Physics

Lesson Plan #10
Light
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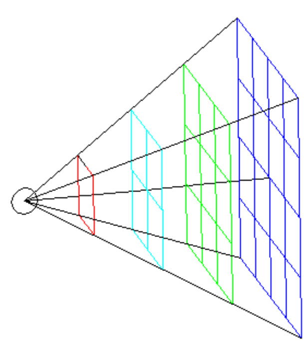
Light Fundamentals

Objectives: Recognize that light is the visible portion of an entire range of electromagnetic frequencies; Describe the ray model of light; Solve problems involving the speed of light; Define luminous, intensity, luminous flux, and illuminance

- The Facts of Light
  - Early scientist thought that light was made of particles emitted by a light source – but not all properties of light could be explained by particles. Today light is explained in terms of duality – particles and waves.
  - Light is a range of electromagnetic frequencies, that happens to stimulate the retina of the eye.
    - From about violet at 400 nm (4.00 x 10^{-7}m) to deep red at 700 nm (7.00 x 10^{-7}m)
    - ROYGBIV – red, orange, yellow, green, blue, indigo, violet
    - Light travels in a straight line from its source – this lead to the development of the **ray model**.
    - Ray models use a straight line to represent the path of a narrow beam of light. This is used in ray diagrams with lenses and mirrors, reflected and refracted light.
  - The speed of light
    - Galileo was the first to hypothesize that light had a finite speed – unfortunately there was no way for him to proved it in his life
    - A Danish astronomer Ole Roemer (1644-1710) was the first person to determine the speed of light.
      - Roemer made 70 precise measurements of the 42.5 hour orbital path of Jupiter's moon Io – measuring Io just as it entered Jupiter's shadow. He found that as the Earth was approaching Jupiter that the Io's orbital time would shorten by up to 14 seconds, and when the Earth was receding from Jupiter that Io's period would decrease by up to 14 seconds.
      - His deduction was that as the Earth was approaching Jupiter that the decrease in distance decreased the time that it took light to reach the Earth, and when the Earth was receding, it increased the time for the light to reach the Earth from Io.
      - In 1676 Roemer calculated that it took light 22 minutes to cross the diameter of the Earth's orbit. This gave light a speed of 220 million meters/second.

- American Albert Michelson (1852-1931) performed the first experiments on Earth to truly determine the speed of light – he found it to be $2.997996 \pm 0.00004 \times 10^8$ m/s
  - For this work he was the first American to receive the Nobel Prize in science.
- With the advent of lasers and technologies, we find that the speed of light, c, is defined as $c = \lambda f$, where λ is the wavelength, and f is the frequency of the light.
- In 1983, the International Committed on Weights and Measurements decided to make the speed of light a defined quantity.
- In a vacuum, c = 299,792,458 m/s, or for most purposes $c = 3.00 \times 10^8$ m/s

o Sources of Light
- What is difference between sunlight and moonlight?
  - The sun is a **luminous body** that emits light, whereas the moon is an **illuminated body** that reflects light.
  - Other sources that are luminous bodies include florescent lights, incandescent lights and LEDs
  - Other illuminated bodies would be bicycle reflectors, highway signs and median reflectors

o Luminous Flux
- The rate at which visible light is emitted from a source is called the **luminous flux** and is abbreviated as P.
- The unit of luminous flux is the **lumen**, lm.
- A 100w light bulb emits ~1750 lm, in all directions, but we often wish to know the amount of light fallen on an object or surface. The illumination of a surface or object is called **illuminance**, E. Illuminance is measured in lumens per square meter, lm/m^2 or the **lux.**
- Consider the 100w light bulb in the center of a sphere – the area of a sphere is $4\pi r^2$, so if we want to know the illuminance at a radius of 1m, we can set up an equation $E = \frac{lumen}{area} = \frac{1750\ lm}{4\pi r^2} = 140\ lux$
- So what happens when the radius of the sphere increases? When you double the radius, the area increases by 4, if you triple the distance the area increases by 9, and if you quadruple the distance.
  - This is known as the **inverse square law** = $\frac{1}{r^2}$
  - 

