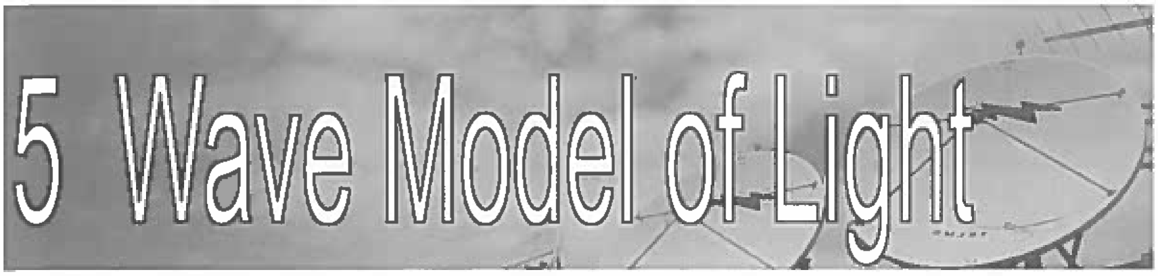


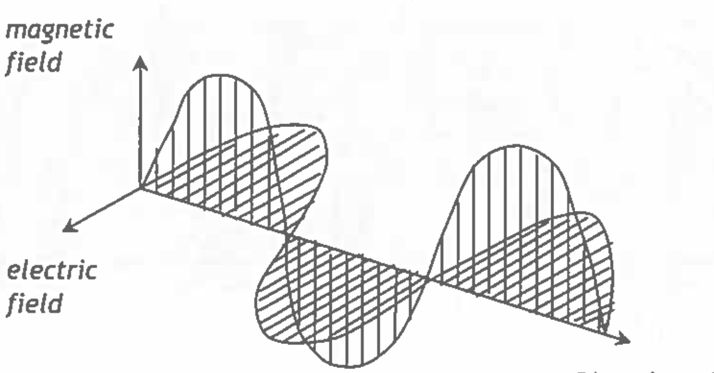
5 Wave Model of Light

Introduction

In physics light is referred to as electromagnetic radiation which is a natural phenomenon that can also be produced and detected through technological means. It has proven invaluable for many uses in medicine, communications and much more.

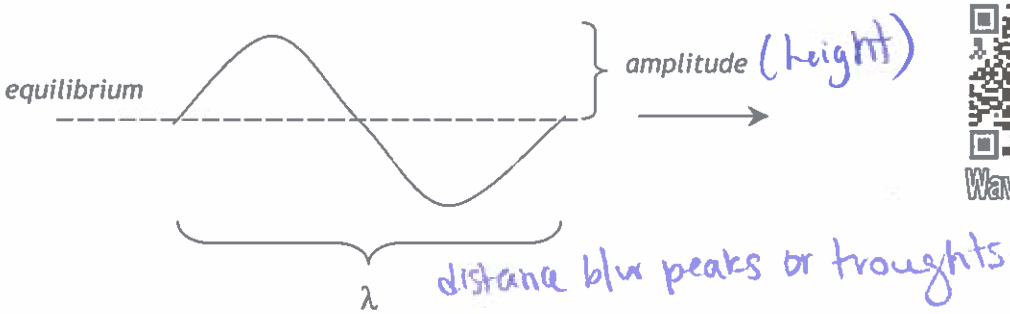
5.1 Summary Notes – The Nature of EMR

- Electromagnetic radiation (EMR) is caused by accelerating charges.
- The greater the acceleration, the higher the energy and frequency of the EMR and the shorter the wavelength.
- EMR are transverse waves.
- EMR has a changing electric field component and a changing magnetic field component.
- The changing electric field generates a changing magnetic field perpendicular to the direction the wave is travelling (i.e., the direction it propagates).



Notes:

While electromagnetic radiation is a three-dimensional wave, it is often drawn two-dimensionally:



Wave Theory

Notes:
amplitude → height of wave
sound → loudness
light → brightness
- energy can travel using particles (mass moves from point A to Point B) or by waves (oscillation of a medium
- properties of waves + particles are different

Diffraction: bending or spreading out of a wave as it passes through an opening.
→ only waves diffracts; light diffracts so it must be a wave.

The **wavelength** (λ) is the measured distance between successive crests (peaks) or troughs.

A **source** is anything that vibrates to create a disturbance and a wave. Vibrating charges or changing electric fields are sources for EMR.

A **medium** is the substance a wave travels through.

Wave **propagation** is the movement of a wave through a medium.

The **frequency** of a wave (Hz) is equal to the number of waves that pass a certain point in a given time.

