

PHYS11 CH:15 The Invisible Rainbow

From Radio Waves to Gamma Rays

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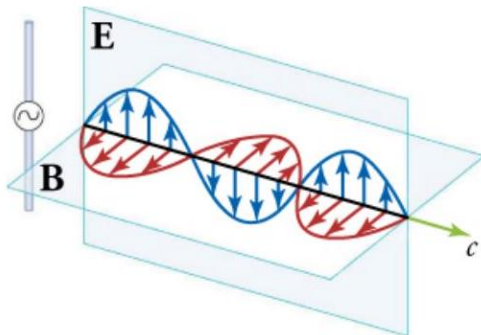
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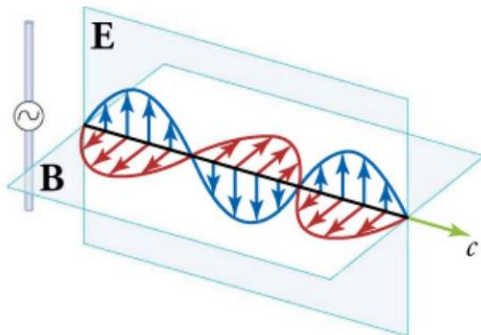
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- Electric current creates electric field E
- Electric current creates magnetic field B
- E and B perpendicular to each other
- When charge oscillates, wave propagates

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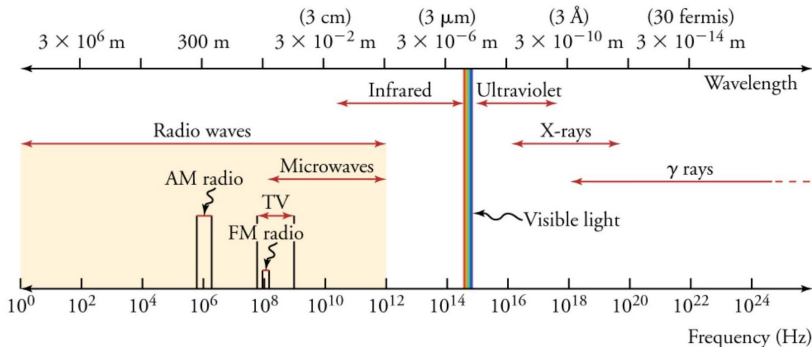
- **Wavelength** λ : Distance between two crests (meters)
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- **Amplitude**: Height of crest above null point

Universal Law: The Speed of Light

$$c = f\lambda$$

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

15.1 The Full Spectrum



15.1 Decoding the Spectrum

Low Frequency (IR):

- Radio waves
- Microwaves
- Infrared (heat)

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- 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

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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

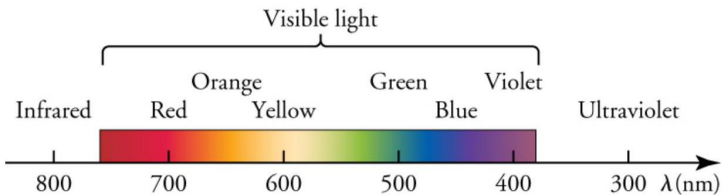
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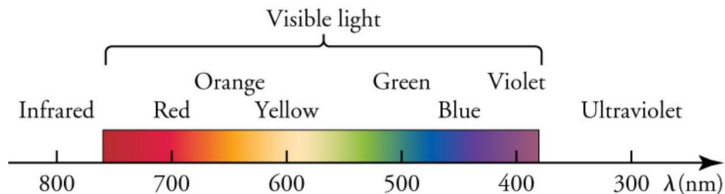
Misconception Alert

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



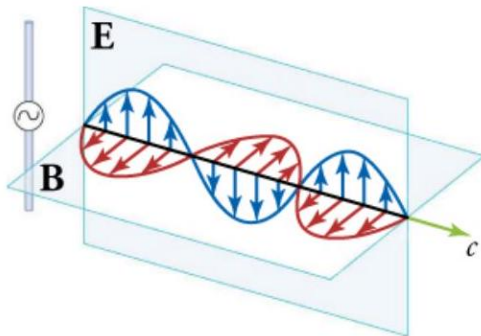
15.1 Visible Light



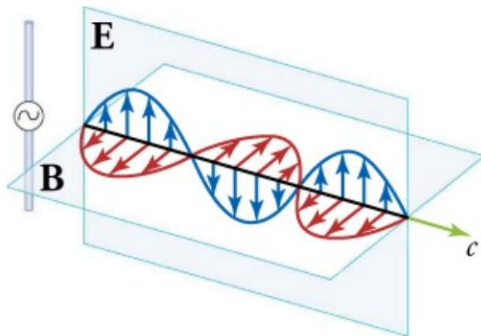
Wavelengths: 400-700 nm

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

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

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- Bees: See UV; rattlesnakes: See IR

