

Fundamentals in Biophotonics

Light, photon-wave particle duality

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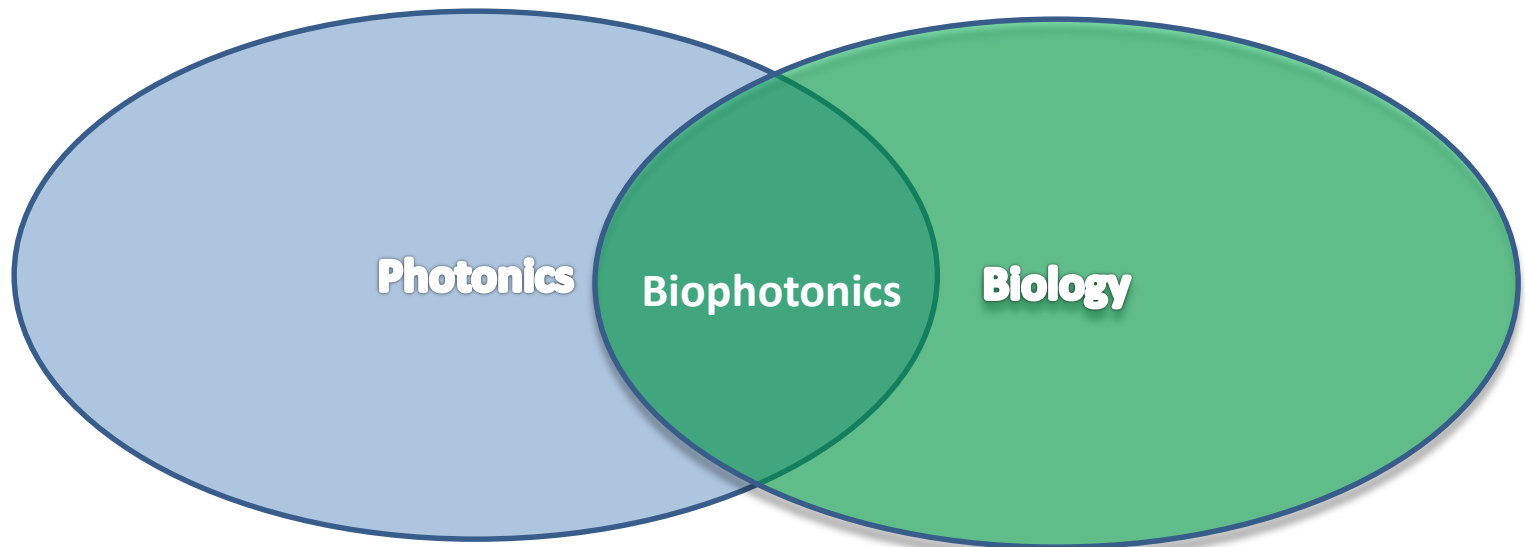


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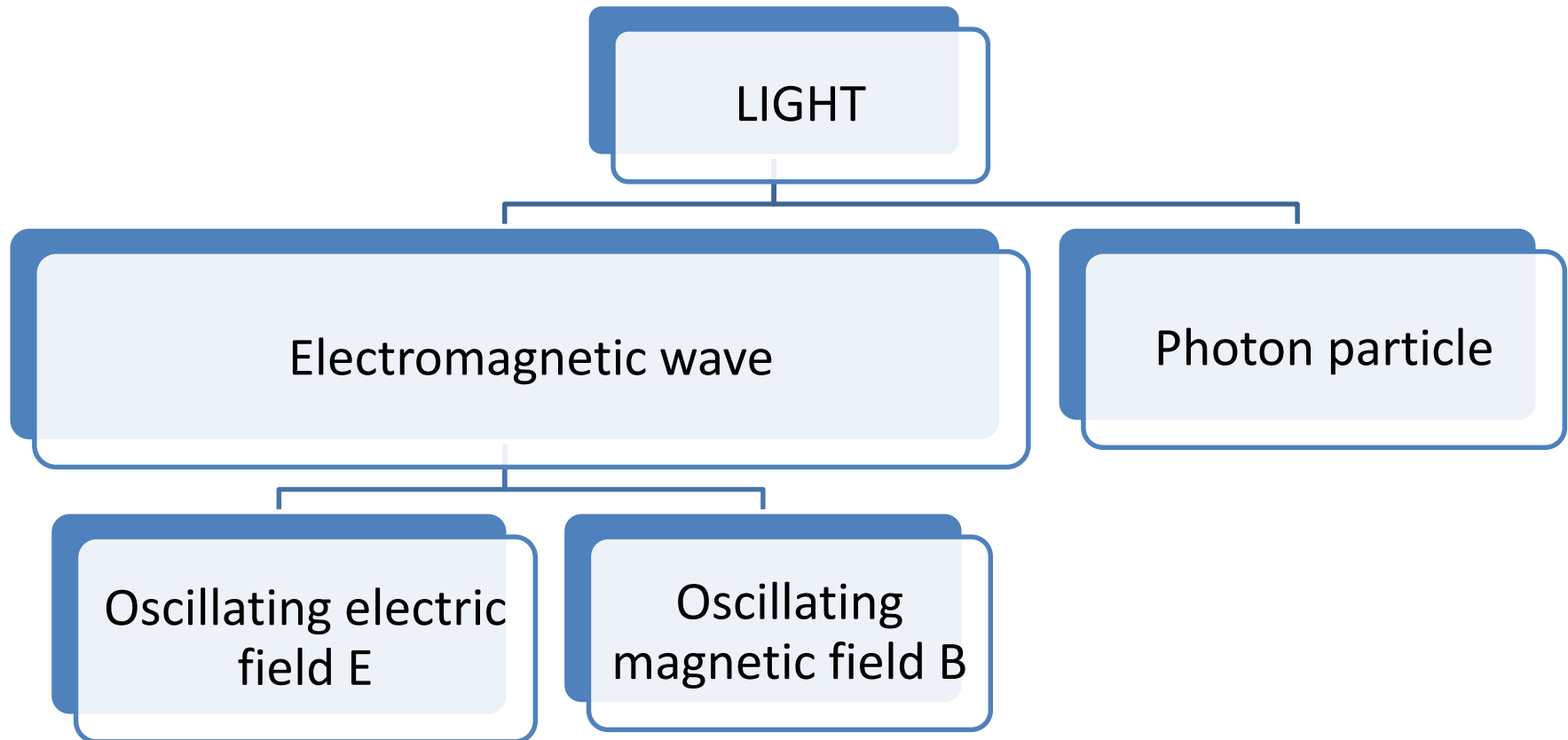
Biophotonics

- Biophotonics, the ‘marriage’ between **photonics** and **biology**, is an emerging interdisciplinary frontier that deals with **interactions between light and biological matter**.
- Through the integration of four principle technologies, ***lasers, photonics, nanotechnology, and biotechnology, biophotonics*** offers immense hope for the early detection and treatment of diseases and for new modalities of light guided and light activated therapies.



Interactions between light and biological matter

- An understanding of properties of light and matter forms very fundamental; basis to create an insight into the nature of interactions between light and biological systems
- NATURE OF LIGHT



What is light?



Light



Waves?

