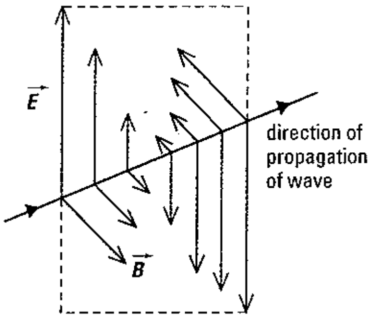
REFERENCE #1

▼ **Table 13.1** The Electromagnetic Spectrum: Characteristics

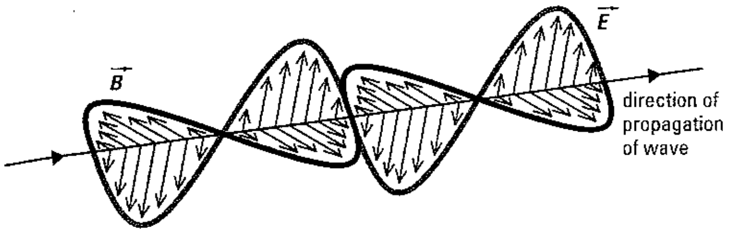
Type of Electromagnetic Radiation	Method of Production	Characteristics	Problems
Radio and Radar $f = 10^4 - 10^{10}$ Hz $\lambda = 10^4 - 10^{-2}$ m relative energy: very low	oscillation of electrons in an electric circuit like an antenna	long wavelength allows a large amount of diffraction making it useful for long-distance communication, e.g., PC broadband	requires government regulations to control transmission and avoid interference
Microwaves $f = 10^9 - 10^{12}$ Hz $\lambda = 10^{-1} - 10^{-4}$ m relative energy: low	oscillation of electrons in special tubes and solid state devices	shorter wavelength reduces diffraction for short-distance communication; frequency matches the natural resonant frequency of water molecules; used in microwave ovens and cell phones	may be linked to some forms of cancer; causes damage to living tissue due to heating of water molecules within tissues
Infrared $f = 10^{11} - 4.0 \times 10^{14}$ Hz $\lambda = 10^{-3} - 7.5 \times 10^{-7}$ m relative energy: low	motion of particles, transitions of valence electrons in atoms and molecules	causes object absorbing it to become warm; used for remote sensing, night vision scopes, and identification of sources of heat	significant exposure can burn tissue
Visible $f = 4.0 \times 10^{14} - 7.5 \times 10^{14}$ Hz $\lambda = 7.5 \times 10^{-7} - 4.0 \times 10^{-7}$ m relative energy: medium	higher-energy transitions involving valence electrons in atoms	reflects off small objects, making them visible; diffracts around very small objects, making them invisible	limits the size of objects that can be seen
Ultraviolet $f = 7.5 \times 10^{14} - 10^{17}$ Hz $\lambda = 4.0 \times 10^{-7} - 10^{-9}$ m relative energy: high	even higher-energy transitions involving valence electrons in atoms	easily absorbed by objects; causes fluorescence of some materials, tanning in humans; kills bacteria	may cause sunburn; prolonged exposure can cause mutations and cancer in humans
X ray $f = 10^{17} - 10^{20}$ Hz $\lambda = 10^{-9} - 10^{-12}$ m relative energy: very high	transitions of electrons in an atom or the sudden acceleration of high-energy free electrons	penetrates most matter and is absorbed by denser material (like bone or metal); destroys carcinogenic or mutant cells; used for medical imaging in humans and in industry	can cause mutations and cancer in humans
Gamma $f = 10^{19} - 10^{24}$ Hz $\lambda = 10^{-11} - 10^{-16}$ m relative energy: extremely high	decomposition of unstable nuclei, either spontaneously or by the sudden negative accelerations from high-energy particle accelerators	penetrates matter very deeply; destroys carcinogenic or mutant cells on a local scale; used to probe the structure of matter and in industrial imaging	can cause radiation sickness and death
Cosmic $f = 10^{24}$ Hz and greater $\lambda = 10^{-16}$ m and less relative energy: extremely high	bombardment of Earth's atmosphere by extremely high-energy particles from space	penetrates matter very deeply; study of cosmic rays allows investigators to formulate ideas about the universe	can cause radiation sickness and death

Now, consider the magnetic field that exists perpendicular to the electric field along this closed path. When the electric field is set in motion, the magnetic field will change along with the electric field, and similarly along a closed path. An electromagnetic wave will propagate in a direction perpendicular to both fields (Figure 13.14).