- Luminous Intensity
  - Some light sources are measured in **candela** (cd, or candle power)
  - This is not a measure of luminous flux, but rather of luminous intensity
  - Defined as the luminous flux that falls on 1 m2 of a sphere at 1 meter, or the luminous flux/4π – thus a bulb with 1750 lm flux has an intensity of 1750 lm/4π = 139cd.
  - A flashlight bulb labeled as 1.5 cd emits a luminous flux of $1\ 1.5cd\ x\ 4\pi = 19\ lm$
- How to illuminate a surface
  - There are two ways to make a surface brighter – use a brighter bulb, or move the existing bulb closer.
  - There is actually an equation that can be used determine how much light will fall on a surface given a distance and luminous flux $E = \frac{P}{4\pi d^2}$, where E is the illuminance, P is the luminous flux, and d is the distance from the light to the surface. This is accurate only for the light rays which are perpendicular to the surface.

Sample Problem

What is the illumination on your desktop if it is lighted by a 1750 lm lamp that is 2.50m above your desk?

Using $E = \frac{P}{4\pi d^2} = \frac{1750\ lm}{4\pi(2.5)^2} = \frac{1750\ lm}{78.5\ m^2} = 22.3\ lm/m^2 = 22.3\ lx$

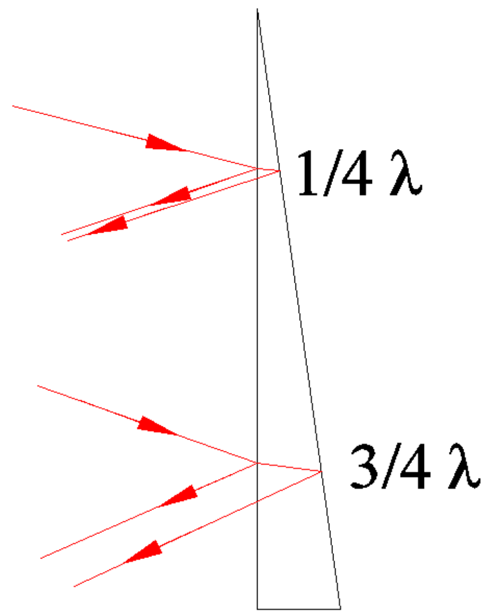
Light and Matter

Objectives: Explain the formation of color by light and by pigments or dyes; Explain the cause and give examples of interference in thin films; Describe methods of producing polarized light.

- Light and Transparency
  - Objects that allow light to pass through without distorting the image are called **transparent**
  - Objects that allow light to pass through, but do not allow objects to be seen are called **translucent**
  - Objects that do not allow light to pass through are called **opaque**
- Color
  - Man first observed the splitting on light into colors by seeing a rainbow.
    - Newton saw the same when a narrow beam of sun light passed through a prism – he thought it was due to a unevenness in the glass, so he put two prisms back to back expecting the colors to spread out even more – he got white light!
      - From this he concluded that white light is made up of colors
  - Color by Addition
    - When you mix colors together, you get different colors – but is there a pattern?
      - Equal amounts of red, blue and green light produce white light.
      - Equal amounts of red and blue light make magenta