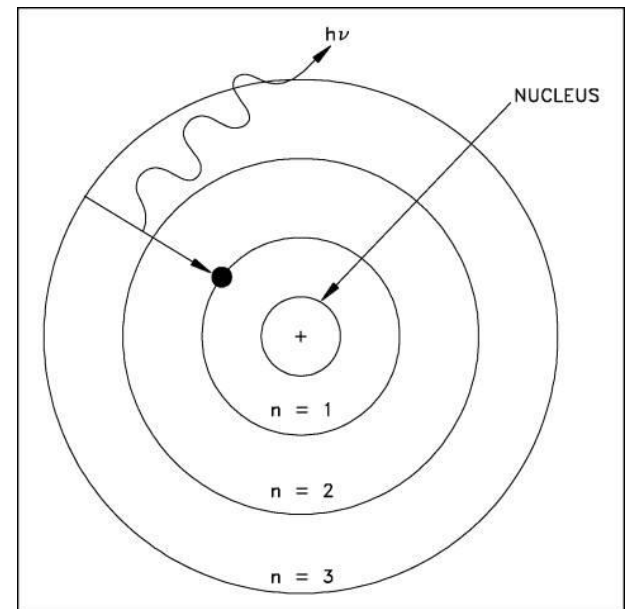


Particles?

What is light?

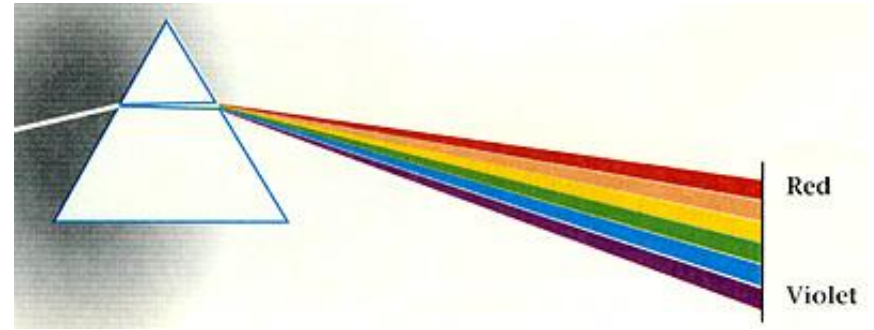
- Light is an **electromagnetic field** consisting of oscillating electric and magnetic disturbances that can propagate **as a wave** through the vacuum as well as through the medium
- However, modern theory, of quantum mechanics also imparts a **particle like description** of light.

- What is a photon and how light is generated ?

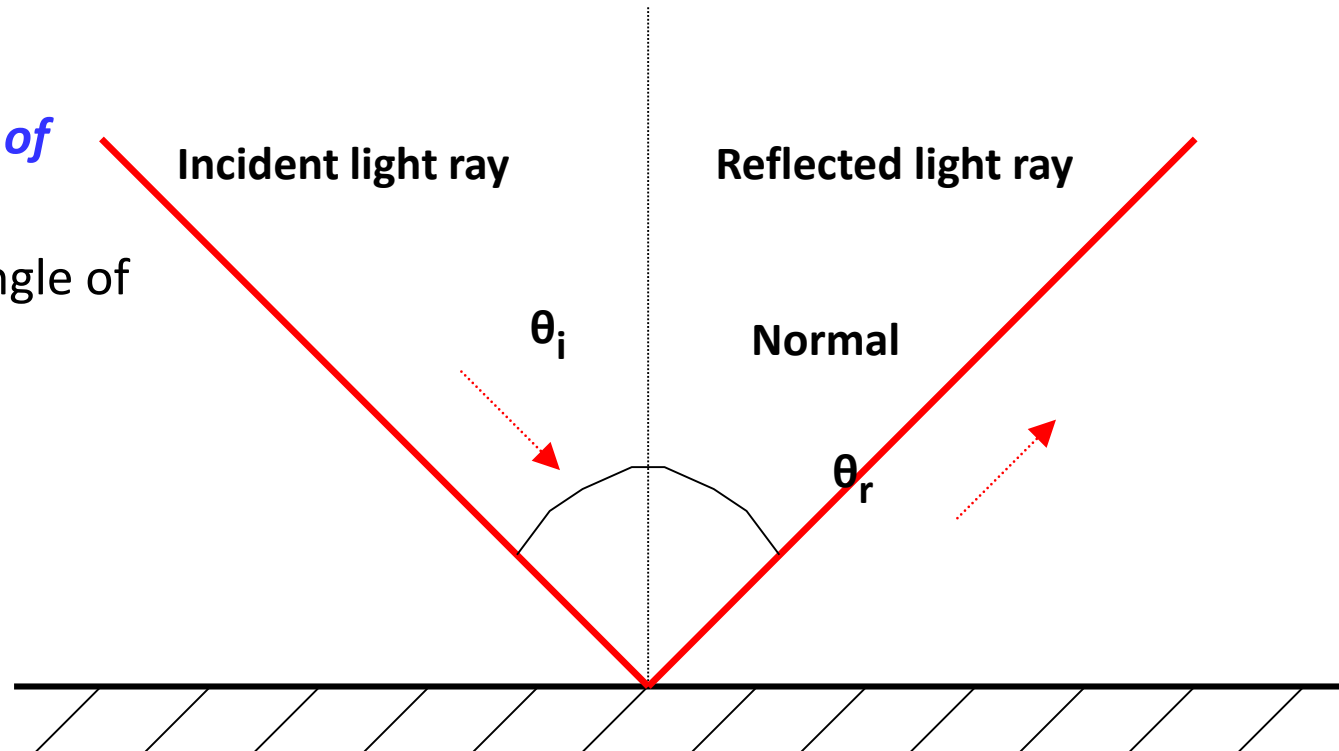


What is light?

- 17th century known facts about light
- Light has different colours.
- Light can travel through a vacuum.
- Light can be reflected and refracted, these processes are described by the *Laws of Reflection* and *Laws of Refraction*.



According to the **Laws of Reflection**,
angle of incidence = angle of reflection ($\theta_i = \theta_r$)

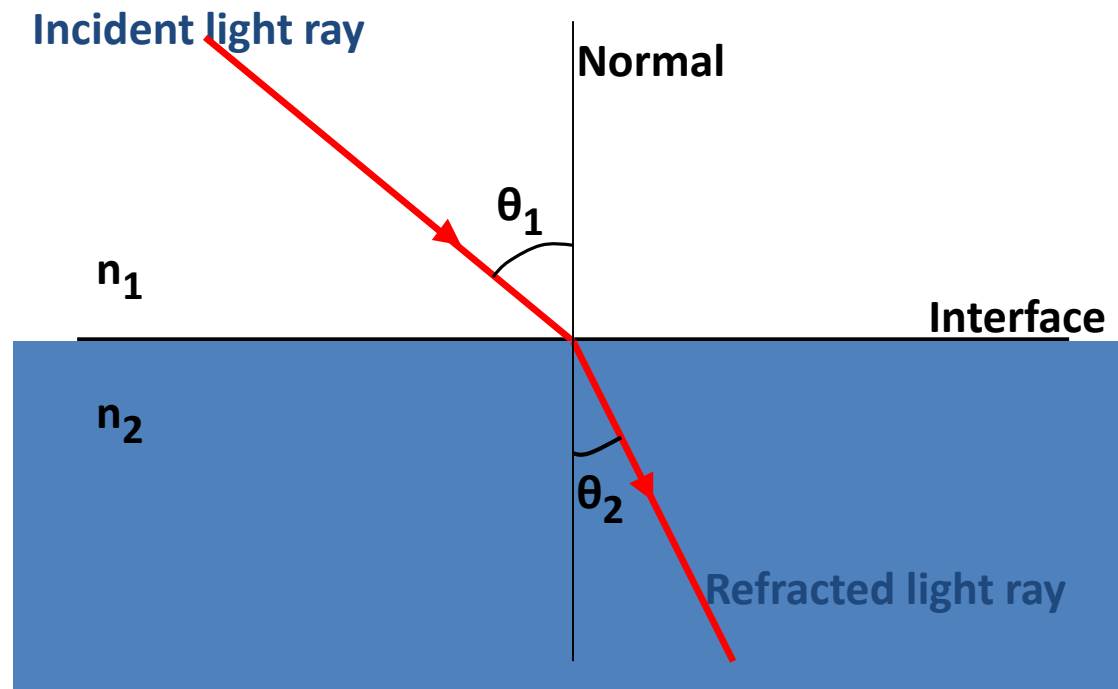


What is light?