The changing electric and magnetic fields will propagate, or radiate, through space in the form of a wave — an **electromagnetic wave** (Figure 13.15). Maxwell proposed that the electromagnetic wave consists of periodic variations in the electric and magnetic field strengths and that these variations occur at right angles to one another as the wave propagates.



▲ **Figure 13.14** The magnetic field lines (in red) allow us to visualize the magnetic field that exists perpendicular to both the electric field and the direction of the wave.



▲ **Figure 13.15** Three-dimensional view of an electromagnetic wave

electromagnetic wave: periodic variation in perpendicular electric and magnetic fields, propagating at right angles to both fields

REFERENCE 2

Maxwell's Predictions

Maxwell's equations not only correctly predicted the existence of electromagnetic waves, but also allowed him to make some predictions about the waves' properties.

1. Electromagnetic waves are produced whenever an electric charge is accelerating. Therefore, as an electric charge oscillates, electrical energy will be lost, and an equivalent amount of energy will be radiated outward in the form of oscillating electric and magnetic fields.
2. When the electric charge is accelerated in periodic motion, the frequency of oscillation of the charge will correspond exactly to the frequency of the electromagnetic wave that is produced.
3. All electromagnetic waves will travel at a speed of 310 740 000 m/s and obey the universal wave equation ($c = f\lambda$) relating speed, frequency, and wavelength. (Note that Maxwell's theoretical prediction was not far from today's currently accepted value of 3.00×10^8 m/s for the speed of light in a vacuum.)
4. The oscillating electric and magnetic fields will always be perpendicular to each other and perpendicular to the direction of propagation of the wave.
5. Electromagnetic waves should show all the phenomena associated with transverse waves: interference, diffraction, refraction, and polarization.

It is Maxwell's last prediction that supports the wave model of EMR and relates his predictions to experimental evidence. Interference, diffraction, polarization, and refraction, as they relate to the wave model of EMR, will be explored in sections 13.4 and 13.5.

WEB

To learn more about ways of representing the relation between electric and magnetic fields, follow the links at www.pearsoned.ca/school/physicssource. Compare and contrast the representations you find.

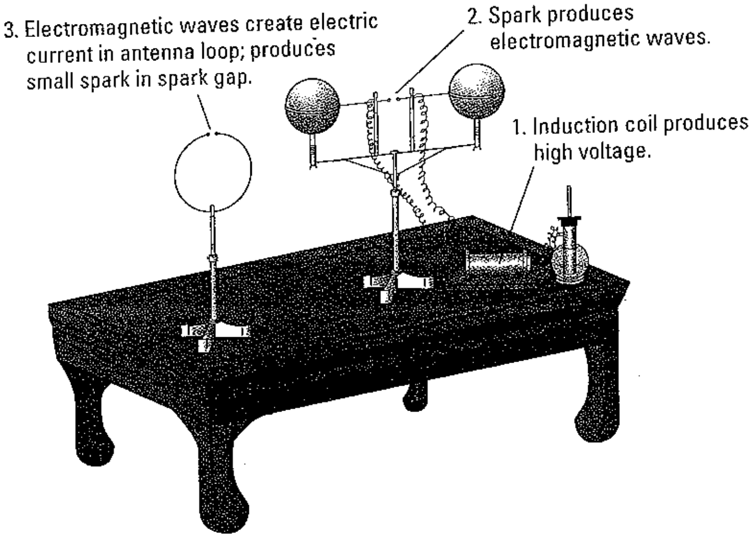
Producing Electromagnetic Radiation — The Story of Accelerating Charge

In 1887, the German physicist Heinrich Hertz (1857–1894) set up an experiment designed both to produce and to detect EMR. In his experimental apparatus, Hertz used a radiator, consisting of a pair of wires attached to both a high-voltage induction coil and a pair of capacity spheres. The wires were separated by a small gap and, given a sufficient quantity of opposite charge on each wire, a current would oscillate back and forth across the gap at a frequency of 10^9 Hz. With each oscillation a spark was produced when the moving charge ionized the air molecules on its way from one wire to the other.