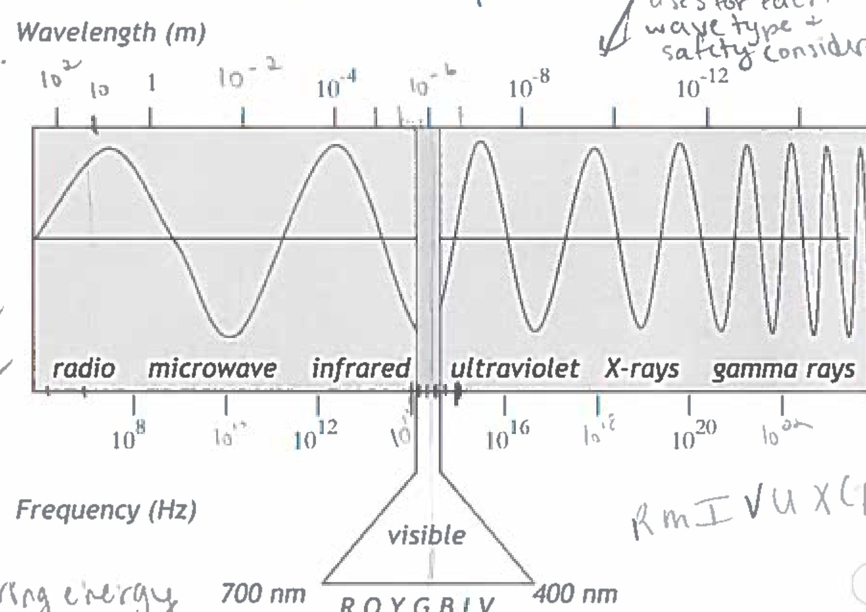
The **speed** of a wave depends on the nature of the medium it is travelling through. All EMR travels at 3.00×10^8 m/s in a vacuum.

* know name, order, uses for each wave type + safety considerations

A range of wavelengths can be organized in the electromagnetic spectrum:

→ EMR propagates (moves) ⊥ to a changing magnetic field + a changing electric field

EMR



- EMR is all around us + comes in different forms
- form of energy + is useful in transferring energy
- use energy in diff ways

ex) cell phone, cell phone radiates energy as EMR + another cellphone receives EMR signal

Wave-particle nature

Light is pure energy. As light (EMR) becomes more energetic the frequency increases and the wavelength decreases allowing it to behave more like a particle than a wave. Generally:

- EMR having a frequency less than visible light is treated as a wave.
- EMR having a frequency greater than visible light is treated as a particle.
- Visible light is treated both as a wave and a particle depending on the experiment or phenomenon being investigated.

Notes:

The universal wave equation and the period-frequency relationship apply to light waves:

$$v = \lambda f \quad \text{or} \quad c = \lambda f$$

$$T = \frac{1}{f}$$

Where:

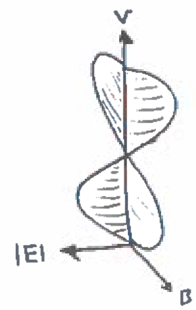
v is the speed of the wave
c is the speed of light in a vacuum
f is the frequency of the wave (cps, s^{-1} or Hz)
λ is the wavelength (λ is the Greek letter "lambda")
T is the period of the wave (s)

- The colour of visible light is usually associated with its frequency, wavelength or energy.
- **Monochromatic** light is light consisting of a single frequency (or wavelength).

Examples

1. An electromagnetic wave is travelling directly upwards, normal to the Earth's surface. The electric field component of this wave is oscillating in an east-west plane. Use a diagram to determine the direction of oscillation of its magnetic field component.

3-dimensional



or

2-dimensional

The magnetic field oscillates North-South.

2. Ultraviolet light travels through a vacuum at a speed of 3.00×10^8 m/s with a wavelength of 3.47×10^{-7} m. Determine its
   a. frequency.
   b. period.

$v = 3.00 \times 10^8 \text{ m/s}$

$\lambda = 3.47 \times 10^{-7} \text{ m}$

$T = ?$

$f = ?$

$v = \lambda f$

$f = \frac{v}{\lambda}$

$f = \frac{3.00 \times 10^8 \text{ m/s}}{3.47 \times 10^{-7} \text{ m}}$

$f = 8.6455 \times 10^{14} \text{ Hz}$

$f = \frac{1}{T}$

$T = \frac{1}{f}$

$T = \frac{1}{8.6455 \times 10^{14} \text{ Hz}}$

$T = 1.15\overline{6} \times 10^{-15} \text{ s}$

a. The frequency is 8.65×10^{14} Hz.
b. The period is 1.16×10^{-15} s.

VIBGYOR

Problems

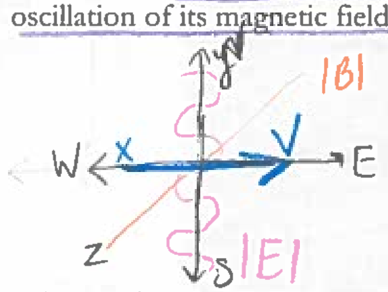
1. List the seven colours of the visible light spectrum from high energy to low energy. [Appendix A]

Hi Energy + Frequency — Short λ { violet, indigo, blue, green, yellow, orange, red } low E+F — long λ

2. The Inuit of the Canadian Arctic protected their eyes from bright sunlight reflected off snow by constructing snow goggles made from ivory or wood with carved narrow slits. By blocking much of the light, snow blindness could be avoided. Identify the region of the EMR spectrum that might be most responsible for damaging the eyes causing snow blindness. Explain. [Appendix A]

ultraviolet → it has the most energy (highest frequency) so it can cause the most damage
→ there is a lot of it