- Willebrord **Snell** discovered in 1621 that when a wave travels from a medium of refractive index, n_1 , to one of different refractive index, n_2 ,

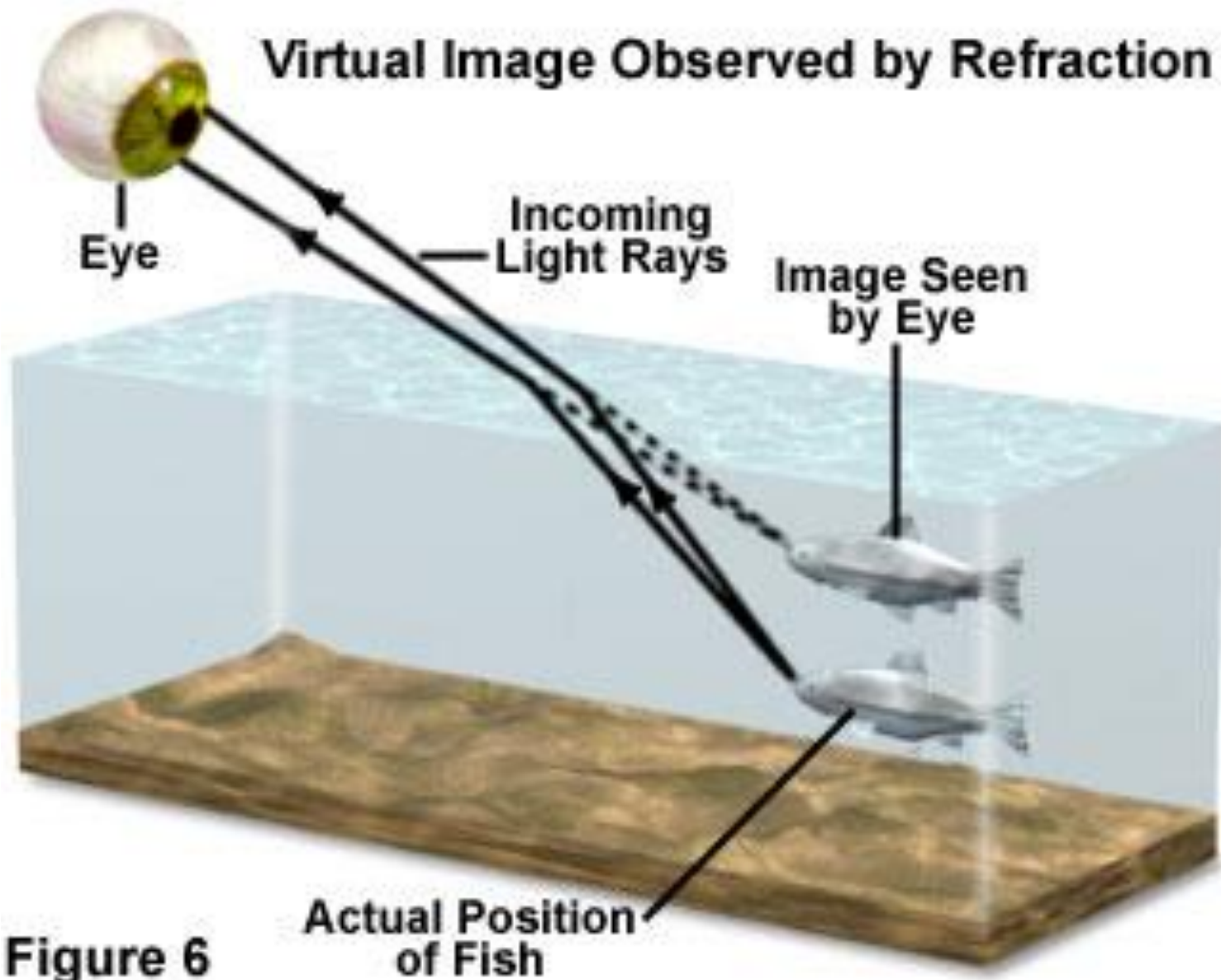
$$n_1 \sin(\theta_1) = n_2 \sin(\theta_2)$$

This relationship is called **Snell's Law**



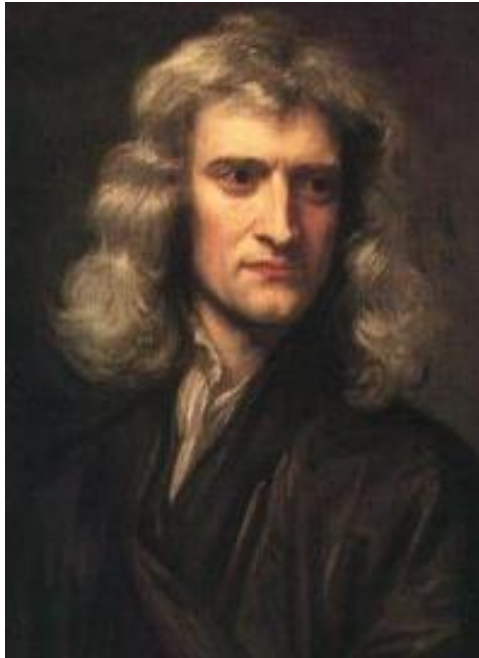
Light bends towards the normal when it travels from an optically less dense medium to an optically more dense medium.

Snell's Law



What is light?

- In the 17th century, two scientists had different views about the nature of light ...



Isaac Newton
1643 - 1727

**Light is
particles**

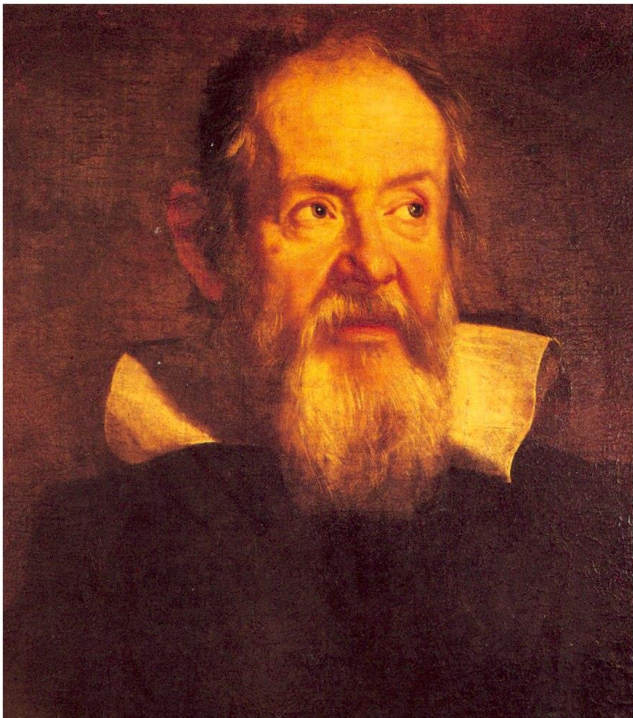
**No! Light is
waves**



Christian Huygens
1629 - 1695

What is light?-Wave

- *Light is an electromagnetic field consisting of oscillating electric and magnetic disturbances that can propagate as a wave through the vacuum as well as through the medium.*
- How **fast** does light travel? How can this speed be measured?
- Every major scientist from Aristotle to Galileo to Newton to Michelson has pondered on the speed of light.