From Maxwell's equations Hertz knew theoretically that this rapidly moving electric charge should produce EMR. A short distance away from the radiator a collector plate containing a small loop of wire, the antenna, was observed to detect the effect of EMR. While the radiator was in operation and when the radiator and the antenna were tuned to the same frequency, a spark was observed at the antenna indicating a potential difference and an electric current (Figure 13.16).

WEB

To learn more about details of Hertz's experiment, follow the links at www.pearsoned.ca/school/physicssource.



▲ **Figure 13.16** Hertz's apparatus consisted of a high-voltage induction coil, a radiator tha produces sparks, and an antenna loop.

Relating Theory and Practice in Hertz's Experiment

The word "changing" appears a number of times in Maxwell's origina proposal. As Maxwell understood it, a "changing" electric field wa crucial to creating an electromagnetic wave. This is where the inductio coil was important in Hertz's experimental design. The induction co rapidly changed the electric field across the spark gap. When this electri field reached a sufficiently high value, the electrons in the wi "jumped" from one electrode to the other. As the charge was rapidl transferred, the electric field underwent a rapid change that caused changing magnetic field, which then caused a changing electric fiel and so on. An electromagnetic wave was produced and it radiated outwa in all directions.

In Hertz's experiment, when the receiver was tuned to the same frequency as the radiator, the induced current flow in the antenna oscillated at a frequency identical to that of the changing electric field in the radiator. This was conclusive evidence that Hertz's device had indeed produced the EMR that was being observed at his antenna. Furthermore, he was able to measure the velocity of the waves by using a zinc reflector plate to produce a standing wave and moving a ring antenna within the standing wave. He could determine the magnitude and direction of the wave's components and therefore the wavelength. Given the frequency of the radiator, the velocity of the wave could be calculated using the universal wave equation ($v = f\lambda$).

Hertz had produced and measured the wavelength and velocity of *non-visible* EMR for the first time. Two years later, in 1889, radio pioneers used this method to transmit the first radio waves across the English Channel. By 1901, the first radio waves were transmitted across the Atlantic Ocean from Cornwall, England to St. John's, Newfoundland and a new age of technology had dawned. The production of EMR was one of the greatest scientific achievements of the 19th century, ushering in new possibilities and technologies that are commonplace today.

WEB

To learn more about Marconi and details of the first trans-Atlantic radio transmission, follow the links at www.pearsoned.ca/school/physicssource.

MINDS ON Going Wireless

Wireless communication systems that transmit data are commonplace today.

1. Create a list of wireless data transmission technologies.
2. What process must be common to all wireless transmission devices?
3. What variable is used to control the acceleration, and hence the energy, of the accelerating electrons in a wireless device?
4. One radio transmission tower transmits at 5.0 kV. Another transmits at 10.0 kV. Which tower has a greater signal strength and why?
5. Cell phones communicate with cell towers that are dispersed throughout urban cities and transportation corridors. Explain the relationship between the distance that separates a cell phone from the nearest cell tower and the operating power of the cell phone.
6. Many studies have been conducted to investigate and determine if there is a relationship between brain cancer and cell phone usage. Why would one suspect a relationship between cell phone use and brain cancer?

Although modern radio signals are generated without a spark, the technology operates in a way similar to Hertz's original experiment. Radio waves are generated by rapidly changing the electric potential, or voltage, in the radiator tower. The oscillating voltage produces an oscillating electric field in the radiator tower (Figure 13.17).

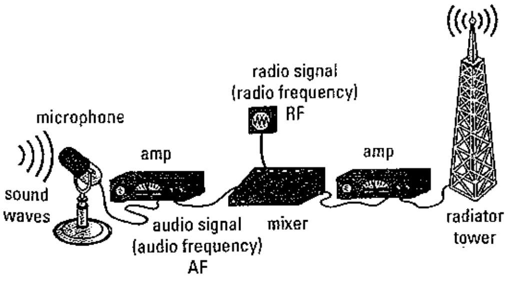
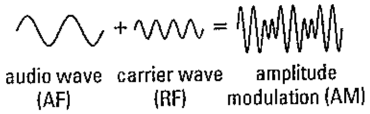
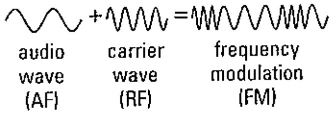


Figure 13.17 Schematic of a simple radio transmitter



▲ **Figure 13.18** Amplitude modulation. The audio signal and the carrier signal are mixed by modifying the amplitude of the carrier signal.