3. An electromagnetic wave is travelling directly east parallel to the Earth's surface producing an electric field oscillating in a north-south plane. Use a diagram to determine the direction of oscillation of its magnetic field component (see example problem 1 for help). [Appendix A]



← perpendicular to both so the |B| is up, down (in + out of the page

4. Fill in the blanks. EMR is produced by accelerating charged particles. The wave is made from a changing electric field that produces a changing magnetic field that travels at the speed of 3.0×10^8 m/s. [Appendix A]

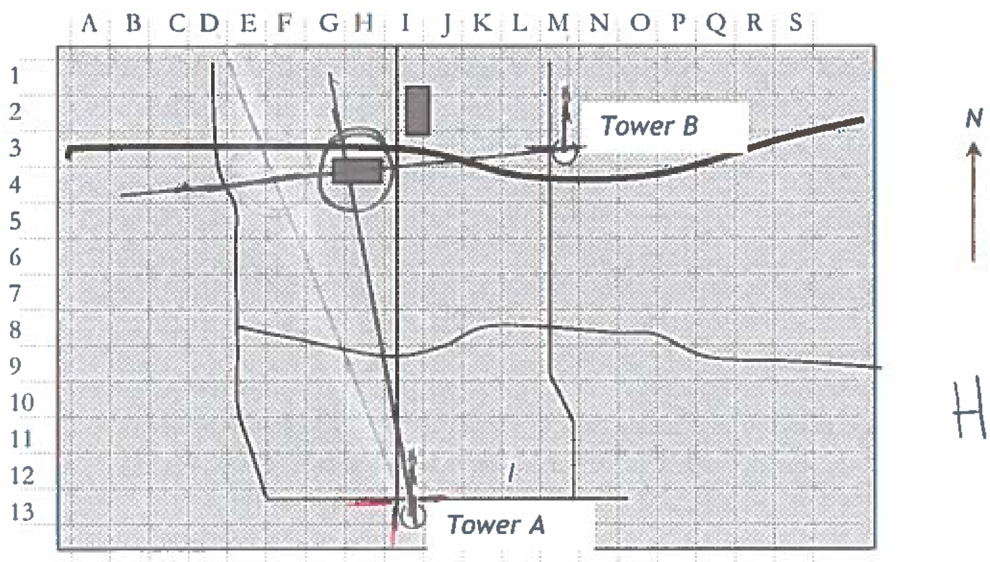
5. Moving charges may create fields. Complete the chart below for an electron exhibiting the described motion. [Appendix A]

Description of motion	Description of field(s) created
Stationary	Gravitational Electrical
Uniform motion	Gravitational Electrical magnetic
Accelerating	Gravitational changing electrical changing magnetic

Use the information below to answer question 6.

Cell phones typically operate on a frequency between 800 Hz to 900 Hz. Cell phones only transmit their signal to nearby cell phone towers that then incorporate the phone call into the regular phone system. Location-tracking technologies make it possible to determine where a cell phone is. One method involves a global positioning satellite sending a unique signal that only your cell phone can pick up (a.k.a "pinging"). The cell phone will then send a signal to nearby cell towers that determines your position through triangulation.

6. Cell phone tower A is at grid location I-13 and tower B is at M-3 on the map shown below. Tower A detects a signal coming from a bearing of 350° (80° N of W). Tower B detects the same signal coming from a bearing of 264° (84° W of S). Determine the most likely grid location of the cell phone. [Appendix A]



5.1a

H-4

7. Calculate the period of the wave for a blue laser diode having a frequency of 4.23×10^{14} Hz. [2.36×10^{-15} s]

$$T = \frac{1}{f} = \frac{1}{4.23 \times 10^{14}\ \text{Hz}} = 2.36 \times 10^{-15}\ \text{s}$$

1nm = 1 X 10^{-9} m.

8. The frequency of a certain monochromatic beam of visible light in a vacuum ($v = 3.00 \times 10^8$ m/s) is found to be 5.50×10^{14} Hz. Determine the wavelength. [545 nm]

$v = f\lambda$ $\lambda = \frac{v}{f} = \frac{3.00 \times 10^8 \text{ m/s}}{5.5 \times 10^{14} \text{ hz}}$

$= 5.45 \times 10^{-7}$ m

9. An X-ray travels at a speed of 3.00×10^8 m/s in a vacuum with a wavelength of 6.53×10^{-10} m. Determine its
   a. frequency. [4.59×10^{17} Hz]
   b. period. [2.18×10^{-18} s]

$v = f\lambda$

$f = \frac{v}{\lambda} = \frac{3.00 \times 10^8 \text{ m/s}}{6.53 \times 10^{-10} \text{ m}}$

$= 4.59 \times 10^{17}$ Hz

$T = \frac{1}{f} = \frac{1}{4.59 \times 10^{17} \text{ Hz}}$

$= 2.18 \times 10^{-18}$ s.

