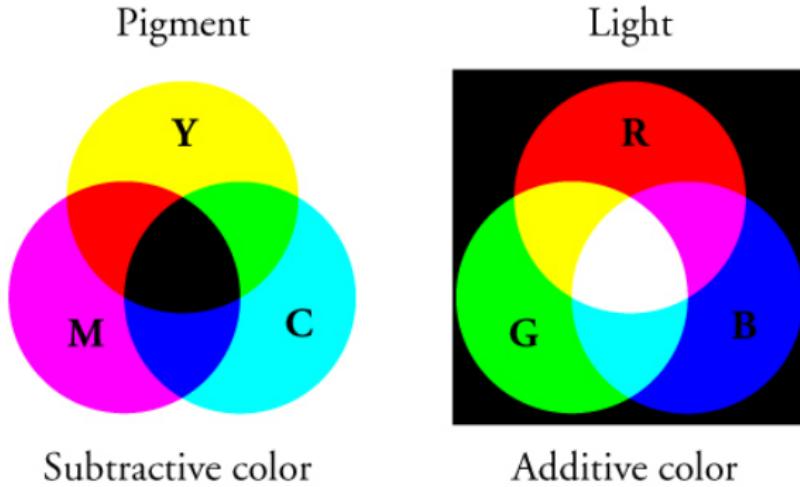
Subtractive color

Light



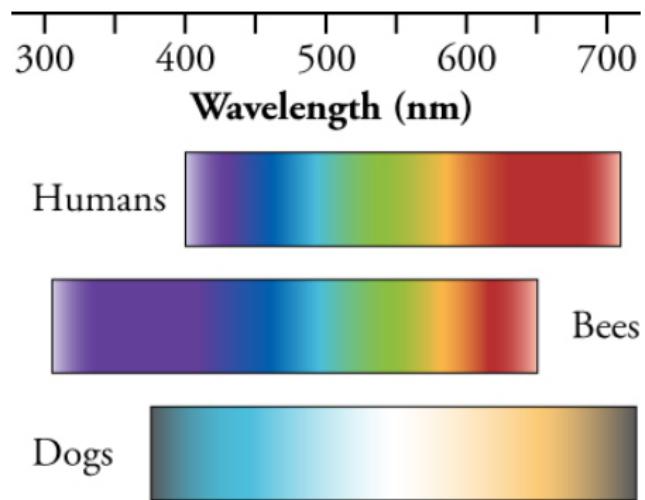
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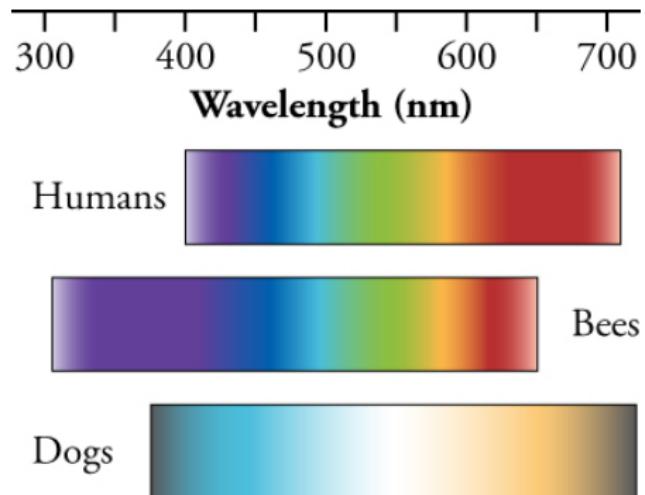


**Subtractive (pigments):** Cyan, Magenta, Yellow primaries → Black  
**Additive (light):** Red, Green, Blue primaries → White