▲ **Figure 13.19** Frequency modulation. The signal is combined with a carrier wave to create a resultant wave with constant amplitude, but varying frequency.

Activity 5.8 – The Wave Model of Light

Pre-Test Assignment

EMR (electromagnetic radiation) is energy that travels outward from all directions from its source. There are different types of emr, identified by their frequency, wavelength and source. Fill in the following summary chart using the reference (1) provided on the McCoy web page.

1 see reference 1 on webpage

Type of emr	How emr is produced	Characteristics	Problems
Radio and radar			
Microwaves			
Infrared			
Visible			
x-rays			
Gamma			
Cosmic			

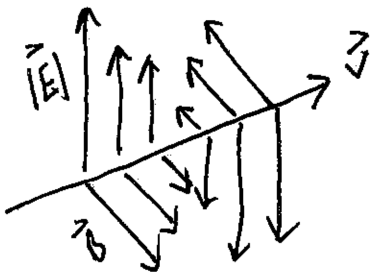
Use the reference (2) provided on the McCoy Web page to answer questions 2 – 6.

2. What is the source of emr ? Emr is produced by accelerating electric charges; as electrical energy is lost, an equal amount of energy is radiated outward by oscillating electric and magnetic fields.

3. How the the frequency of the emr produced compare to the frequency of the accelerating charge producing it? The frequency of vibration of the electric charges exactly matches the frequency of emr generated. For example FM radio waves of 96 MHz are produced by electrons vibrating back and forth 96 million times/second in a transmitting antennae.

4. What is the speed of emr in air or vaccum? Do different types of emr have different speeds in air or vaccum? Maxwell originally speculated that light was a form of emr based on the idea that light travels at 3.0×10^8 m/s --- which was the speed Maxwell predicted for emr! All emr, regardless of freq or wavelength, travels at 3.00×10^8 m/s in air or vaccum.

5. Describe the orientation of the oscillating electric and magnetic fields and veleocity of the emr.



The magnetic field is perpendicular to both the electric field and the direction ($\vec{v}$) of the wave.

See workbook bottom page 185.

6. Describe the experiment Hertz performed to detect and produce non-visible emr. What types of emr did he produce?

1) Hertz created an apparatus which created an oscillating spark which jumped between 2 wires

2) The spark (an accelerating charge) created an electromagnetic wave.

3) The emr was detected by an antennae loop, by producing a small spark in the gap. Hertz had produced the first non-visible emr - RADIO WAVES.

"means one color"

↗

7. Calculate the wavelength of monochromatic light of frequency 5.50 x 10^{14} Hz. Report your answer in nm.

$$\lambda = \frac{v}{f} = \frac{3.00\times10^{8}\,\frac{m}{s}}{5.50\times10^{14}\,Hz} = 5.45\times10^{-7}\,m \times \frac{1\,nm}{10^{-9}\,m}$$

or

545 nm

8. List the 7 colors of visible light from high to low frequency.

V I B G Y O R

high freq, short λ, higher Energy $\longrightarrow$ low freq, longer λ, lower energy

9. Determine the speed of light if Michelson used an 8 sided mirror rotating at 545 RPS placed 36.20 km from the plane mirror.

① $\frac{545R}{1s} = \frac{\frac{1}{8}R}{?s}$

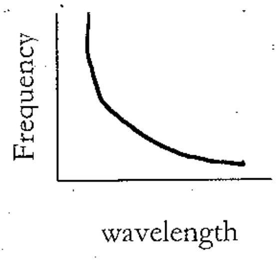
$?s = 2.293.. \times10^{-4}\,s$

In the time the mirror made $\frac{1}{8}R$, the light had travelled 36.20km × 2

② $v = \frac{d}{t} = \frac{72400\,m}{2.293.. \times10^{-4}\,s}$

$= 3.00\times10^{8}\,\frac{m}{s}$

10. Sketch a graph showing the relationship between the frequency of a wave and its wavelength.



$v = \lambda f$

$f \propto \frac{1}{\lambda}$ (inverse)

as wavelength increases, freq decreases (speed stays the same)