10. Street lamps are typically sodium vapour lamps or mercury vapour lamps. Sodium vapour lamps emit a visible wavelength of 590 nm. Calculate the frequency of this sodium light. [5.08×10^{14} Hz]

5.9×10^{-7} m

$v = f\lambda$ $f = \frac{v}{\lambda} = \frac{3 \times 10^8 \text{ m/s}}{5.9 \times 10^{-7} \text{ m}}$

$= 5.08 \times 10^{14}$ Hz

11. A common pen laser has a wavelength of 680 nm. -red? 6.8×10^{-7}
   a. Calculate the frequency of the laser light. [4.41×10^{14} Hz]
   b. Identify the colour of the laser beam. [Appendix A]

$f = \frac{v}{\lambda} = \frac{3.0 \times 10^8 \text{ m/s}}{6.8 \times 10^{-7}}$

$= 4.41 \times 10^{14}$ Hz

b) laser is red

1 GHz = 1x10^9 Hz
1 mHz = 1x10^6 Hz
1 kHz = 1000 Hz

12. Some people have the ability to see greater wavelength range than most: from 380 nm to 780 nm. Calculate the frequency of the longer wavelength. [3.85 x 10^{14} Hz]

3.8×10^{-7} 7.8×10^{-7}

$v = f\lambda$ $f = \frac{v}{\lambda} = \frac{3\times10^{8} m/s}{7.8\times10^{-7}} = 3.85\times10^{14}$

13. Many cordless telephones and baby monitors use a radio frequency of 2.4 GHz. Calculate the magnitude of the phone's wavelength. [13 cm]

$v = f\lambda$ $\lambda = \frac{v}{f} = \frac{3\times10^{8} m/s}{2.4\times10^{9} Hz} = 0.125 m$

535 000 Hz 1 700 000 Hz

14. AM radio stations broadcast between 535 kHz and 1700 kHz while FM radio stations broadcast from 88 MHz through 108 MHz. A local radio station broadcasts at a frequency of 90.9 MHz. Calculate the

9.09×10^{7} 8.8×10^{7} 1.08×10^{8}

a. wavelength of the 90.9 MHz radio waves. [3.30 m]
b. number of complete 90.9 MHz radio waves over a 1.50 km distance. [454]

a) $\lambda = \frac{v}{f} = \frac{3\times10^{8} m/s}{9.09\times10^{7}} = 3.3 m$

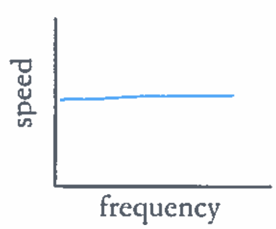
b) 1500m 1.5km = 1500m

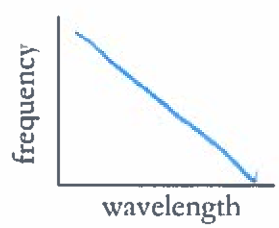
$= \frac{1500}{3.3}$

x = 454.54 waves

454 complete ways

15. Sketch the graphs shapes illustrating the following relationships for EMR travelling through a vacuum. [Appendix A]

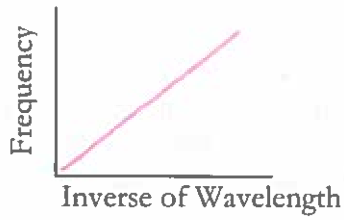




As f↑ λ↓

speed is constant regardless of frequency

16. Frequency is plotted as a function of the inverse of wavelength.
   a. Sketch the graph of the relationship. [Appendix A]
   b. Identify what the slope would represent. [Appendix A]



slope = $\frac{rise}{run}$ = $\frac{f}{\frac{1}{\lambda}}$ $f \div \frac{1}{\lambda}$ = $f \cdot \lambda$

b) slope → $V = C = 3 \times 10^8$ m/s

17. Electromagnetic waves may be detected by the current they produce in a conducting wire called an antenna. The most efficient antenna is one that is one-half the size of the wavelength it is to detect. Calculate the most efficient antenna length for a radio signal of 630 kHz. [238 m]

$V = f\lambda$

$\lambda = \frac{V}{f} = \frac{3 \times 10^8 \text{ m/s}}{630\,000 \text{ Hz}}$

$\lambda = 476.19 \text{ m}$

$476.19 \times \frac{1}{2} = \boxed{238 \text{ m}}$

18. The first radios were called spark gap transmitters because they produced a spark (accelerating electrons) to create radio waves. Spark gap transmitters are now illegal because they create radio waves across a large part of the spectrum and interfere with radio communications. In a modern electronic device radio waves are produced by accelerating electrons along a conductor which is called the antenna. Calculate the wavelength of a radio station broadcasting at 100.3 MHz. [2.99 m]

100.3×10^6 Hz

$\lambda = \frac{V}{f} = \frac{3.8 \times 10^8}{100.3 \times 10^6} = \boxed{2.99 \text{ m}}$

19. Alex and Fiona measure the speed of microwaves in air using a microwave oven. They first place cheese cubes on a paper plate and place it in the microwave on high for 20 s. They identify hot spots in the cheese spread to be 6.08 cm apart. Knowing that the hot spots are areas of constructive interference that occurs every half a wavelength, together with the frequency of the microwave listed on the back of the device as 2450 MHz, determine the speed of the microwaves. [2.98 x 10^8 m/s]

6.08 cm $= 6.08 \times 10^{-2}$ m

2450×10^6

$\lambda = 6.08 \times 10^{-2} \times 2$
$= 12.16 \times 10^{-2}$ m

$V = f\lambda$
$= (2450 \times 10^6)(12.16 \times 10^{-2} \text{ m})$
$= \boxed{2.98 \times 10^8 \text{ m/s}}$

5.2 Summary Notes – Speed of EMR

Notes:

Early attempts to measure the speed of light proved difficult due to its speed being so great. As equipment improved it was possible to measure the speed of light with increasing precision.