1564–1642

Galileo tried **unsuccessfully** to determine the speed of light using an assistant with a lantern on a distant hilltop

Why?

“I have not been able to ascertain with certainty whether the appearance of the opposite light was instantaneous or not; but if not instantaneous it is extraordinarily rapid – I should call it momentary.”

How fast does light travel? How can this speed be measured?

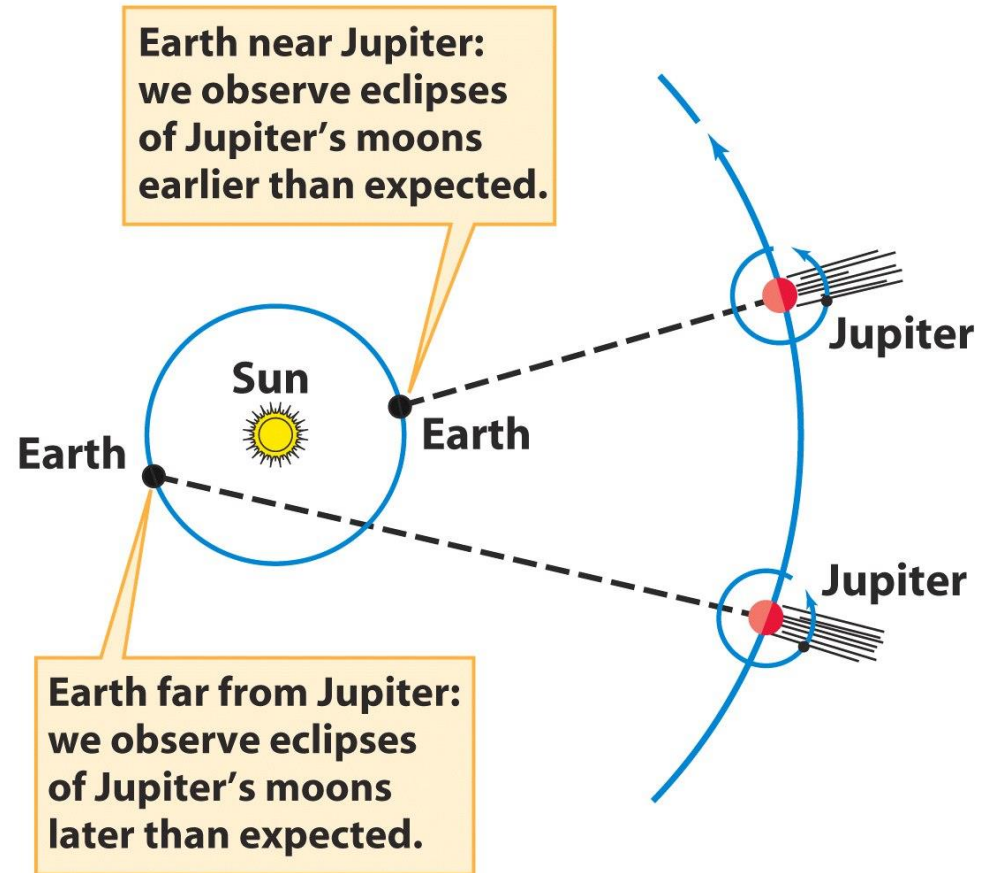
- Light travels through empty space at a speed of 300,000 km/s
- $299\,792\,456.2 \pm 1.1$ m/s

In 1676, Danish astronomer Olaus Rømer discovered that the exact time of eclipses of Jupiter's moons depended on the distance of Jupiter to Earth

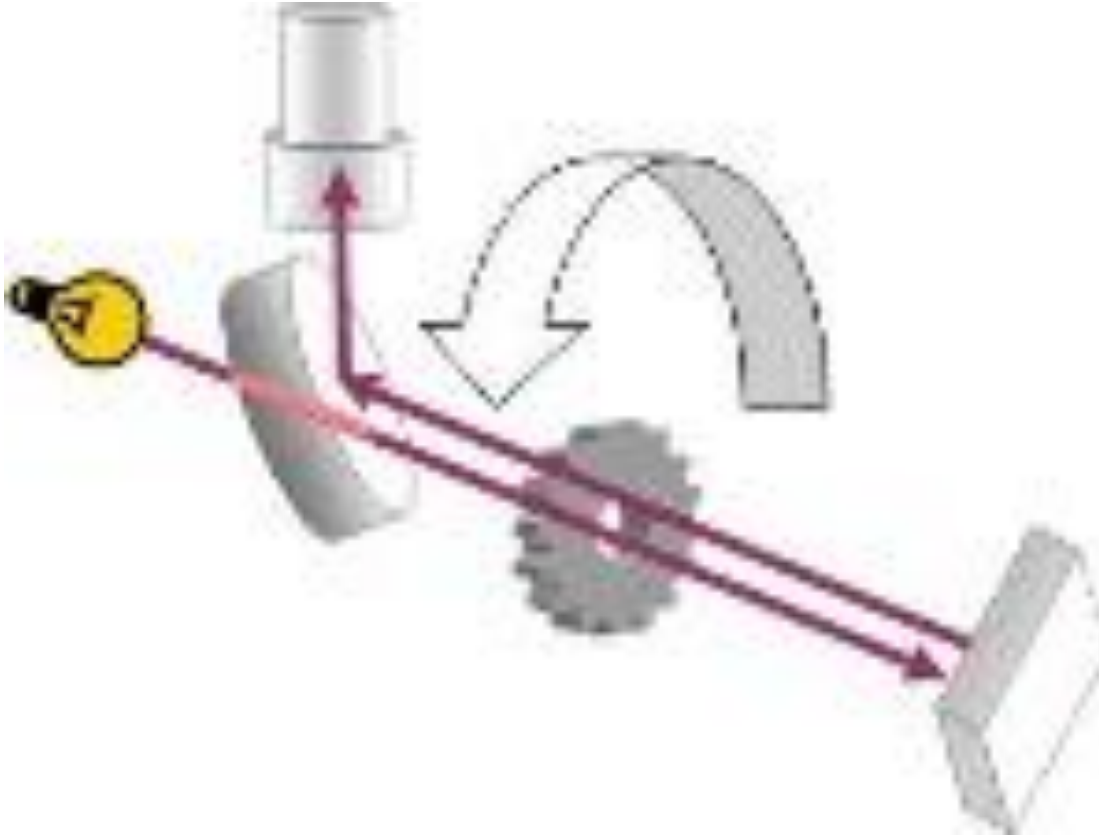
This happens because it takes varying times for light to travel the varying distance between Earth and Jupiter

Using $d=rt$ with a known distance and a measured time gave the speed (rate) of the light

2.20×10^8 m/s which gives a percent error of about 26% from the currently accepted value.



