THE NATURE OF LIGHT

Prof. Stephen Sekula

4/12/2010

Supplementary Material for PHY1308 (General Physics - Electricity and Magnetism)

WHAT IS LIGHT?

GALILEO GALILEI

1564-1642

Considered the first "modern scientist," Galileo combined mathematics with observation and argued that this was the way to understand the natural world.

He perfected the telescope and observed that the earth could not be the center of the universe. He was tried and convicted by the Inquisition for heresy and was placed under house arrest for the remainder of his life. *He died the year before Isaac Newton was born.*

SPEED OF SOUND

Make measurements of the round trip that sound takes from Dallas Hall to points 100m and 200m south of Dallas Hall.

(Don't get shut down by the cops)

SPEED OF LIGHT

Ole Roemer

First to measure speed of light to be finite (1676)

Jupiter

Io

Discovered by Galileo in 1610

Earth

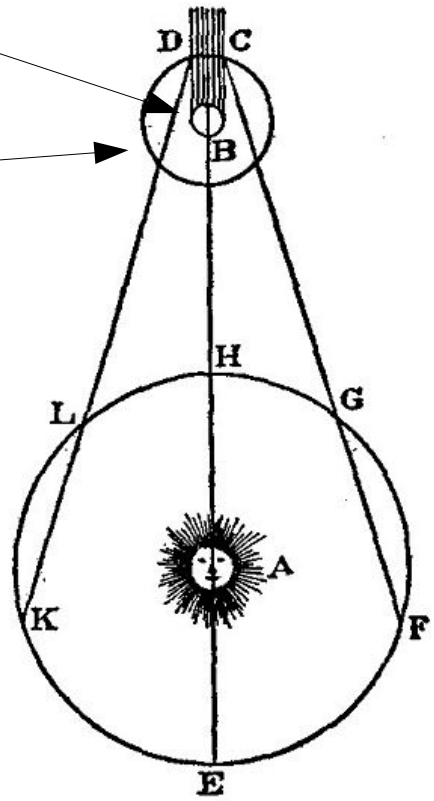


FIG. 70.

Roemer estimated the speed of light to be 220,000 km/s by observing Earth-seasonal variations in Io's orbit.

THE 4 LAWS OF ELECTRICITY AND MAGNETISM

$$\oint \vec{E} \cdot d\vec{l} = -\frac{d\Phi_B}{dt}$$

Faraday's Law - changing magnetic flux induces ***electric field***

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 I$$

Ampere's Law - electric current is the source of magnetic field

$$\int \vec{E} \cdot d\vec{A} = \frac{1}{\epsilon_0} q$$

Gauss's Law for Electric Fields - electric charge is the source of electric field

$$\int \vec{B} \cdot d\vec{A} = 0$$

Gauss's Law for Magnetic Fields - there are no single magnetic charges

THE 4 LAWS OF ELECTRICITY AND MAGNETISM - "FREE SPACE"

$$\oint \vec{E} \cdot d\vec{l} = -\frac{d\Phi_B}{dt}$$

Faraday's Law - changing magnetic flux induces ***electric field***

$$\oint \vec{B} \cdot d\vec{l} = 0$$

Ampere's Law - electric current is the source of magnetic field

$$\int \vec{E} \cdot d\vec{A} = 0$$

Gauss's Law for Electric Fields - electric charge is the source of electric field

$$\int \vec{B} \cdot d\vec{A} = 0$$

Gauss's Law for Magnetic Fields - there are no single magnetic charges

JAMES CLERK MAXWELL

1831-1879

Brilliant scientist working in Britain.

- United electricity and magnetism into a single "force"
- Developed a theory of large numbers of particles
- Made the first true color photograph

Published in 1864 "A Dynamical Theory of the Electromagnetic Field," which was seen by Faraday before his death in 1867.