The speed of visible light was determined before other parts of the Electromagnetic spectrum.

Examples

1. A disk with 600 cogs must be spun at 111.0 Hz for light to travel a distance of 1164 m, reflect off a mirror and travel the return trip of 1164 m to be blocked or eclipsed by the adjacent cog. The beam of light requires 7.5075×10^{-6} s for the round trip. Calculate the speed of light as determined by this experiment.

$n = 600$

$f = 111\ Hz$

$d = 1164m$

$t = 7.5075 \times 10^{-6} s$

$v = ?$

$v = \frac{d}{t}$

$v = \frac{2(1164m)}{7.5075 \times 10^{-6} s}$

$v = 3.100899 \times 10^{8} m/s$

The speed of light was measured to be 3.101×10^8 m/s.

2. An eight-sided mirror is used to measure the speed of light. The first image (minimum frequency) occurred when the mirror was rotating 610 Hz. Calculate the speed of light if the fixed mirror is 30.0 km from the rotating mirror.

$n = 8$

$d = 30km$

$f = 610Hz$

$v = ?$

$T = \frac{1}{f}$

$T = \frac{1}{610Hz}$

$T = 0.001639s$

fraction of turn $\frac{1}{8}$

time for fraction of turn

$0.001639s \times \frac{1}{8}$

$= 0.0002049s$

$v = \frac{d}{t}$

$v = \frac{2(30 \times 10^3 m)}{2.049 \times 10^{-4} s}$

$v = 2.928 \times 10^8 m/s$

The speed of light was found to be 2.93×10^8 m/s.

Problems

1. Determine the speed of light if light requires 1.187 s to travel a distance of 3.56×10^8 m from the Moon to the Earth. [3.00×10^8 m/s]

$$V = \frac{d}{t} = \frac{3.56 \times 10^8 \text{ m}}{1.187 \text{ s}}$$

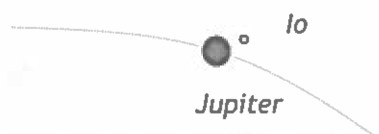
$$= 2.999 \times 10^8 \sim 3.00 \times 10^8 \text{ m/s}$$

2. Calculate the time for light to travel from the Sun to the Earth if they are separated by a distance of 1.49×10^{11} m. Assume a speed of light of 3.00×10^8 m/s. [497 s]

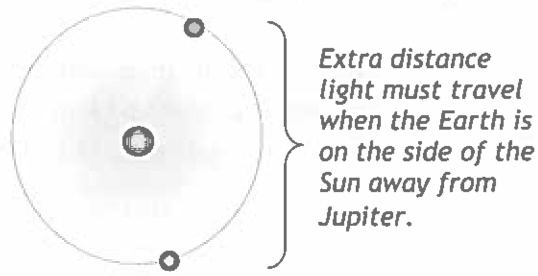
$$v = \frac{d}{t} \qquad = \frac{1.49 \times 10^{11}}{3 \times 10^8}$$

$$t = \frac{d}{v} \qquad = 497 \text{ s}$$

Use the information below to answer question 3.



Olaf Römer made the first known determination for the speed of light using the eclipse of Jupiter's moon, Io, by Jupiter in 1676. Astronomical data allowed him to predict when the eclipses would occur, but due to the time required for light to travel to the Earth, the eclipses appeared later than they actually occurred. A simplified diagram of this situation is shown on the right.



3. Assume Römer made his initial observations of Io when Earth was in its closest approach to Jupiter and his second observation six months later. Römer thought that light required 22 minutes to cross Earth's orbit. Determine Römer's value for the speed of light if the diameter of the Earth's orbit around the Sun is 2.82×10^{11} m. [2.14×10^8 m/s]

$$V = \frac{d}{t} = \frac{2.82 \times 10^{11} \text{ m}}{1320 \text{ s}}$$

$$= 2.14 \times 10^8 \text{ m/s}$$

$$22 \text{ mins} = 1320 \text{ s} \quad (22 \times 60)$$

Use the information below to answer question 4.

Römer's value of light's time lag of 22 minutes to cross the Earth's orbit was too large. When the Earth and Jupiter are on the same side of the Sun they are separated by 6.28×10^{11} m and when they are on opposite sides they are separated by 9.28×10^{11} m. Jupiter's eclipse of Io is 16 minutes later when the Earth is farther away than when it's at the closest approach.