## 15.1 Animal Color Perception

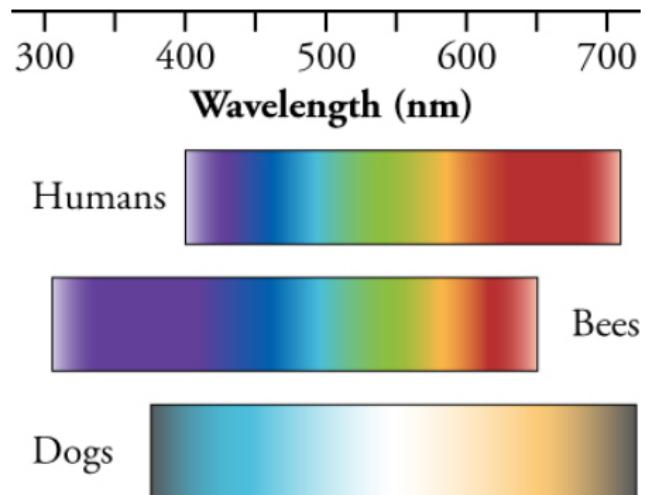


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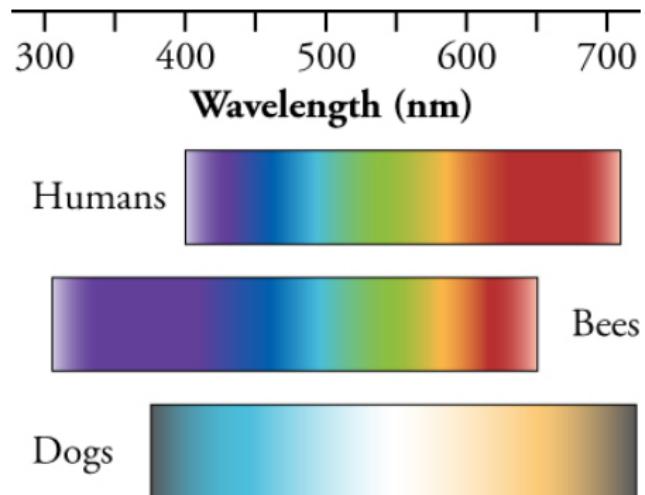


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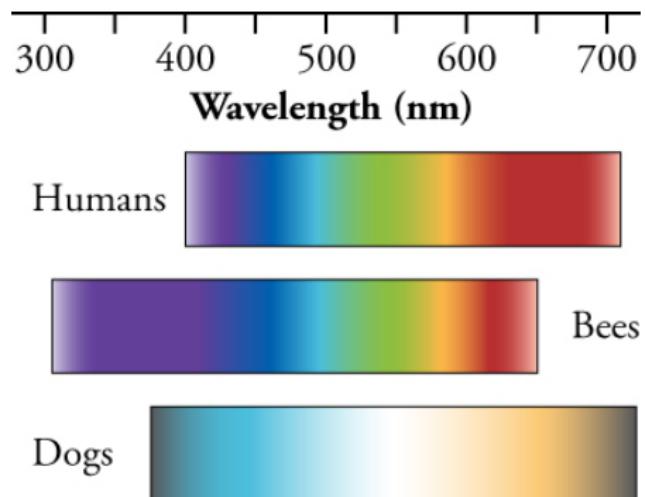


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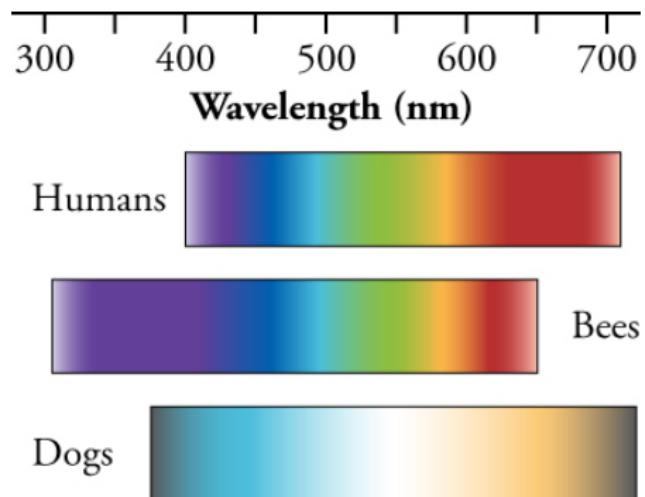


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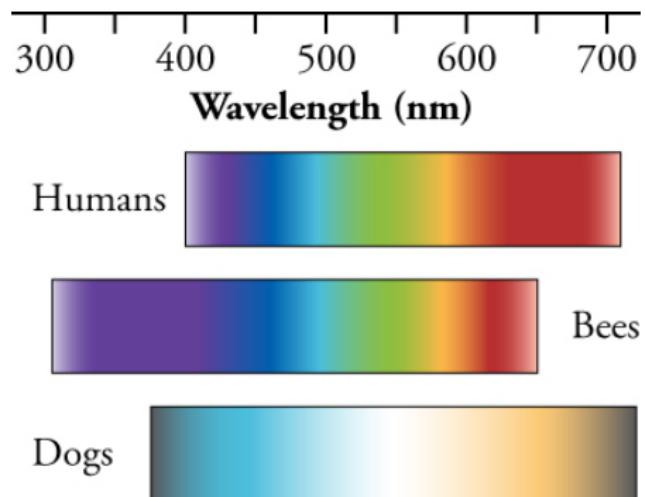