How fast does light travel? How can this speed be measured?



In 1850 Fizeau and Foucault also experimented with light by bouncing it off a rotating mirror and measuring time

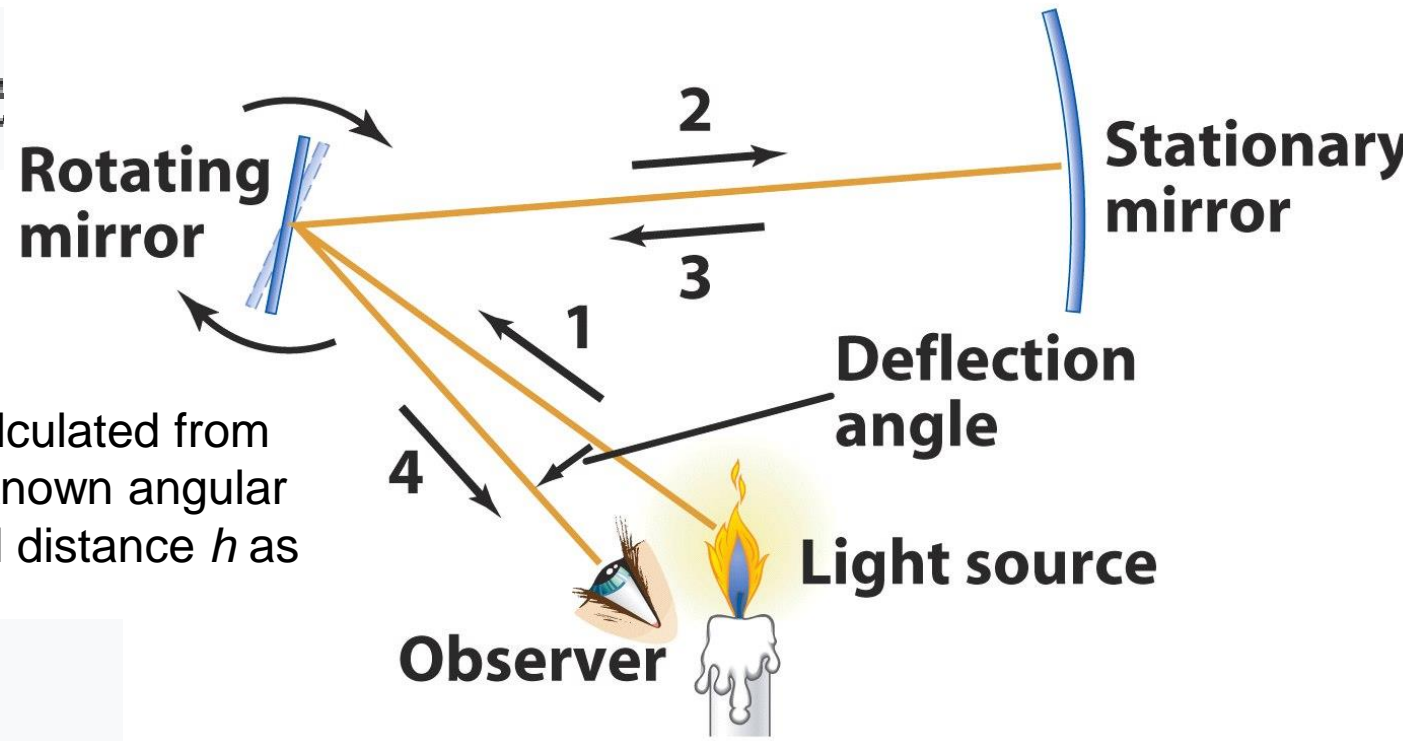
Using simple math he obtained a value of $3.15 \times 10^8 \text{m/s}$; roughly 5% too high.

How fast does light travel? How can this speed be measured?

Leon Foucault

If the distance between mirrors is h , the time between the first and second reflections on the rotating mirror is $2h/c$ (c = speed of light). If the mirror rotates at a known constant angular rate ω , it changes angle during the light roundtrip by an amount θ given by

$$\theta = \frac{2h\omega}{c} = \omega t$$



The speed of light is calculated from the observed angle θ , known angular speed ω and measured distance h as

$$c = \frac{2\omega h}{\theta} .$$

History of measurements of c (in km/s)

1675	Rømer and Huygens , moons of Jupiter	220,000 ^{[85][106]}
1729	James Bradley , aberration of light	301,000 ^[91]
1849	Hippolyte Fizeau , toothed wheel	315,000 ^[91]
1862	Léon Foucault , rotating mirror	298,000±500 ^[91]
1907	Rosa and Dorsey, EM constants	299,710±30 ^{[96][97]}
1926	Albert Michelson , rotating mirror	299,796±4 ^[107]
1950	Essen and Gordon-Smith, cavity resonator	299,792.5±3.0 ^[99]
1958	K.D. Froome, radio interferometry	299,792.50±0.10 ^[103]
1972	Evenson <i>et al.</i> , laser interferometry	299,792.456.2±0.0011 ^[105]
1983	17th CGPM, definition of the metre	299,792.458 (exact) ^[81]

Now the speed of light is constant. It will never have to be measured again.

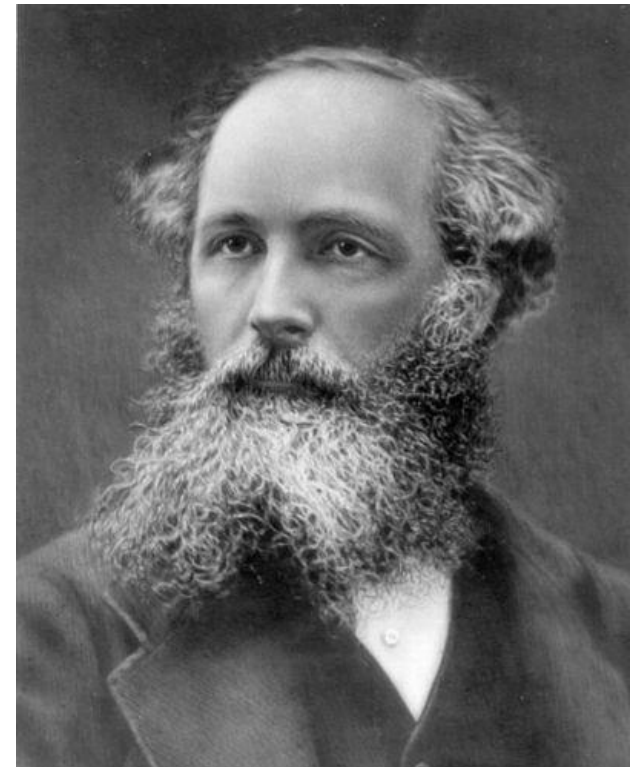
The Nature of Light

- In the 1860s, the Scottish mathematician and physicist James Clerk Maxwell succeeded in describing all the basic properties of electricity and magnetism in four equations
- This mathematical achievement demonstrated that electric and magnetic forces are really two aspects of the same phenomenon, which we now call **electromagnetism**

$$\begin{array}{ll}\vec{\nabla} \cdot \vec{E} = 0 & \vec{\nabla} \times \vec{E} = -\frac{\partial \vec{B}}{\partial t} \\ \vec{\nabla} \cdot \vec{B} = 0 & \vec{\nabla} \times \vec{B} = \mu\epsilon \frac{\partial \vec{E}}{\partial t}\end{array}$$

where \vec{E} is the electric field, \vec{B} is the magnetic field, ϵ is the **permittivity**, and μ is the **permeability** of the medium.