4. Determine the speed of light using the more precise data. [3.1×10^8 m/s]

$v = \frac{d}{t} = \frac{3 \times 10^{11}}{960}$

$= 3.1 \times 10^8$ m/s

$d = 9.28 \times 10^{11} - 6.28 \times 10^{11} = 3 \times 10^{11}$

$t = 16 \text{ min} \times \frac{60 \text{ min}}{1 \text{ s}} = 960 \text{ s}$

Use the information below to answer questions 5 – 7.

In 1849 Armand Fizeau performed the first terrestrial experiment to determine the speed of light. He used an extremely bright lamp and pulsed the light using a rotating wheel constructed with 720 cogs. He separated the rotating wheel and a reflecting mirror a distance of 8.63 km between Montmartre and Suresnes in Paris, France. He observed the light source through the gaps between the cogs and then gradually increased the rotational speed of the wheel until he could not see the light source. The light had been eclipsed (i.e., blocked) by a cog in the wheel.

5. Fizeau gradually increased the wheel's frequency of rotation to 12.6 Hz, which showed that the light travelled the 8.63 km, and back in a time of 5.51×10^{-5} s. Calculate the speed of light as determined by Fizeau. [3.13×10^8 m/s]

$d = 8.63 \times 10^3 \times 2$

$v = \frac{d}{t} = \frac{2 \times 8.63 \times 10^3 \text{ m}}{5.51 \times 10^{-5} \text{ s}} = 3.1 \times 10^8$ m/s.

6. In an experiment similar to Fizeau's a spinning wheel with 360 cogs and a distance of 450 m between the wheel and the mirror, was used to measured the speed of light to be 3.00×10^8 m/s. Determine the time required for light to travel from the spinning wheel to the mirror and back. [3.00×10^{-6} s]

$v = \frac{d}{t}$

$t = \frac{d}{v}$

$= \frac{2 \times 450 \text{ m}}{3 \times 10^8}$

$= 3.0 \times 10^{-6}$ s.

7. A spinning wheel with 360 cogs can be used to determine distance. The light used requires a total of 2.15×10^{-6} s to travel from the wheel to the mirror and back to the mirror. Assuming a speed of light of 3.00×10^{8} m/s determine the distance between the wheel and the mirror. [323 m]

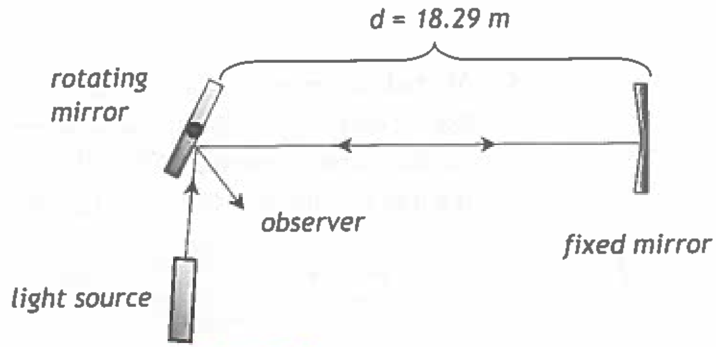
$v = \frac{d}{t}$ $\quad = (3\times10^8 \text{ m/s})(2.15\times10^{-6} \text{ s})$

$d = vt$ $\quad d = 645 \text{ m}$ (there + back)

$\frac{645}{2} = \boxed{323 \text{ m}}$ one way

Use the information below to answer questions 8 & 9.

Foucault's method for finding the speed of light in 1862 was similar to Fizeau's but Foucault used a rotating plane mirror as shown in the diagram. This greatly improved the results.



8. Foucault separated the rotating mirror and fixed mirror by 18.29 m. If the total time for the light beam to travel the distance between the rotating mirror and fixed mirror (there and back) was 1.221×10^{-7} s, determine Foucault's measurement for the speed of light. [2.996×10^{8} m/s]

$v = \frac{d}{t} = \frac{2\times18.29 \text{ m}}{1.221\times10^{-7} \text{ s}} = 2.996\times10^{8} \text{ m/s}$

9. In 1850 Foucault used the same apparatus to measure the speed of light through water and showed that it moved slower, which added support to the idea that light was a wave. The total time to travel the separation distance of 18.29 m in water was 1.62×10^{-7} s. Calculate the speed of light in the water. [2.26×10^{8} m/s]

$v = \frac{d}{t} = \frac{2(18.29) \text{ m}}{1.62\times10^{-7} \text{ s}}$

$= 2.26\times10^{8} \text{ m/s}$

10. Albert Michelson was born in Poland and moved to the United States to avoid persecution due to his Jewish heritage. His first attempt to measure the speed of light was in 1878 at the U.S. Naval Academy in Annapolis and was based on Foucault's rotating mirror apparatus. Michelson obtained better results, however, by improving the precision of his measurements.