THE 4 LAWS OF ELECTRICITY AND MAGNETISM - "FREE SPACE"

$$\oint \vec{E} \cdot d\vec{l} = -\frac{d\Phi_B}{dt}$$

Faraday's Law - changing magnetic flux induces ***electric field***

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 \epsilon_0 \frac{d\Phi_E}{dt}$$

Ampere's and Maxwell's Law - changing electric flux is the source of ***magnetic field***

$$\int \vec{E} \cdot d\vec{A} = 0$$

Gauss's Law for Electric Fields - electric charge is the source of electric field

$$\int \vec{B} \cdot d\vec{A} = 0$$

Gauss's Law for Magnetic Fields - there are no single magnetic charges

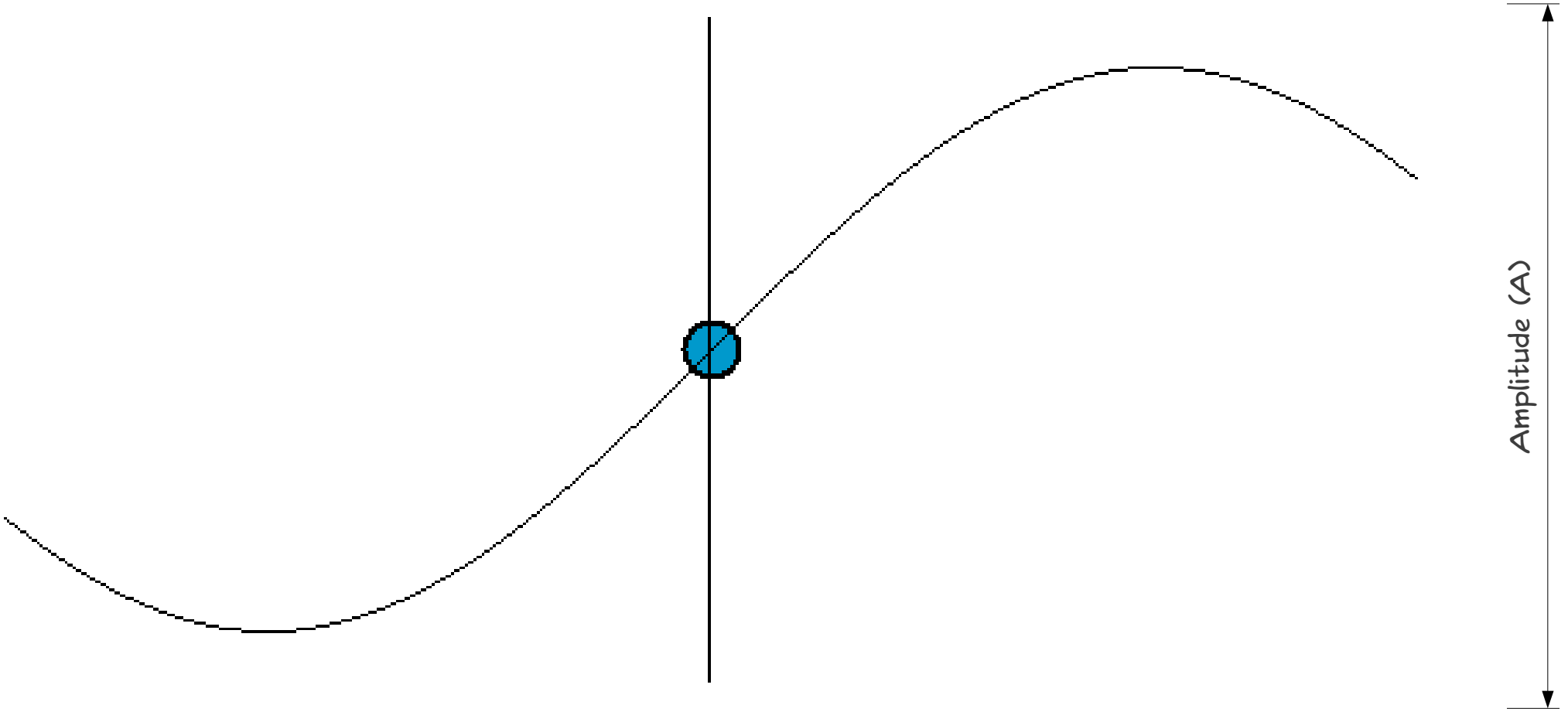
THE SOLUTIONS TO MAXWELL'S EQUATIONS

$$\vec{E}(x,t) = E_{max} \sin(kx - \omega t)\,\hat{j}$$

$$\vec{B}(x,t) = B_{max} \sin(kx - \omega t)\,\hat{k}$$

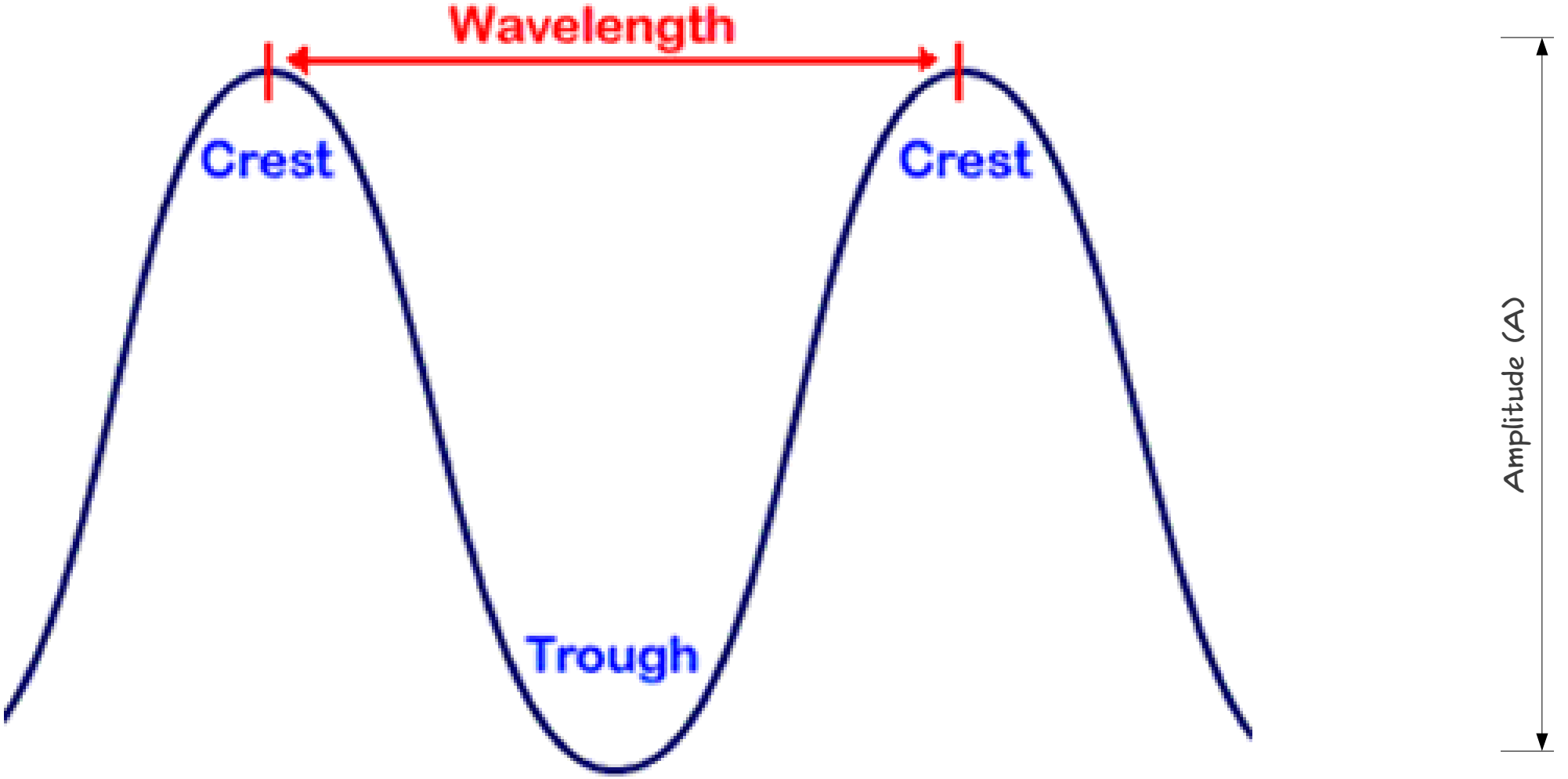
What do these equations describe???