11. Determine the frequency of rotation necessary to produce an observed image if the distance separating a rotating 32 sided mirror from the fixed mirror is 12. Km.

assume $v = c$

$t = \frac{d}{c} = \frac{24000\,m}{3.00\times10^{8}\,m/s}$

$= 8.0\times10^{-5}\,s$

$\frac{\frac{1}{32}R}{8.0\times10^{-5}\,s} = \frac{?R}{1s}$

$= 3.9\times10^{2}\,Hz$

11. Determine the frequency of rotation necessary to produce an observed image if the distance separating a rotating 32 sided mirror from the fixed mirror is 12. Km.

omit on previous page

12. Calculate the speed of a blue laser (wavelength 485 nm) in plastic if its refracted wavelength is 442 nm in plastic. refraction - use Snell's law

med 1 - air
med 2 - plastic

$$\frac{V_1}{V_2} = \frac{\lambda_1}{\lambda_2}$$

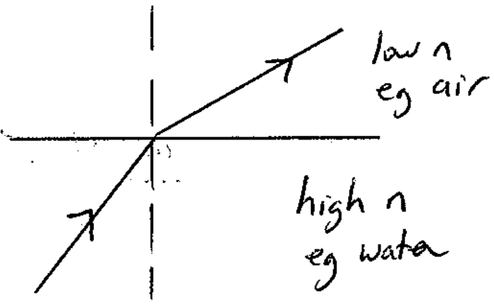
$$\frac{3.00 \times 10^8 \text{ m/s}}{V_2} = \frac{485 \text{ nm}}{442 \text{ nm}}$$

$$V_2 = 2.73 \times 10^8 \text{ m/s}$$

13. Light passes from a medium with a high refractive index to one with a low refractive index. Describe what happens to the direction, speed, wavelength and frequency. Draw a sketch.

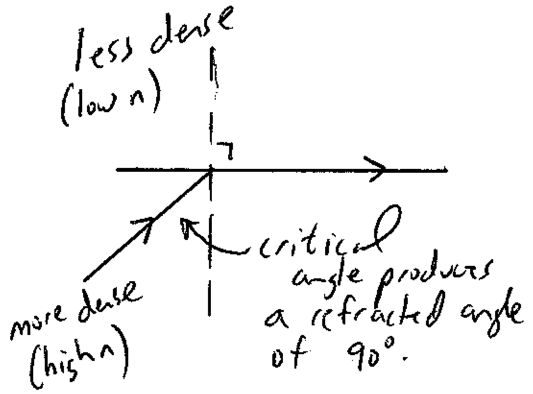
high n $\xrightarrow{\text{more dense}}$ low n

① wave bends away from normal
② speed increases
③ λ increases
④ freq is constant

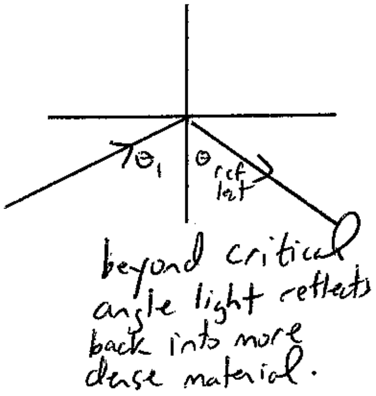


14. Draw a diagram outlining the conditions necessary to produce a critical angle. Calculate the critical angle for a diamond – air system. ($n_{diamond} = 2.42$)

med 1 – diamond
med 2 – air



critical angle produces a refracted angle of 90°.



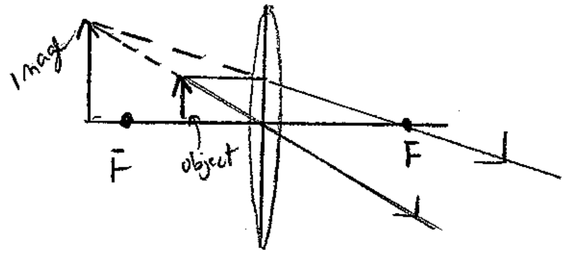
beyond critical angle light reflects back into more dense material.

$$\frac{n_2}{n_1} = \frac{\sin\theta_1}{\sin\theta_2}$$

$$\frac{1.00}{2.42} = \frac{\sin\theta_i}{\sin 90°}$$

$$\theta_1 = 24.4°$$

15. A 5.0 cm high object is 10.5 cm from a convex lens with a 20.0 cm focal length. Determine the image's characteristics and image distance.