Michelson used a $10 mirror rotating at 128.00 Hz placed 152.40 m away from a plane mirror. The light beam required a total time of 1.0153×10^{-6} s to travel from the rotating mirror to the fixed mirror and back. Determine Michelson's first value for the speed of light. [3.0021×10^{8} m/s]

$$V = \frac{d}{t} = \frac{2 \times 152.4\text{ m}}{1.0153 \times 10^{-6}\text{ s}}$$

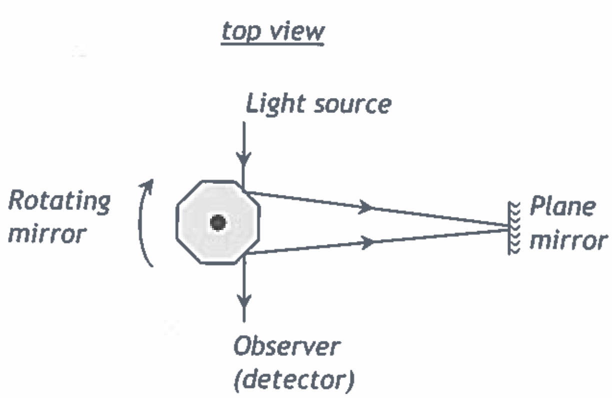
$$= 3.0021 \times 10^{8}\text{ m/s}$$

11. In 1879 Michelson improved his experiment by using a longer distance, more precisely measured at 605.4029 m, and better equipment. The light beam required a total time of 4.0380×10^{-6} s to travel from the mirror rotating at 257.39 Hz to the fixed mirror and back. Determine Michelson's improved value for the speed of light. [2.9985×10^{8} m/s]

$$V = \frac{d}{t} = \frac{2 \times 605.4029\text{ m}}{4.0380 \times 10^{-6}\text{ s}} = 2.9985 \times 10^{8}\text{ m/s}$$

Use the information below to answer question 12.

Michelson won a Nobel Prize for his work in 1907. His value for the speed of light was widely used for 40 years until he repeated his experiment many times between 1926 and 1931 using the 35.51 km distance between Mount Wilson and Mount San Antonio in California. This time he used a rotating 8-sided mirror which again improved his results.



An eight-sided mirror must rotate through at least 1/8 of a rotation for the light beam to be reflected off the rotating mirror, to the plane mirror and return to the rotating mirror.

distance x 2 → there + back

12. Determine Michelson's value for the speed of light using an 8-sided mirror rotating at 527.6 Hz placed 35.51 km from the plane mirror. (Note example #2, page 194) [2.998×10^8 m/s]

35.51×10^3 m

→ no time, use T (period) to solve for time. $\frac{1}{8}T = t$

$T = \frac{1}{f} = \frac{1}{527.6\text{Hz}}$

$= 0.0018954\text{s}$

(time for 1 full rotation, need time for 1/8 rotation)

$t = \frac{1}{8}(0.0018954\text{s})$

$= 2.36922 \times 10^{-4}\text{s}$

$V = \frac{d}{t} = \frac{2(35.51 \times 10^3\text{m})}{2.36922 \times 10^{-4}\text{s}}$

$= 2.998 \times 10^8 \text{m/s}$

13. Michelson experimented with several types of rotating mirrors to produce observed images when measuring the speed of light. Determine the frequency of rotation necessary to produce an image at a fixed distance of 25.0 km from a rotating 12-sided mirror. [500 Hz]

25×10^3 m

→ solve for t. use t to solve for T. Use T to solve for f

$V = \frac{d}{t}$

$t = \frac{d}{V}$

$= \frac{2(25 \times 10^3)}{3 \times 10^8}$

$t = 1.66667 \times 10^{-4}\text{s}$

$T = 12t$

$= 12(1.6667 \times 10^{-4}\text{s})$

$= 0.0025$

$T = \frac{1}{f}$

$t = \frac{T}{12}$ so $T = 12t$

$f = \frac{1}{T} = \frac{1}{0.0025}$

$= 500\text{Hz}$

14. Michelson's final experiment before he died was to measure the speed of light in a vacuum. He took years constructing precision instrumentation and obtaining exact measurements. He set up a 1594.2658 m long vacuum tube in Orange County, California. A system of mirrors caused the light beam to reflect back and forth along the tube a total of 10 times while a 32-sided mirror revolved at 587.60395 Hz. Determine Michelson's value for the speed of light in a vacuum. [$2.997\ 750\ 0 \times 10^8$ m/s]

$V = \frac{d}{t} = \frac{10 \times 1594.2658\text{m}}{5.318207953 \times 10^{-5}}$

$= 2.99775002 \times 10^8 \text{m/s}$

$T = \frac{1}{f} = \frac{1}{587.60395}$

$= 0.0017018265$

$t = T \times \frac{1}{32}$

$= \frac{0.0017018265}{32}$

$t = 5.318 \times 10^{-5}\text{s}$

Use the information below to answer question 15.

The metre was originally defined in 1793 as one ten-millionth of the distance between the Earth's equator and pole as it passes through Paris, France. Later it was redefined as the distance between two marks on a platinum-iridium bar kept in Paris, France. This became the standard that all length measurements were referenced to. In 1983 the metre was re-defined as the distance light travels in 1/299 792 458 of a second in a vacuum.

15. List two benefits to referencing the length of a metre to the speed of light rather than the length of a metal bar. [Appendix A]

1) The speed of light does not change, the bar might

2) Bar is in one place, light is everywhere.

Use the following information to answer question 16.