WAVES



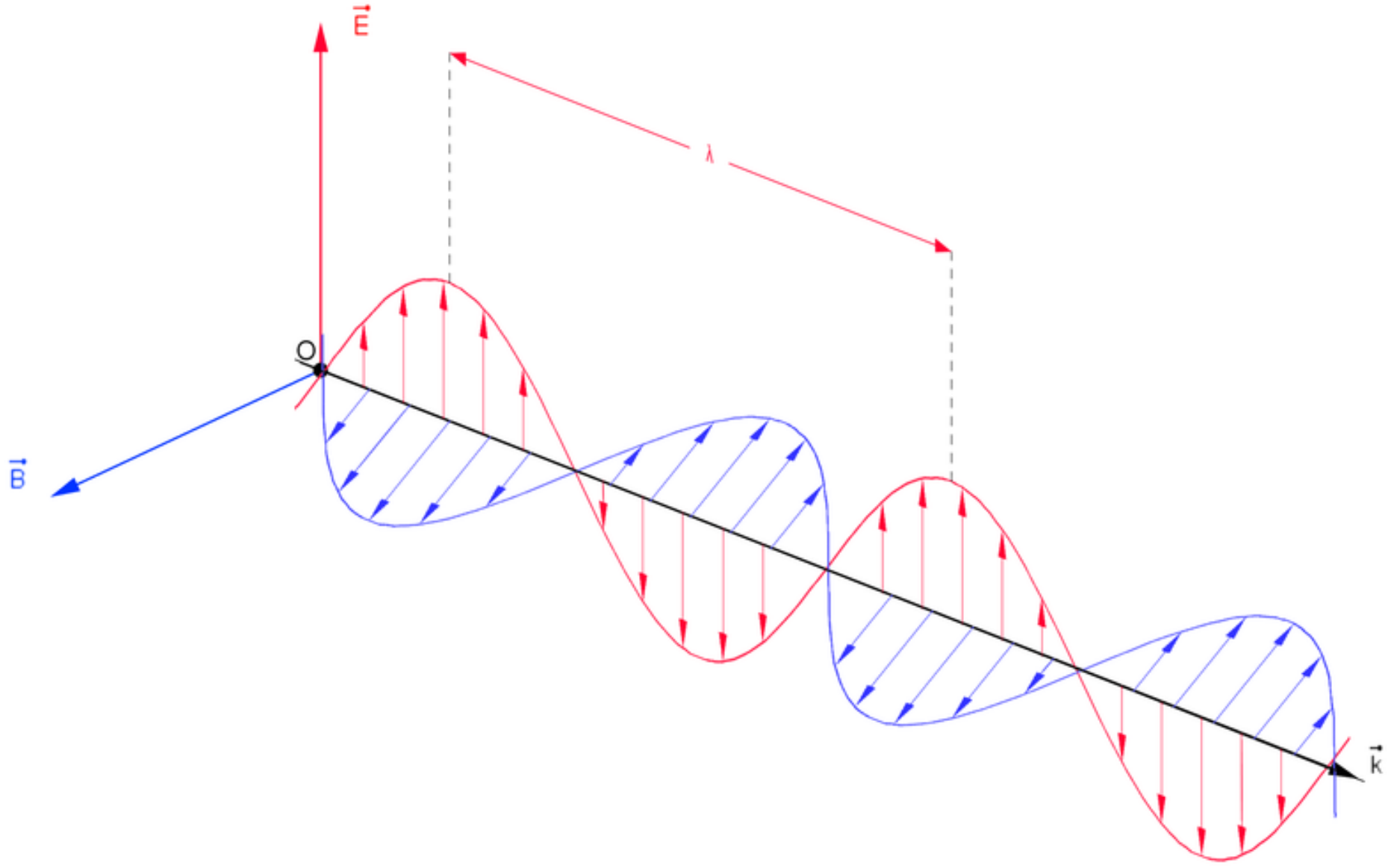
$$u(x,t) = A \sin\left(2\pi \frac{x}{\lambda} - 2\pi f t \right)$$