As written, they assume no charges (or free space).



The Nature of Light

- Maxwell was able to derive the speed of EM waves in vacuum. EM waves do not need a medium to travel through.

ϵ_0 = permittivity of free space (E field)

μ_0 = permeability of free space (M Field)

$$\begin{aligned} c &= \frac{1}{\sqrt{\epsilon_0 \mu_0}} \\ &= \frac{1}{\sqrt{(8.85 \times 10^{-12} \text{ C}^2/\text{Nm}^2)(4\pi \times 10^{-7} \text{ Tm/A})}} \\ &= 3.00 \times 10^8 \text{ m/s} \end{aligned}$$

When Hertz found this solution, he recognized that the value of this quantity was the speed already known for light, which strongly suggested that light was a wave, and part of the [electromagnetic spectrum](#), along with radio waves.

Wavelength and Frequency

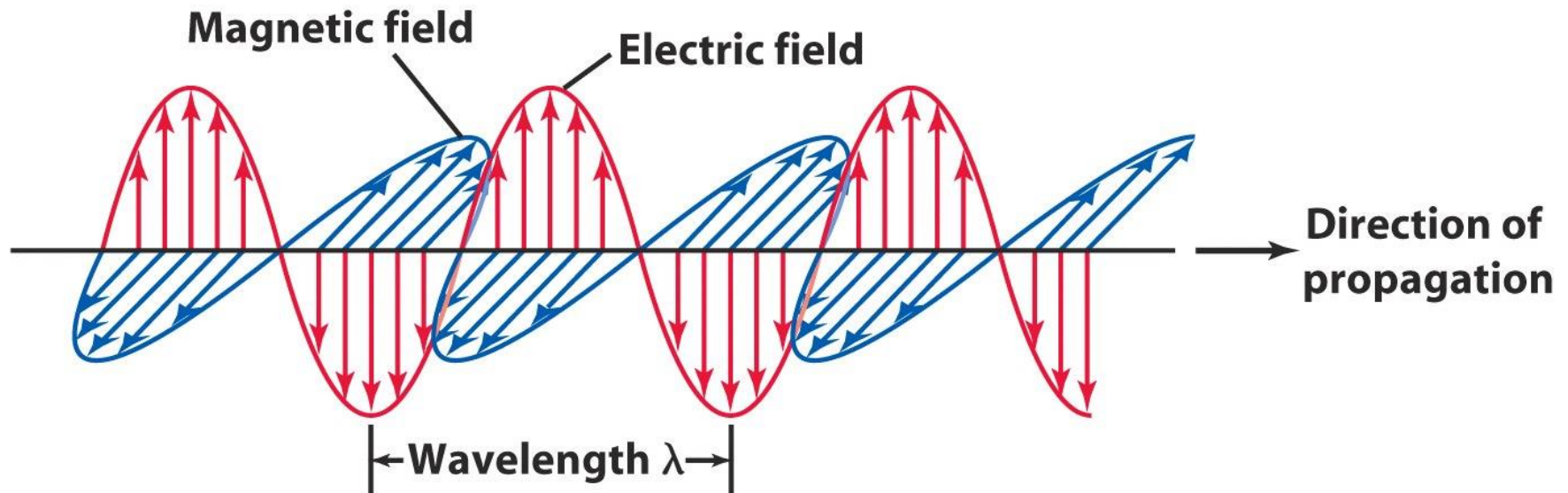
- Frequency and wavelength of an electromagnetic wave

$$\nu = \frac{c}{\lambda}$$

ν = frequency of an electromagnetic wave in [Hz]

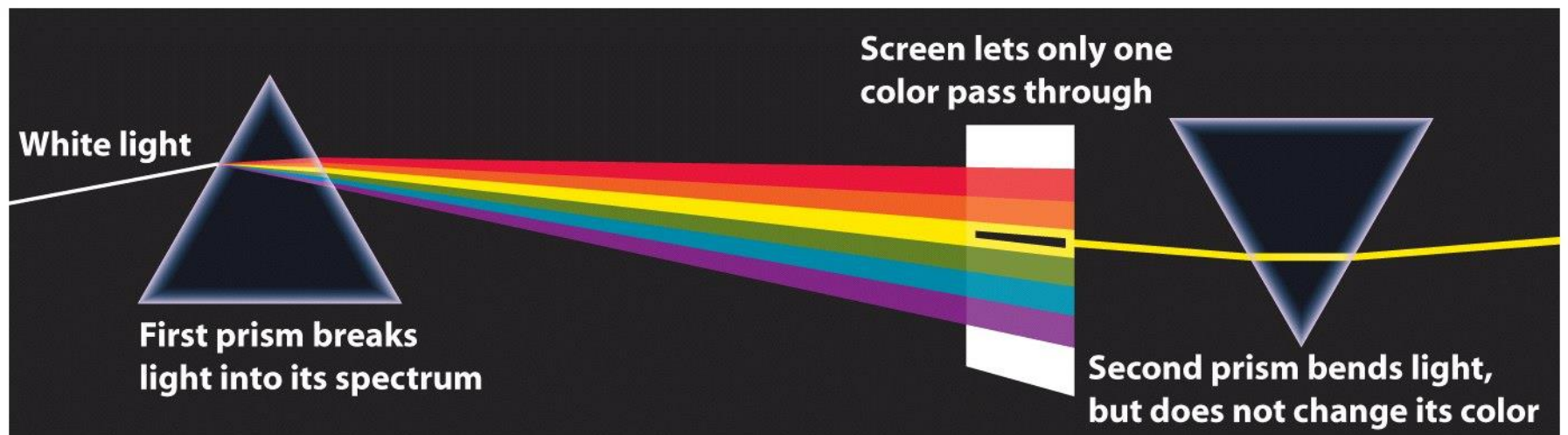
c = speed of light = 3×10^8 [m/s]

λ = wavelength of the wave in [m]