In 1969 the Apollo 11 crew left a reflector on the Moon as part of the "Laser Ranging Retro-reflector Experiment". Laser pulses from the Earth are aimed at this reflector to determine the distance between the Earth and the Moon. It has been found that the Moon has been gradually moving away from the Earth at a rate of 3.8 cm per year.

0.038 m

16. A laser pulse aimed at a reflector on the Moon requires a total travel time of 2.72 s between the initial pulse and the detection of the reflected signal when the Moon is at its apogee. Calculate the separation distance between the Earth and the Moon at its apogee (i.e., where it is furthest from the Earth). [4.08×10^8 m]

$t = \frac{2.72}{2} = 1.36$ (one way time)

$v = \frac{d}{t}$

$d = vt$

$= 1.36\ s\,(3 \times 10^8\ m/s)$

$= 4.08 \times 10^8\ m$ one way

or $\frac{2.72(3 \times 10^8)}{2}$

17. Microwaves are used in telecommunications to transmit signals. Radar (an acronym for radio detection and ranging) uses microwave radiation. Radar was invented during the Second World War and can be used to determine the distance and speed of an object. A radar signal with a wavelength of 4.0 cm is reflected off a distant object and returns for a total travel time of 4.0 ms. Determine the distance separating the radar source and the object. [6.0×10^5 m]

4.0 cm = 0.04 m   4.0 ms = 4×10^{-3} s

$t = \frac{4 \times 10^{-3}}{2}$ (one way) $= 2 \times 10^{-3}$ s

$d = vt$

$= (3 \times 10^8\ m/s)(2 \times 10^{-3}\ s)$

$= 6.0 \times 10^5\ m$

Use the information below to answer questions 18 & 19.

Lasers and extremely precise timing devices used to be nonexistent, then prohibitively expensive. Now, laser ranging has become affordable enough that many department stores sell lasers for determining distance. They emit a short laser pulse, which is timed by an extremely accurate clock. When the beam contacts a target it is reflected and scattered in many directions, some of the reflected beam returns to the ranger, which detects it and measures the total time between emission and detection. The detector must be very sensitive and a highly reflective target will enable a longer range and better measurement.

18. Determine the total time for a pulse of laser light to be emitted and detected from a range finder measuring a distance of 13.2 m. [8.80×10^{-8} s]

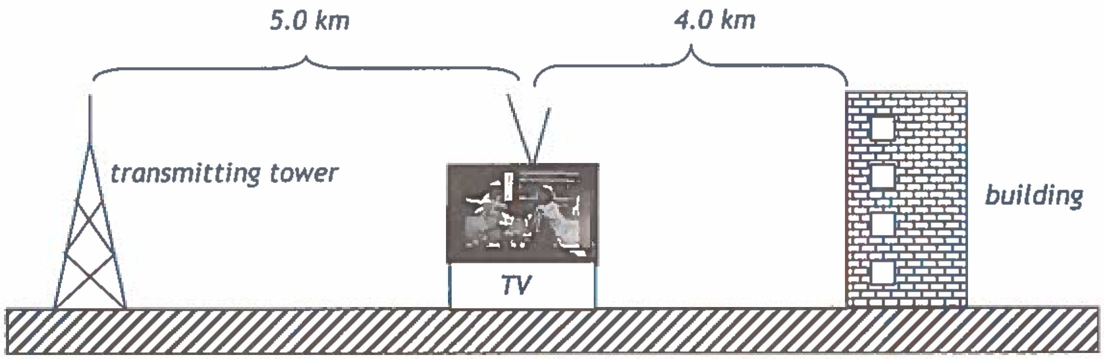
19. Determine the distance measured by a laser rangefinder if the total time between the light emission and detection is 2.83×10^{-7} s. [42.5 m]

Use the information below to answer question 20.

Hertz could only produce and detect waves in his laboratory. Guglielmo Marconi helped the communications revolution by producing and detecting radio waves over much longer distances. He is often credited with receiving the first transatlantic signal that was sent from Cornwall England to Signal Hill St. Johns Nfld. on December 12, 1901, a distance of 3425 km.

20. Calculate the time required for Marconi's radio signal to be transmitted across the Atlantic. [11.4 ms]

21. A television transmitting tower is 5.0 km from a receiving TV set as shown below. The person watching has to use "rabbit ear" antennas since he does not have cable or satellite TV. The television signal can take more than one path to get to the receiving set. It can take the direct path and it can also reflect off a nearby high rise building and then return to the set. As a result, the TV receives multiple signals producing multiple pictures called "ghosting." Calculate the time difference between the direct signal and reflected signal. [2.7×10^{-5} s]



Use the information below to answer question 22.

Electromagnetic radiation can be used for communication by changing (modulating) some aspect of the wave. Three common methods have been used:

i. pulse modulation (PM) changes the time the wave is on. This method is used to produce dots and dashes in Morse Code.
ii. amplitude modulation (AM) where changes in amplitude carry the message.
iii. frequency modulation (FM) where changes in frequency carry the message.

22. A radio wave having a wavelength of 2.5 cm is pulsed for a time of 0.60 s. Determine the number of complete wavelengths in the pulse. [7.2×10^{9} wavelengths]