WAVES



$$u(x,t) = A\sin\left(2\pi\frac{x}{\lambda} - 2\pi f t\right)$$

ELECTROMAGNETIC WAVES



Heinrich Hertz

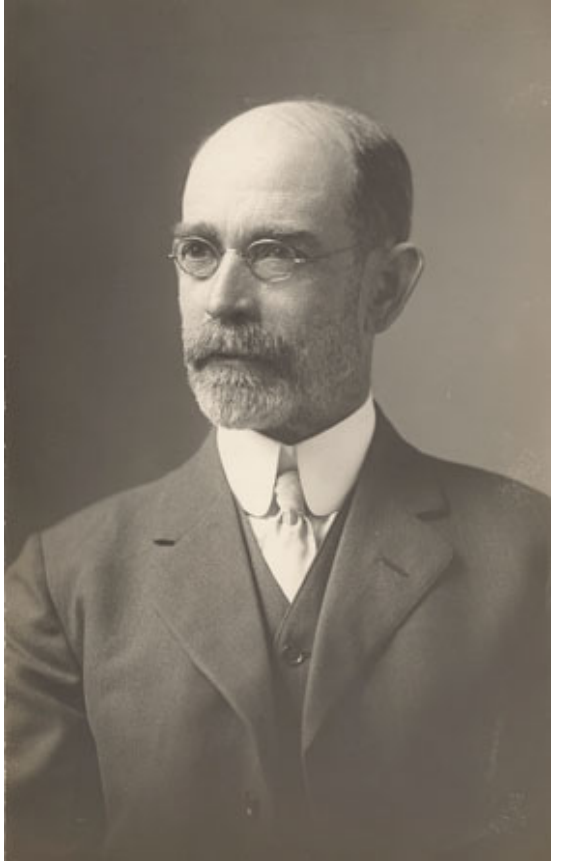
(1857-1894)

First to satisfactorily demonstrate the existence of EM waves

Guglielmo Marconi

(1874-1937)

Italian inventor who developed the radio telegraph system (first demonstrated in 1894)



Robert Hyer

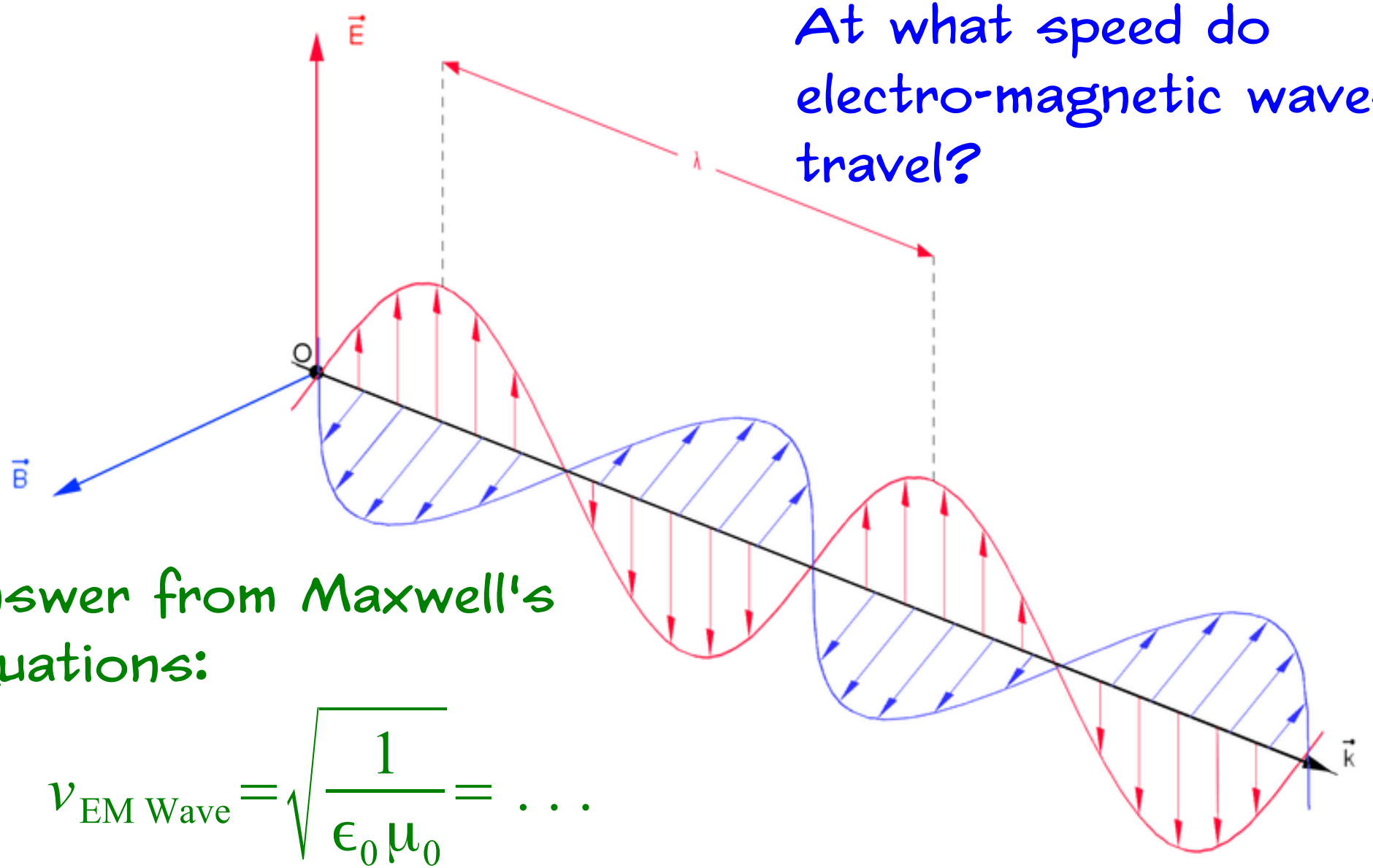
(1860-1929)