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- Black lights, counterfeit detection

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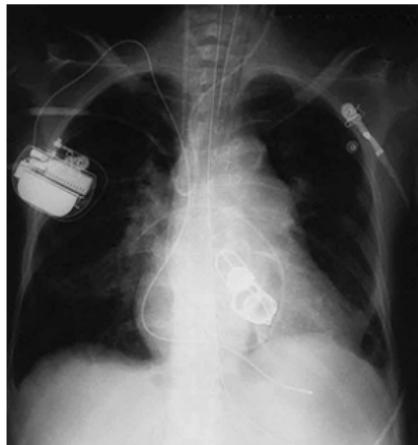
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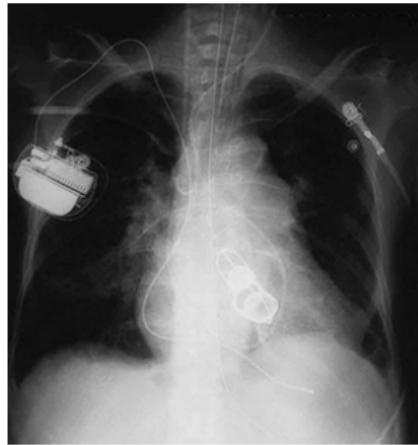
## Health Hazard

UV radiation damages cells. Higher energy than visible light. Always use sunscreen!

## 15.1 X-Rays



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**Very high energy, very penetrating**  
**Applications:**

- Medical imaging (see bones)
- Airport security scanners

# 15.1 Gamma Rays

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**Extremely dangerous - ionizing radiation damages DNA**

## 15.1 Maxwell's Unification



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Electric and magnetic forces are two manifestations of the same thing - the electromagnetic force

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- **15.2:** Solve quantitative problems involving EM radiation

## 15.2 The Universal Speed Limit

Nature's Law: Speed of Light

$$c = 3.00 \times 10^8 \text{ m/s}$$

All EM radiation travels at this speed in a vacuum. 671 million mph.  
Constant everywhere in the universe.

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**Cosmic distances:**

- Sun to Earth: 8.3 minutes
- Nearest star: 4.2 years
- Nearest galaxy: 25,000 years

## 15.2 Light in Different Media

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- Water: 75% of  $c$
- Diamond: 41% of  $c$

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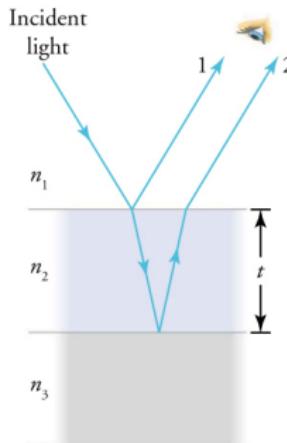
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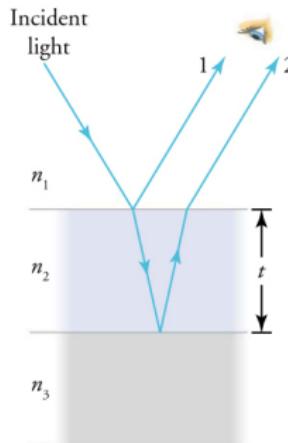
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When light changes speed at boundary, it changes direction. This is called **refraction**.