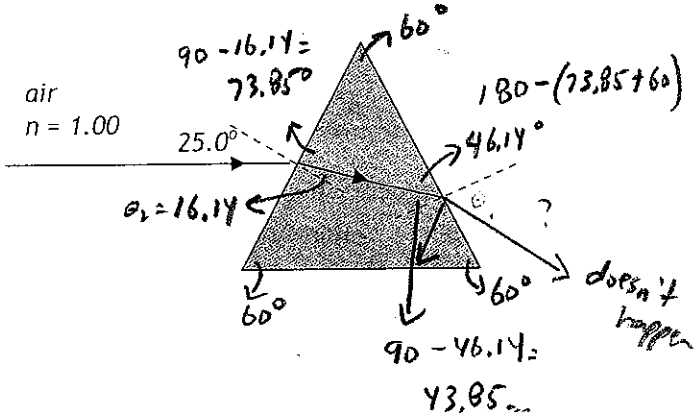
Characteristics
- erect
- larger
- virtual (object and image are on the same side of lens)

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$\frac{1}{20} = \frac{1}{10.5} + \frac{1}{d_i}$$

$d_i = -22.1 cm$ (− means virtual)

16. Determine the angle of refraction of light as it leaves the opposite side of the equilateral prism made of glass (n = 1.52) challenge question



1st refraction

air (1) → glass (2)

$$\frac{n_2}{n_1} = \frac{\sin\theta_1}{\sin\theta_2}$$

$$\frac{1.52}{1.00} = \frac{\sin 25.0}{\sin\theta_2}$$

$\theta_2 = 16.14..°$

2nd refraction

glass (1) → air (2)

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1}$$

$$\frac{\sin 43.85}{\sin\theta_2} = \frac{1.00}{1.52}$$

error = no angle - light does not refract it reflects into prism

17. The color blue is most affected by refraction blue changes speed and direction most!

The color red is most affected by diffraction.

long waves diffract more than shorter waves.

17. The color ______________________ is most affected by refraction

The color ______________________ is most affected by diffraction.

18. A glass grating is ruled with 5700 lines/cm. Determine the wavelength of light diffracted at 28.0 ° forming a second order image.

$$1)\quad 5700\,\frac{\text{lines}}{\text{cm}} \times \frac{100\,\text{cm}}{1\,\text{m}} = 570000\,\frac{\text{lines}}{\text{m}} \xrightarrow[\text{for } d]{\text{take inverse}} 1.75 \times 10^{-6}\,\frac{\text{m}}{\text{lines}}$$

$$2)\quad X = \frac{d \sin\theta}{n} = \frac{1.75 \times 10^{-6}\,\text{m} \times \sin 28.0^\circ}{2}$$

$$\lambda = 4.12 \times 10^{-7}\,\text{m} \text{ or } 412\,\text{nm}$$

19. A monochromatic beam of light is passed through 2 slits and forms an interference pattern on a screen with a special detector. The distance between the slits is 0.0620 cm and the distance to the screen is 4.50 m. The distance from the central bright line to the second order maximum is 2.65 cm. Calculate the wavelength of the light used and the region of the emr spectrum the light is coming from.

$$X = \frac{dx}{n\ell} = \frac{(0.062 \times 10^{-2}\,\text{m})(2.65 \times 10^{-2}\,\text{m})}{(2)(4.50\,\text{m})}$$

$$= \quad \times 10^{-6}\,\text{m}$$

[✓ IR]	visible	UV	X-ray
10^{-6} m	10^{-7} m	10^{-8} m	10^{-10} m

Complete the multiple choice practice that follows. Show work for calculations.

Name: ______________________ **Class:** _________________ **Date:** _________ **ID: A**

e- Test Wave Model of Light

Multiple Choice

Identify the choice that best completes the statement or answers the question.