Physicist, Founder and First President of SMU

First American to communicate using EM waves (1894)

ELECTROMAGNETIC WAVES

At what speed do electro-magnetic waves travel?

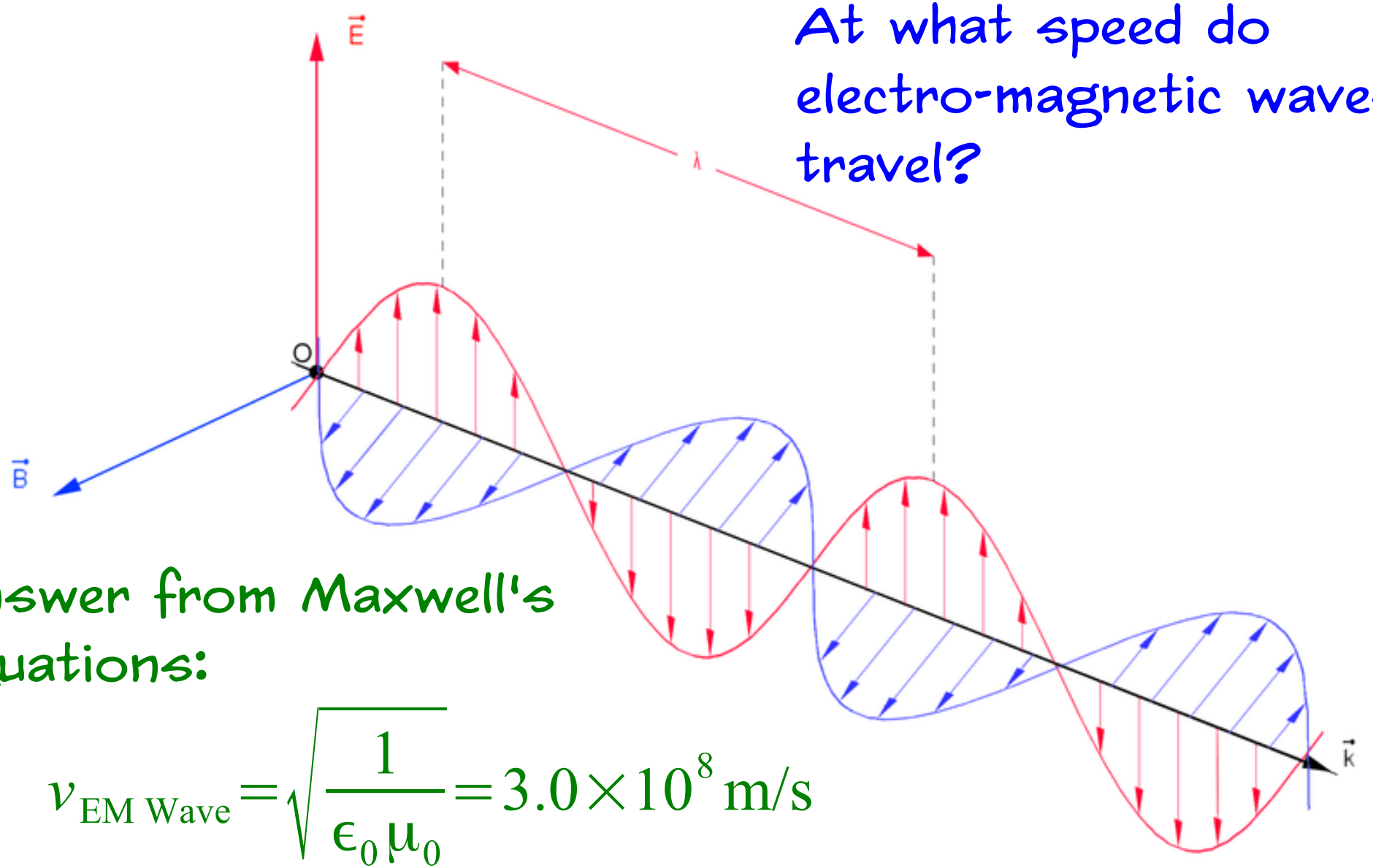


Answer from Maxwell's Equations:

$$v_{\text{EM Wave}} = \sqrt{\frac{1}{\epsilon_0 \mu_0}} = \ldots$$

ELECTROMAGNETIC WAVES

At what speed do electro-magnetic waves travel?