## 15.2 Thin-Film Interference



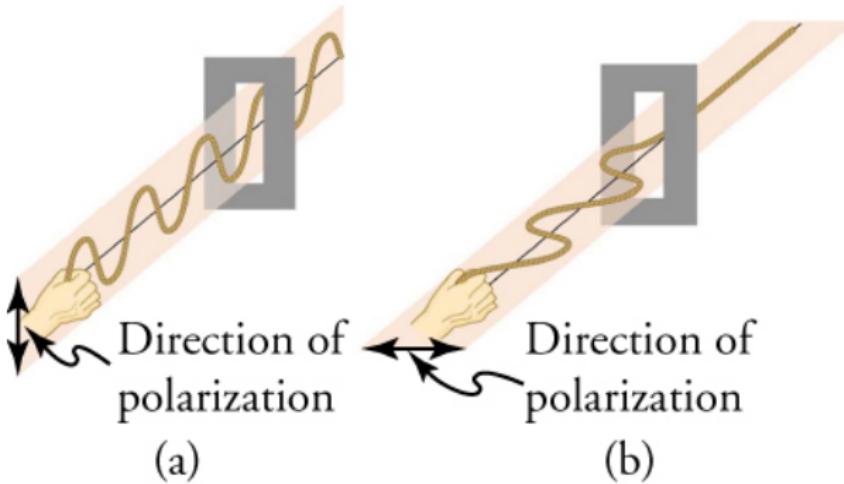
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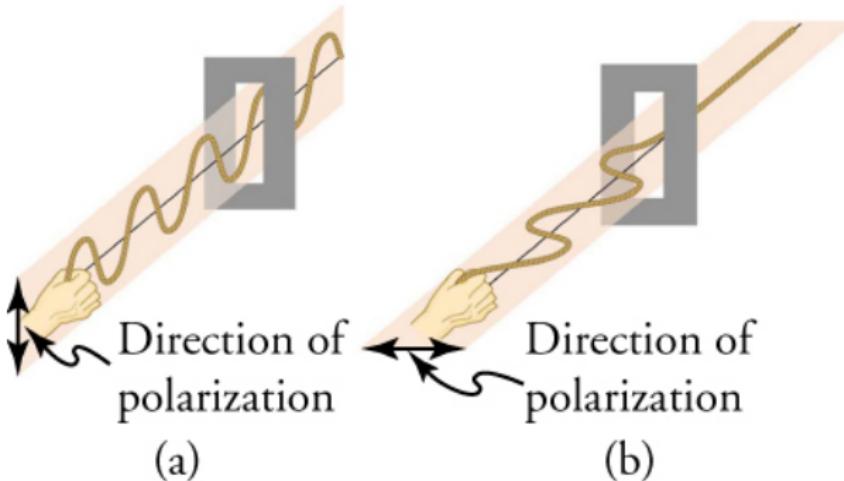
**Rainbow colors from:** Soap bubbles, oil slicks, CDs

**Cause:** Light reflects from top and bottom of thin film, waves interfere

## 15.2 Polarization



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**Polarized light:** Electric field vibrates in only one direction

**Polarizing filter:** Transmits one direction, blocks others

## 15.2 Polarized Sunglasses



(a)

(b)

## 15.2 Polarized Sunglasses



**How they work:** Block horizontally polarized light (glare from water/glass)

**Result:** Reduced glare, clearer vision

# Attempt: Decoding Yellow Light

## The Challenge (3 min, silent)

Yellow light has a wavelength of  $6.00 \times 10^{-7}$  m.

**Given:**

- $\lambda = 6.00 \times 10^{-7}$  m
- $c = 3.00 \times 10^8$  m/s

**Find:** Frequency  $f$  in Hz

*Can you calculate the frequency? Work silently.*

# Compare: Wave Equation

**Turn and talk (2 min):**

- ① What equation relates  $c$ ,  $f$ , and  $\lambda$ ?
- ② How did you rearrange to solve for  $f$ ?
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**Name wheel:** One pair share your approach (not your answer).

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**Check:**  $10^{14}$  Hz is in visible range. Reasonable!

## 15.2 Illuminance: Light Intensity

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Universal Law: Inverse Square Law

$$\text{Illuminance} = \frac{P}{4\pi r^2}$$

Light intensity decreases with square of distance.

# Attempt: Reading Light

## The Challenge (3 min, silent)

A floor lamp has luminous flux of 2000 lm. You hold a book 2.00 m from the bulb.

### Given:

- $P = 2000 \text{ lm}$
- $r = 2.00 \text{ m}$
- $\pi = 3.14$

### Find: Illuminance in lux

*Can you calculate the illuminance? Work silently.*

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**Check:** At 3 m, illuminance drops to 17.7 lx. Light fades rapidly!

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- ⑦ Illuminance decreases with inverse square of distance

# Key Equations

$$c = f\lambda \quad (1)$$

$$c = 3.00 \times 10^8 \text{ m/s} \quad (2)$$

$$f = \frac{c}{\lambda} \quad (3)$$

$$\lambda = \frac{c}{f} \quad (4)$$

$$\text{Illuminance} = \frac{P}{4\pi r^2} \quad (5)$$

# Homework

Complete the assigned problems  
posted on the LMS