

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

What if everything you see
is only 0.0035% of what exists?

The Mystery

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Visible light is a narrow sliver of electromagnetic radiation.

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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.

Learning Objectives

By the end of this lesson, you will be able to:

- **15.1:** Define the electromagnetic spectrum in terms of frequencies and wavelengths

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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

Nature's Broadcasting System

Electromagnetic radiation is generated by a moving electric charge.

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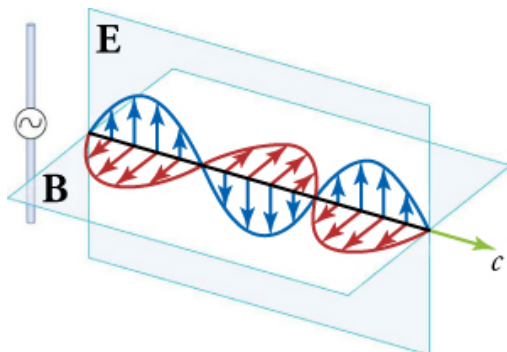
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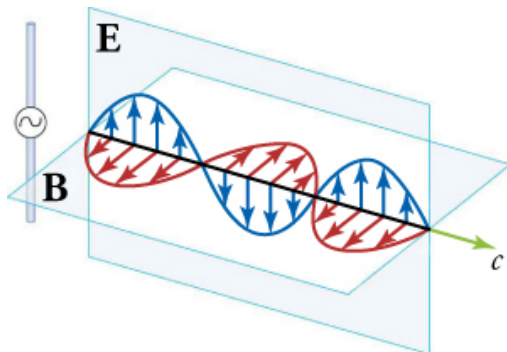
What makes an EM wave:

- 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.

15.1 Wave Properties Review

All waves share these features:

- **Wavelength** λ : Distance between two crests (meters)

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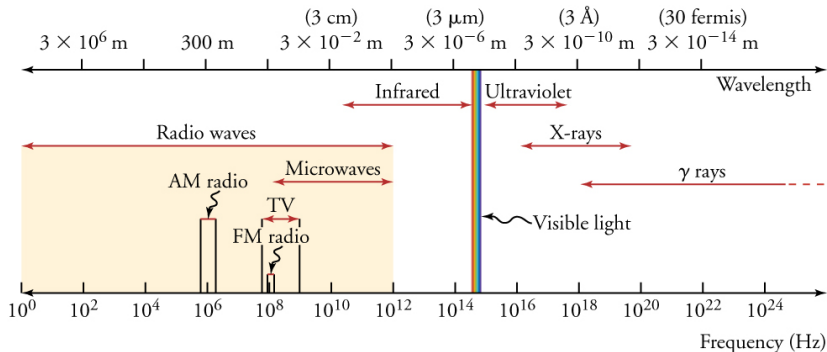
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Universal Law: The Speed of Light

$$c = f\lambda$$

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

15.1 The Full Spectrum



15.1 Decoding the Spectrum

Low Frequency (IR):

- Radio waves
- Microwaves
- Infrared (heat)

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- Ultraviolet
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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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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
- Longest wavelengths, lowest frequencies

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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 2.45×10^9 Hz
- Cause polar molecules (water) to rotate
- Rotational energy becomes heat
- Radar: detect location and speed of objects

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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

15.1 Infrared Radiation

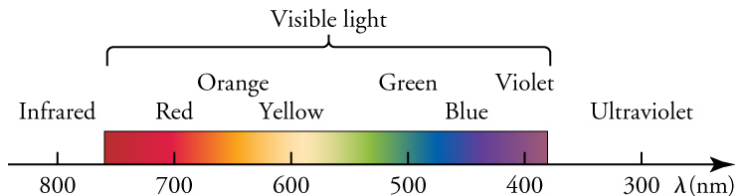
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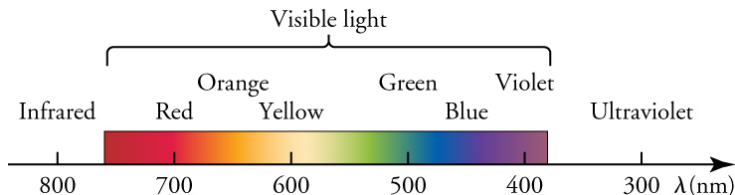
Misconception Alert

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



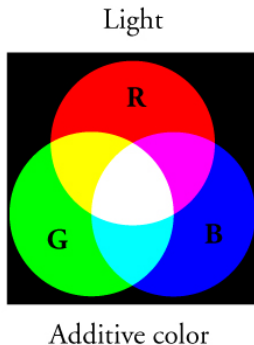
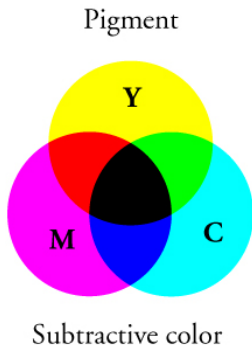
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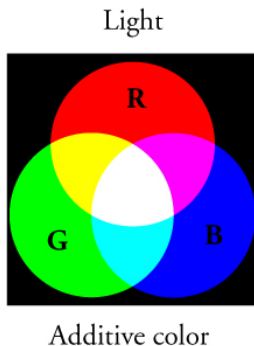
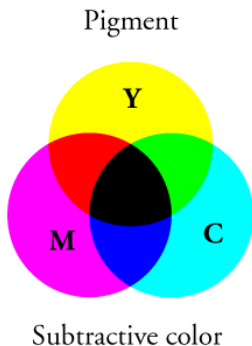
Wavelengths: 400-700 nm