D 1. Electromagnetic radiation, listed in order of increasing energy, is
- a. radio wave, X ray, microwave, infrared
- b. AC, radio wave, visible, infrared
- c. microwave, visible, infrared, ultraviolet
- d. microwave, infrared, visible, X ray

$E_{light} \propto f$

MW IR visible X ray $\longrightarrow$

low f high f

A 2. Which of the following is the same for all electromagnetic radiation in a vacuum?
- [✓ a. speed]
- b. period
- c. frequency
- d. wavelength

$v = c$
$= 3.00 \times 10^8$ m/s

D 3. The direction of electromagnetic wave propagation is

I	parallel to the electric field
II	perpendicular to the electric field
III	parallel to the magnetic field
IV	perpendicular to the magnetic field

The correct combination of choices is
- a. I only
- b. III only
- c. I and III only
- [✓ d.] II and IV only

$B_\perp, |\vec{E}|_\perp, \vec{v}_\perp$

D 4. Maxwell was a mathematician who predicted that light and electromagnetic radiation are one and the same thing. The most important evidence that Maxwell provided was that
- a. light and electromagnetic radiation both reflected.
- b. light and electromagnetic radiation both refracted.
- c. light and electromagnetic radiation both diffracted.
- [✓ d.] light and electromagnetic radiation both travelled at similar speeds.

Maxwell's "predicted" speed matched the actual speed of emr.

B 5. Use the following information to answer the next question.

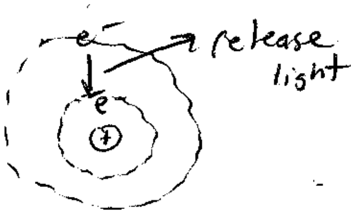
The paragraph below contains a factual error.

Electromagnetic radiation consists of a wide range of frequencies. However, different frequencies and wavelengths are measured in different media. The speed of all frequencies of electromagnetic radiation is the same in a vacuum, but differs in different media. Electromagnetic waves are transverse waves and can be polarized.

Which statement below identifies the factual error in the paragraph?
- a. Electromagnetic radiation consists of a wide range of frequencies. ✓
- b. [✓ Different frequencies and] wavelengths are measured in different media. frequency doesn't change!
- c. The speed of all frequencies of electromagnetic radiation is the same in a vacuum but differs in different media. ✓
- d. Electromagnetic waves are transverse waves and can be polarized. ✓

D 6. EMR is the result of accelerating charges. Visible light is produced by

a. DC current.
b. an oscillating crystal.
c. rapid deceleration of high-energy electrons.
d. electron transitions from higher to lower energy levels in atoms.



C 7. Metal foil was used during the Second World War to reduce the effectiveness of radar used to detect aircraft. The foil, cut to about 30.0 cm in length, or about $\frac{1}{2}\lambda$, was useful for rendering ineffective frequencies of

a. 5.00×10^6 Hz.
b. 1.00×10^7 Hz.
c. 5.00×10^8 Hz.
d. 1.00×10^9 Hz. ⑦

λ must be 60.0cm

$$f = \frac{c}{\lambda} = \frac{3.00 \times 10^8\ \frac{m}{s}}{0.60\,m}$$

$$f = 5.0 \times 10^8\ Hz$$

A 8. Blue light of wavelength 4.80×10^{-7} m has a period of vibration of

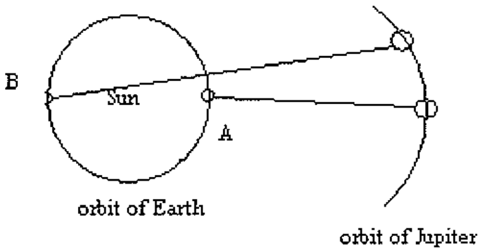
a. 1.60×10^{-15} s
b. 6.94×10^{-3} s
c. 1.44×10^2 s
d. 6.25×10^{14} s ⑧

$$f = \frac{c}{\lambda} = \frac{3 \times 10^8}{4.8 \times 10^{-7}} = 6.25 \times 10^{14}\ Hz$$

$$T = \frac{1}{f} = \frac{1}{6.25 \times 10^{14}}$$

$$T = 1.60 \times 10^{-15}\ s$$

C 9. Use the following information to answer the next question.