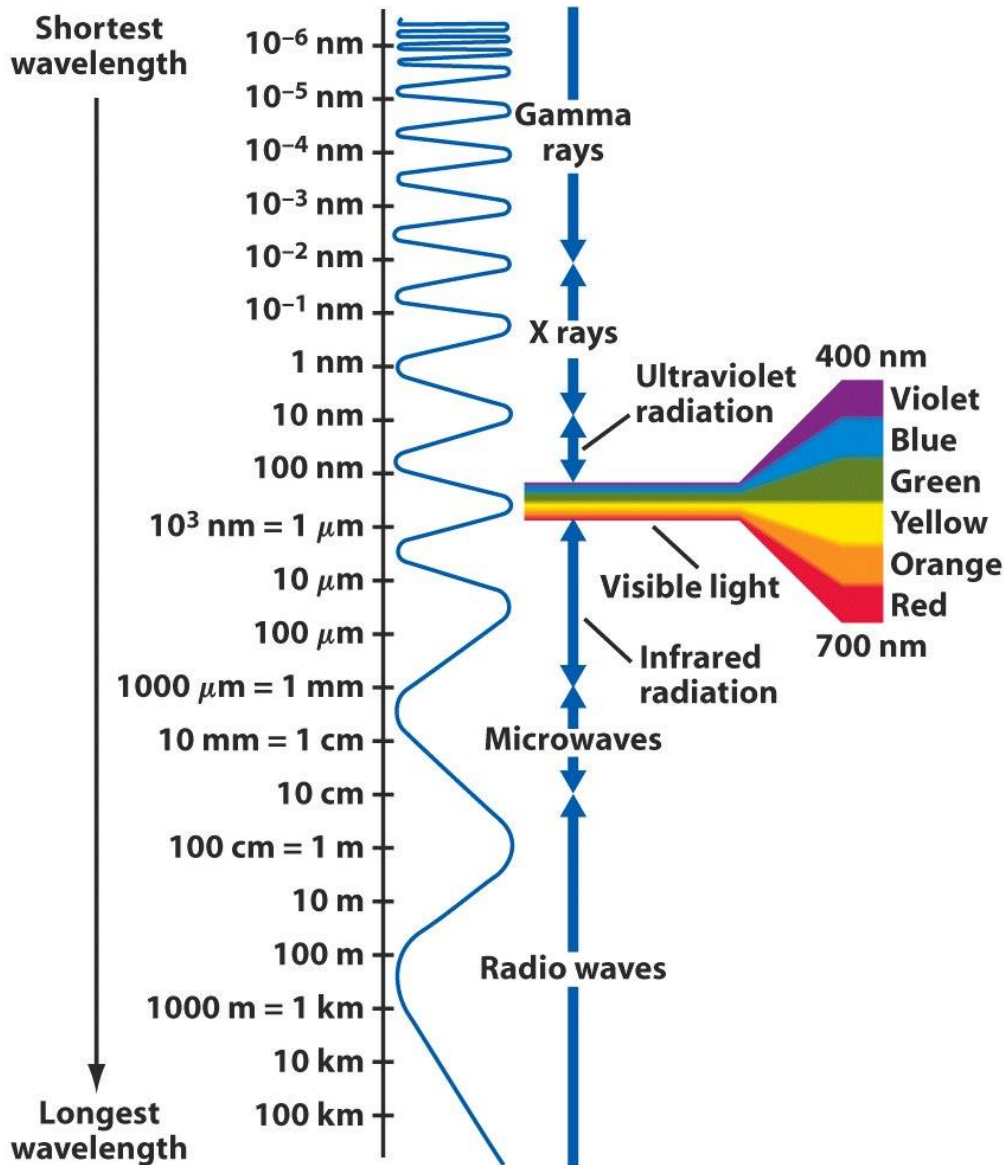


Light is electromagnetic radiation

- Light is electromagnetic radiation and it is characterized by its wavelength (λ)