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The Illusion

Bulls are colorblind to red. The matador's cape color doesn't matter - it's the motion!

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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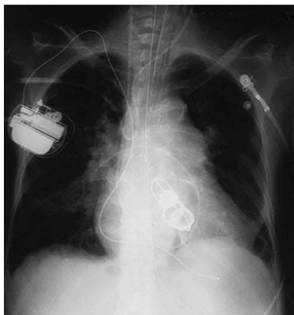
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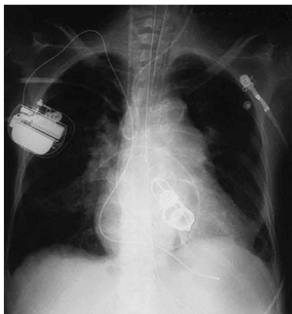
Health Hazard

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



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

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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:** Describe the behavior of electromagnetic radiation
- **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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In vacuum: $c = 3.00 \times 10^8 \text{ m/s}$

In other materials (slower):

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

15.2 Thin-Film Interference



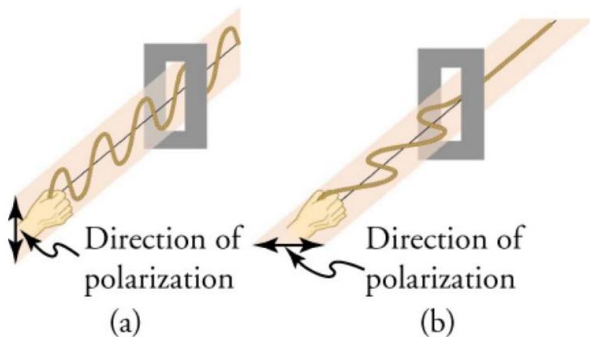
15.2 Thin-Film Interference



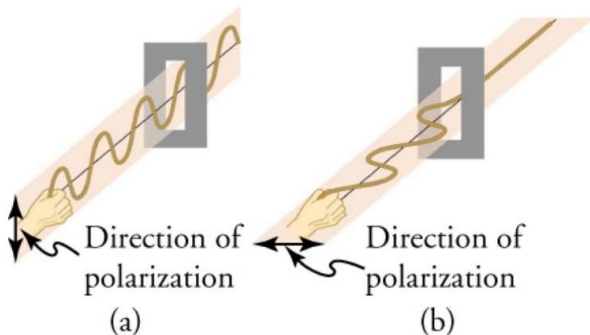
Rainbow colors from: Soap bubbles, oil slicks, CDs

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

15.2 Polarization



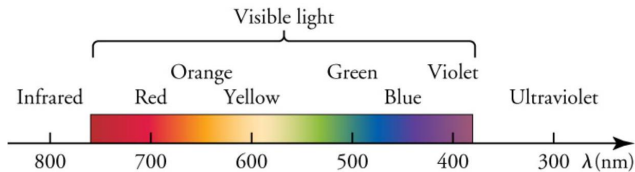
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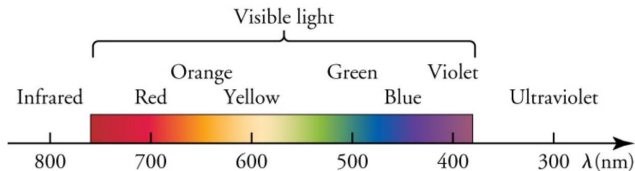
Polarized light: Electric field vibrates in only one direction

Polarizing filter: Transmits one direction, blocks others

15.2 Polarized Sunglasses



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

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

15.2 Illuminance: Light Intensity

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

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

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

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

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

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

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

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

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

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

Complete the assigned problems
posted on the LMS