Answer from Maxwell's Equations:

$$v_{\text{EM Wave}} = \sqrt{\frac{1}{\epsilon_0 \mu_0}} = 3.0 \times 10^8 \text{ m/s}$$

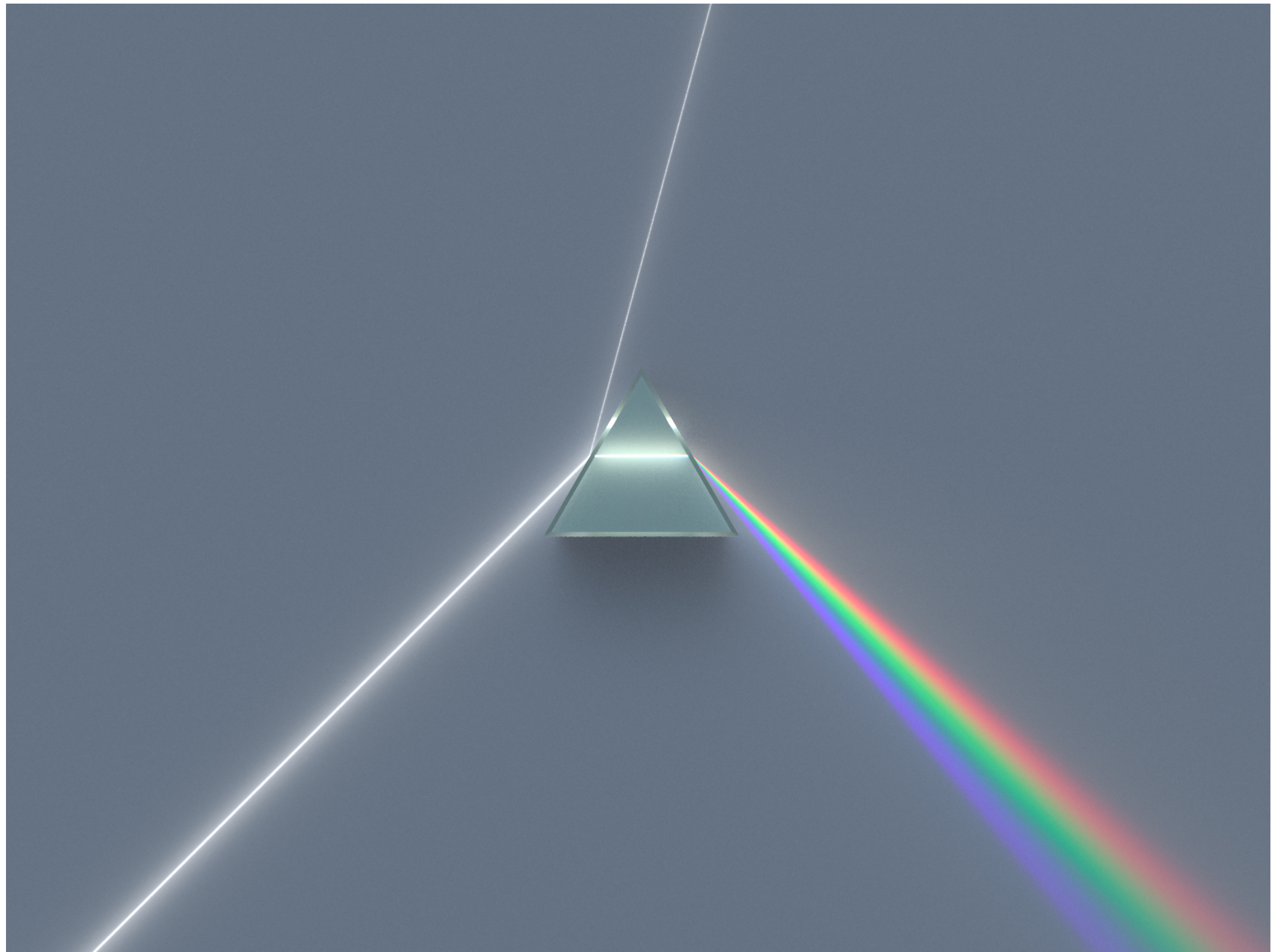


Chart of the Electromagnetic Spectrum

Size reference


football field


man's height


baseball


paperclip thickness


paper thickness


cells


bacteria


viruses


water molecule


atom

subatomic particles →

wavelength λ (m)