        - Equal amounts of blue and green light make cyan
        - Equal amounts of red and green light make yellow
        - Red, green and blue are called **Primary Colors**.
        - Magenta, Cyan and yellow are called **Secondary Colors**
        - Then there are **Complementary Colors**
            - Yellow and blue are complementary colors since yellow is made of red and green primary colors
            - Cyan and red are complementary colors since cyan is made of green and blue primary colors
            - Magenta and green are complementary colors since magenta is made of red and blue primary colors
- Color by Subtraction
    - A **dye** is a molecule that absorbs certain wavelengths of light and reflects others.
        - A tomato appears red to us since it reflects red and absorbs all other wavelengths.
        - If you were to shine a blue light on a red tomato it would appear black, since there is no red to reflect and it absorbs all other colors.
    - Similar to a dye, a **pigment** is colored material that absorbs certain colors and transmits of reflects other colors.
        - A pigment can be larger than a molecule
        - Common pigments include titanium(IV) oxide (white), chromium(III) oxide (green) and cadmium sulfide (yellow).
    - The absorption of light creates colors by a subtractive process
    - When a pigment absorbs light from only one primary color, it is called a **primary pigment**
        - Yellow absorbs blue and reflects red and green
        - Magenta absorbs green and reflects blue and red
        - Cyan absorbs red and reflects green and blue
    - When a pigment absorbs two primary colors and reflects one, it is called a **secondary pigment**
        - Red absorbs green and blue
        - Green absorbs red and blue
        - Blue absorbs red and green
    - Note that the primary pigment colors are the secondary light colors and the secondary pigment colors are the primary light colors.
    - Primary pigment yellow absorbs blue light – if you mix primary pigment yellow with secondary pigment blue, you get total absorption – black. These are subtractive complementary colors
- Formation of Colors in Thin Films
    - Have you ever noticed colors in a soap bubble or in a thin film of oil (or gas) on water? The colors are not due to separation of the colors by a prism or by absorption due to dyes or pigments.
    - This can be explained in terms of interference of light waves – both constructive and destructive interference, or **thin-film interference**

- When a soap bubble is held vertically, the top is thinner than the bottom – this leads to a wedge shape.
- As a light ray comes in, part of it is reflected by the front of the soap bubble, but some of the light is reflected by the back of the soap bubble.
- Depending on the thickness of the bubble at that point, the light ray which reflects off the back may be up to 180º out of phase with the ray reflected from the front surface .
    - When they are 180º out of phase, then they cancel each other out and a dark area appears.
    - If they are in phase, then a bright area appears.
    - The color is dependent on the wavelength and the thickness of the bubble



- If the thickness is ¼ λ then the wave which is reflected off the back of the bubble would come back ½ λ, or 180º out of phase, canceling out the front surface wave
    - Except that when a ray of light is reflected off a more dense medium, it is inverted.
    - Therefore at a thickness of ¼ λ the back reflected ray travels ½ λ and is exactly in phase with the front reflected ray, therefore intensifying it
    - At any thickness other than ¼ λ, the reinforcement is less, varying from partial to complete destructive interference.
    - Since each color has a different wavelength, then you end up with a band of color, starting with the shortest wavelength (violet) and moving through to the longer wavelengths (red).
    - When the thickness reaches 3 λ/4 then the round trip distance is 3 λ/2 and the constructive interference happens again. This is true for any odd multiple of quarter wavelengths - 3 λ/4, 5 λ/4, 7 λ/4, 9 λ/4, 11 λ/4, . . .
    - There is no color at the top of the soap bubble, because the film is too thin to perform interference.

- Polarization of Light
  - What is the big deal about Polaroid sunglasses?
  - Have you looked at light reflected off an asphalt road while wearing Polaroid sunglasses? If you rotate your head the road will go from dark to light and back to dark. This is because the road is reflecting light and some of that light has become polarized.
  - Consider a wave of light – looking like a sine wave. So far we have only thought of it in a two dimensional surface. But in reality, a wave can rotate around a central axis. Selecting a particular angle is to choose an angle of polarization.
  - Polarized material has long molecules that allow light (electromagnetic radiation) to pass through only if the waves are at the same angle around the central axis as the molecules.
  - This can be visualized by a rope with a wave in it. If a slot is parallel to the wave in the rope, the wave will pass through – if it is at right angles, then the wave is blocked. As you turn the slot from being parallel to right angles, an ever-deceasing amount of the wave is allowed through. This is the same for light.
  - Light can be polarized by two methods
    - Pass un-polarized light through a polarizing filter – only the light whose waves are parallel to the long molecules will pass through
    - Light can be polarized by reflections. If light off a road is polarized, then Polaroid sunglasses will reduce the amount of light reflected, thus reducing the glare. This principle also works on light reflected off water – thus allowing you to see past the surface of the water.
- The sky is polarized!
  - Take a pair of Polaroid sunglasses and look straight up on a sunny, cloudless day.
  - As you spin around, you will find a band of the sky that will change from light blue to dark blue – the sky is polarized.