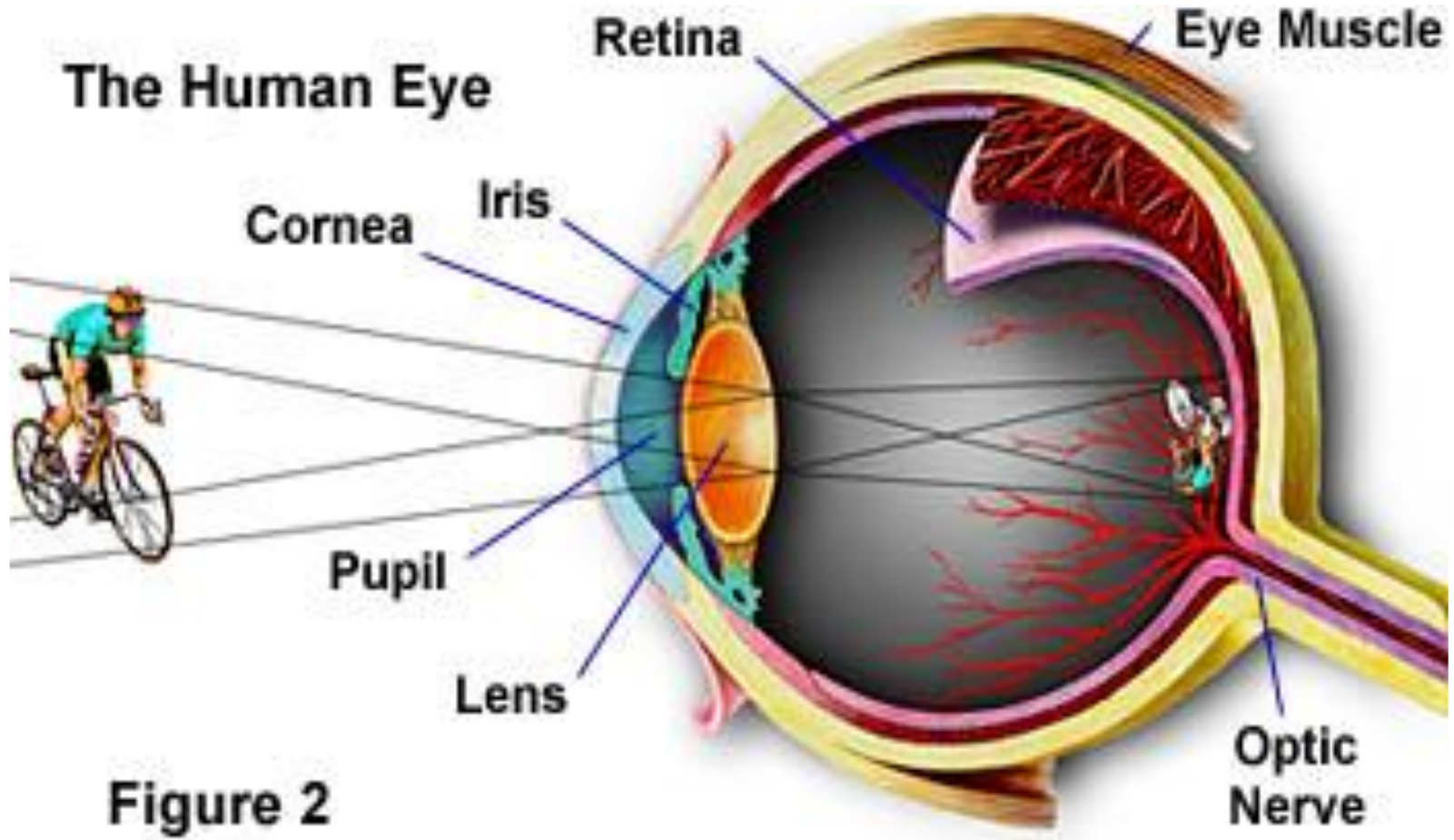


Electromagnetic spectrum



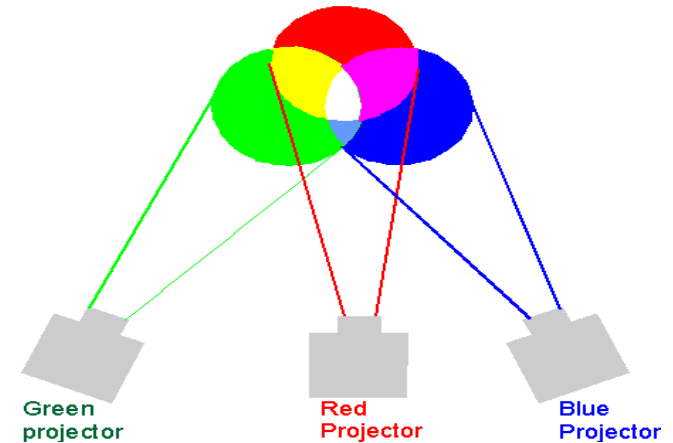
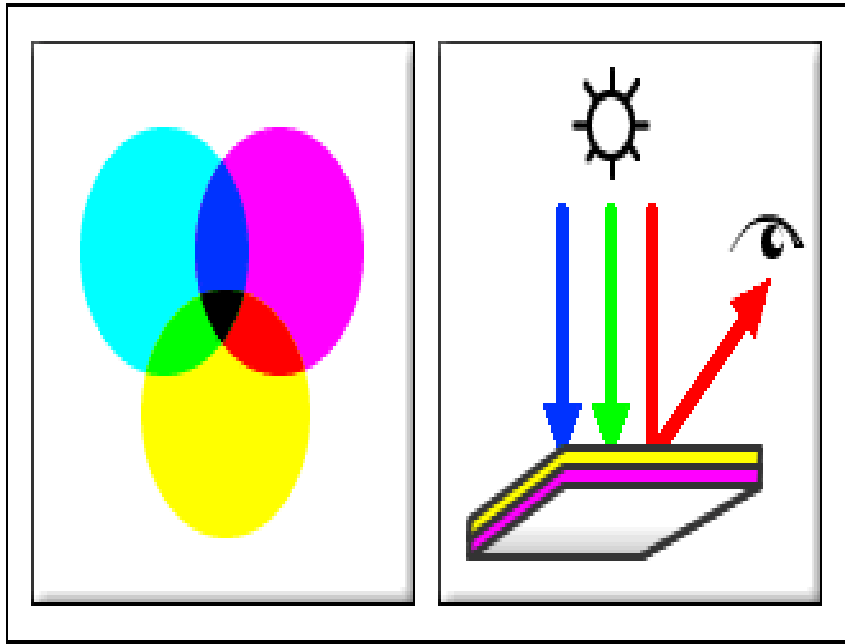
- Because of its electric and magnetic properties, light is also called **electromagnetic radiation**
- Visible light falls in the 400 to 700 nm range
- Stars, galaxies and other objects emit EM radiation in all wavelengths

So, why can we only see a small portion of these E-M waves?

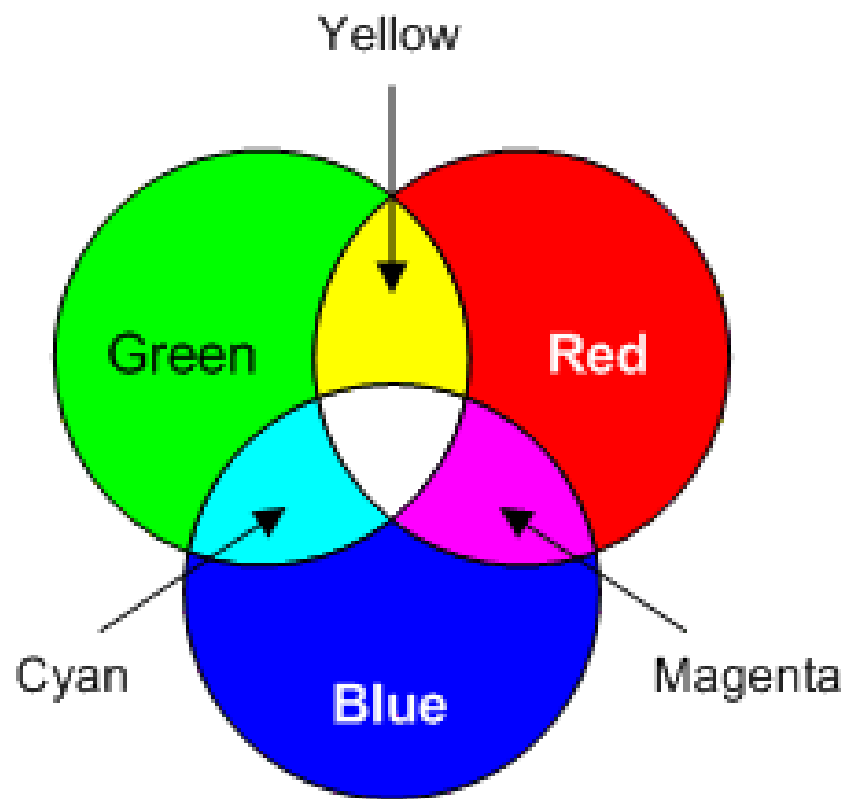


Color by Addition of Light

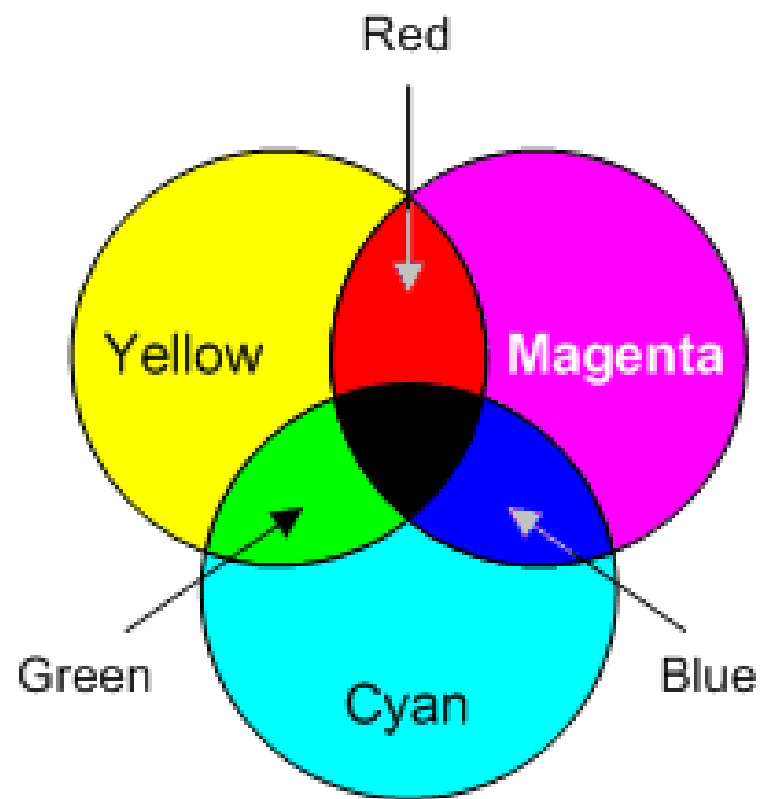
- 3 Primary Colors of Light
 - Red
 - Green
 - Blue
-
- White = red & green & blue
-
- 3 Complimentary Colors of Light
 - Yellow = red & green
 - Cyan = green & blue
 - Magenta = blue & red



Color by Addition and Subtraction



Additive (light)



Subtractive (paint)

Additive and subtractive color combinations

What color is the dress ?



<http://blogs.discovermagazine.com/d-brief/2015/02/27/what-color-is-the-dress/>

Visible light

- We now know what we see is part of the electromagnetic spectrum. We know that the light waves enter our eye, and stimulate parts of it that cause a electrical impulse to be sent to the brain which creates this visual image.
- But everything does not emit radiation. How do we see those things? And why cant we see a window?
- We know that when waves run into a boundary they are partially transmitted and partially reflected.
- Light behaves as a wave, so it to is reflected.
- Therefore, an object does not need to **emit photons** itself to be seen, it just has to reflect light back to our eyes where we can detect it.
- Objects that do not allow light to pass through them are called **opaque**.
- Objects that allow light to pass through them are considered **transparent**.
- Objects in between are called **translucent**

A person in infrared -color coded image -red is hottest