Frequencies: 4.0×10^{14} to 7.9×10^{14} Hz

15.1 The Color Wheels



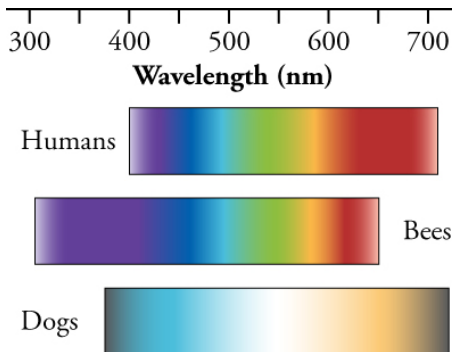
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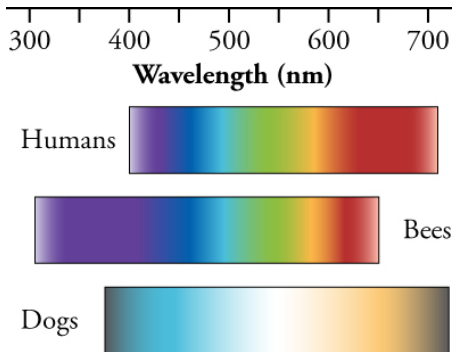
Subtractive (pigments): Cyan, Magenta, Yellow primaries → Black

Additive (light): Red, Green, Blue primaries → White

15.1 Animal Color Perception

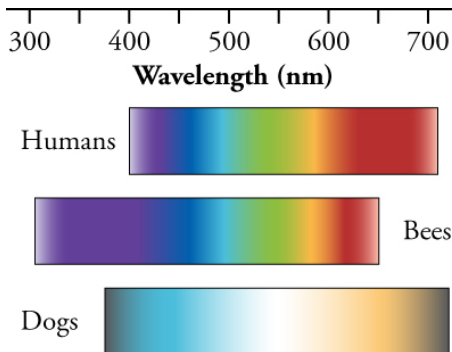


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Human vision: Three cones (red, green, blue)

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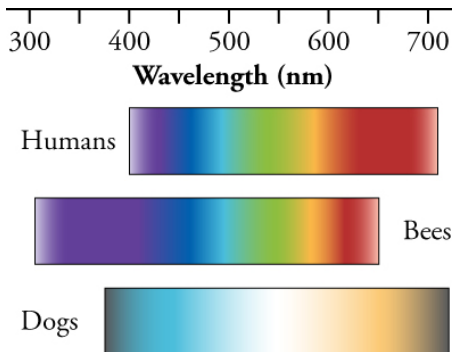


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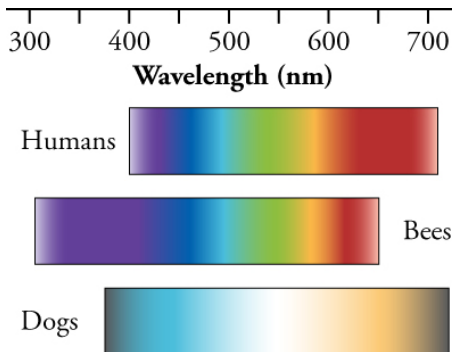


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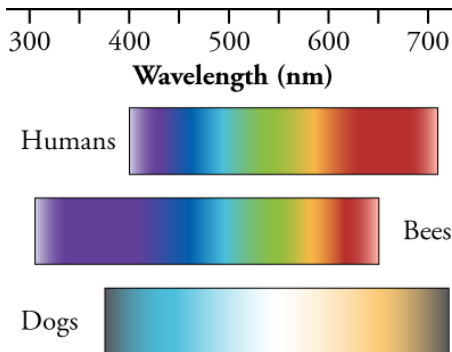


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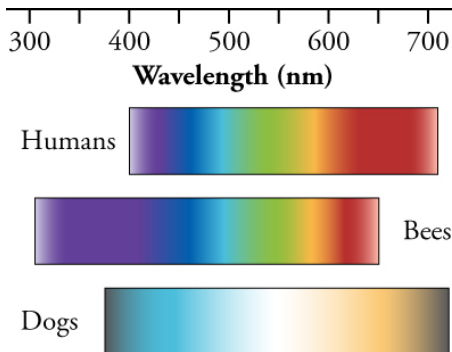