1 ft | 1 cm | 1 mm | 1 mil | 1 μ | 1 nm | 1 Å | 1 pm

10^{3} 10^{2} 10 1 10^{-1} 10^{-2} 10^{-3} 10^{-4} 10^{-5} 10^{-6} 10^{-7} 10^{-8} 10^{-9} 10^{-10} 10^{-11} 10^{-12}

wavenumber (cm^{-1})

10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 1 10 10^{2} 10^{3} 10^{4} 10^{5} 10^{6} 10^{7} 10^{8} 10^{9} 10^{10}

electron volt (eV)

10^{-9} 10^{-8} 10^{-7} 10^{-6} 10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 1 10 10^{2} 10^{3} 10^{4} 10^{5} 10^{6}

frequency (Hz)

1 MHz | 1 GHz | 1 THz | 1 PHz | 1 EHz | 1 ZHz

10^{5} 10^{6} 10^{7} 10^{8} 10^{9} 10^{10} 10^{11} 10^{12} 10^{13} 10^{14} 10^{15} 10^{16} 10^{17} 10^{18} 10^{19} 10^{20} 10^{21}

Bands

Radio Spectrum | Terahertz | Infrared | Ultraviolet | X-ray | Gamma

Broadcast and Wireless | Microwave | Far IR | Mid IR | Near IR | Near UV | Extreme UV | Soft X-ray | Hard X-ray

Visible wavelengths (nm): 700 625 575 540 470 440

electronics ◄ optics ►

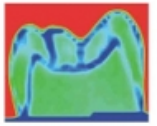
Sources and Uses of Frequency Bands


AM radio
600kHz-1.6MHz


FM radio
88-108 MHz

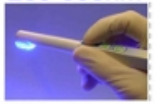

Mobile Phones
900MHz-2.4GHz


Radar
1-100 GHz


Bio imaging
1-10 THz


Fiber telecom
0.7-1.4 μ


Visible Light
425-750THz
700-400nm


Dental Curing
200-350nm


Medical X-rays
10-0.1 Å


Cosmic ray observations
<<1 Å


Baggage screen
10-1.0 Å


TV Broadcast
54-700 MHz


Wireless Data
~ 2.4 GHz


Ultrasound
1-20 MHz


Screening
0.2-4.0 THz


Remotes
850 nm


Suntan
400-290nm

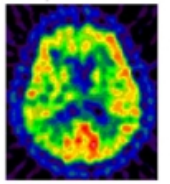

Sound Waves
← 20Hz-10kHz


Microwave Oven
2.4 GHz

"mm wave"
"sub-mm"


Night Vision
10-0.7 μ


Crystallography
2.2-0.7 Å


PET imaging
0.1-0.01 Å

$\lambda = 3\times10^{8}/\text{freq} = 1/(\text{wn}*100) = 1.24\times10^{-6}/\text{eV}$

QUESTION

If water waves travel in water . . .

and sound waves travel in air . . .

in what medium does light travel?

ANSWER FROM MAXWELL'S EQUATIONS: NONE???

$$\oint \vec{E} \cdot d\vec{l} = -\frac{d\Phi_B}{dt}$$

Faraday's Law - changing magnetic flux induces ***electric field***

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 \epsilon_0 \frac{d\Phi_E}{dt}$$

Ampere's and Maxwell's Law - changing electric flux is the source of ***magnetic field***

$$\int \vec{E} \cdot d\vec{A} = 0$$

Gauss's Law for Electric Fields - electric charge is the source of electric field

$$\int \vec{B} \cdot d\vec{A} = 0$$

Gauss's Law for Magnetic Fields - there are no single magnetic charges

Albert Einstein
(1879-1955)

In 1905, published three papers on atomic theory, the nature of light, and *the re-interpretation of space and time based on the theory of electromagnetism ("relativity").*