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15.1 Ultraviolet Radiation

Real-World: Sun and Sterilization

- Sunlight contains UV (causes sunburn)
- Kills bacteria (UV sterilization)
- Black lights, counterfeit detection

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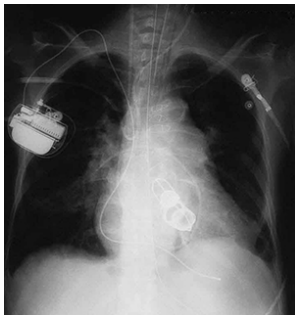
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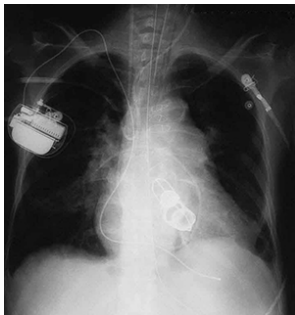
Health Hazard

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

Highest energy, most penetrating EM radiation

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Extremely dangerous - ionizing radiation damages DNA

15.1 Maxwell's Unification



James Clerk Maxwell (1831-1879)

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

Learning Objectives

By the end of this section, you will be able to:

- **15.2:** Describe the behavior of electromagnetic radiation

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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

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

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In other materials (slower):

- Air: 99.97% of c
- Water: 75% of c
- Diamond: 41% of c

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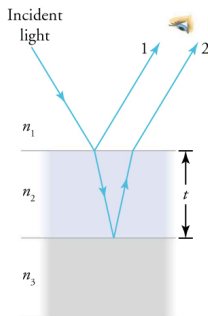
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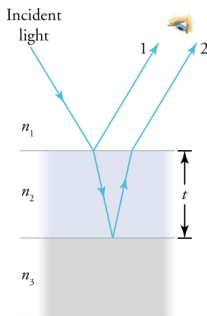
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When light changes speed at boundary, it changes direction. This is called **refraction**.

15.2 Thin-Film Interference



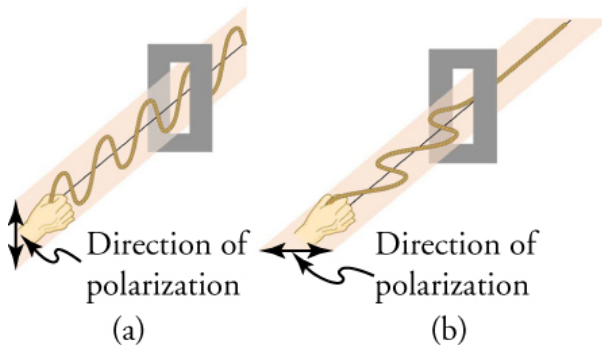
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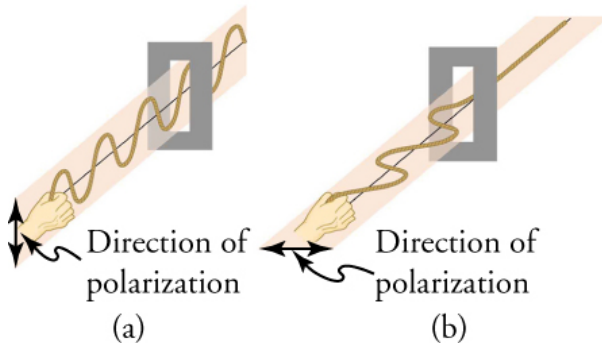
Rainbow colors from: Soap bubbles, oil slicks, CDs

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



(a)

(b)

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 6.00×10^{-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 λ ?
- 2 How did you rearrange to solve for f ?
- 3 Did you divide or multiply?

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Name wheel: One pair share your approach (not your answer).

Reveal: Frequency of Yellow Light

Self-correct in a different color:

Equation: $c = f\lambda$

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Rearrange: $f = \frac{c}{\lambda}$

Reveal: Frequency of Yellow Light

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Substitute: $f = \frac{3.00 \times 10^8 \text{ m/s}}{6.00 \times 10^{-7} \text{ m}}$

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$$f = 5.00 \times 10^{14} \text{ Hz}$$

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

15.2 Illuminance: Light Intensity

Luminous flux P : Rate light radiates from source (lumens, lm)

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Illuminance: Lumens per square meter (lux, lx)

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.

Compare: Inverse Square Law

Turn and talk (2 min):

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Reveal: Illuminance Calculation

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Reveal: Illuminance Calculation

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Substitute: $\text{Illuminance} = \frac{2000 \text{ lm}}{4(3.14)(2.00)^2 \text{ m}^2}$

Calculate: $\text{Illuminance} = \frac{2000}{50.24}$

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Calculate: $\text{Illuminance} = \frac{2000}{50.24}$

$\text{Illuminance} = 39.8 \text{ lx}$

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

What You Now Know

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- 6 Polarization = E field vibrates in one direction
- 7 Illuminance decreases with inverse square of distance

Key Equations

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

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

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

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

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

Complete the assigned problems
posted on the LMS