The two positions, A and B, of Earth in orbit around the Sun are shown above. The eclipse of Jupiter's moon from position B is observed 22 min after its eclipse from position A. Given that Earth's orbital diameter is 3.0×10^{11} m, the speed of light, as calculated by Huygens, is

a. 1.4×10^8 m/s
b. 1.9×10^8 m/s
c. 2.3×10^8 m/s
d. 3.0×10^8 m/s

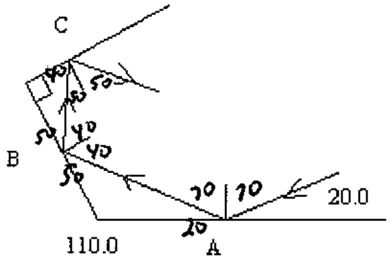
$$V = \frac{d}{t} = \frac{3.0 \times 10^{11}\,m}{22\,min \times \frac{60\,s}{min}} = 2.3 \times 10^8\ \frac{m}{s}$$

B 10. The speed of an electromagnetic wave is determined by the

a. period.
[✓ b.] medium.
c. source.
d. wavelength.

The denser the medium (↑er "n" value) the slower emr travels through it.

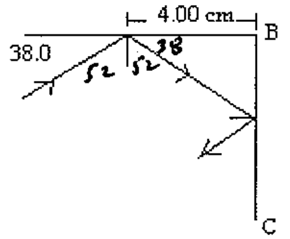
C 11. Plane mirrors, A, B and C, are shown below.



The angle between the incident ray and mirror A is 20.0°. If the angle between mirrors A and B is 110.0° and the angle between mirrors B and C is 90.0°, then the final angle of reflection from mirror C is

a. 20.0°
[✓ c. 50.0°]
b. 40.0°
d. 70.0°

C 12. Use the following information to answer the next question.



$\tan 38 = \frac{opp}{4.0cm}$

$opp = 3.13cm$

Mirrors AB and BC are perpendicular to each other. A light ray strikes mirror AB at an angle of 38.0° and 4.00 cm from B. The distance from B at which the reflected ray strikes mirror BC is

a. 0.195 cm
c. 3.13 cm
b. 2.46 cm
d. 3.15 cm

D 13. With optical fibres, light undergoes total internal reflection sometimes hundreds of thousands of times. In order for the light to reflect internally, the light must be travelling

a. at the speed of light outside the fibre, continually reflecting off the air-glass interface.
b. at the speed of light inside the fibre, continually reflecting off the air-glass interface.
c. at less than the speed of light outside the fibre, continually reflecting off the air-glass interface.
d. at less than the speed of light inside the fibre, continually reflecting off the air-glass interface.

- in order to have internal reflection, emr must be trapped in the more dence medium.

D 14. Use the following information to answer the next question.

I	Frequency increases.
II	Frequency decreases.
III	Frequency stays the same.
IV	Wavelength increases.
V	Wavelength decreases.
VI	Wavelength stays the same.
VII	Speed increases.
VIII	Speed decreases.
IX	Speed stays the same.
X	Total internal reflection is possible.
XI	Total internal reflection is not possible.

air - less dense $(n=1.00)$

water - more dense $(n=1.33)$

When light goes from air into water, the true statements above are

a. I, IV, VII, and X

b. II, V, VII, and XI

c. III, VI, IX, and X

d. III, V, VIII, and XI

$3000 \frac{\text{lines}}{\text{cm}} \times \frac{100\text{cm}}{\text{m}} = 3 \times 10^5 \frac{\text{lines}}{\text{m}}$

D 15. In order to determine the wavelength of light, a student acquires a diffraction grating that has a spacing of 3.00×10^3 lines/cm. She then directs the light through the grating onto a screen 5.00 m away. She measures the first antinodal line at 0.868 m from the central maximum. With this information, the student calculates the wavelength of light to be

antinode - bright line

$$\lambda = \frac{dx}{nl} = \frac{\left(\frac{1}{3\times10^5}\right)(.868)}{(1)(5.00\text{m})}$$

a. 1.73×10^6 m

b. 1.73×10^4 m

c. 5.79×10^{-5} m

d. 5.79×10^{-7} m

B 16. The amount of diffraction of light through an opening depends on two variables: the wavelength of the light and the relative size of the opening. The most diffraction occurs with

a. short wavelengths and a small opening.

b. long wavelengths and a small opening.

c. short wavelengths and a large opening.

d. long wavelengths and a large opening.

D 17. Diffuse reflection results from

a. incoming parallel rays, reflecting according to the law of reflection and parallel, to produce a clear image after total internal reflection.

b. incoming parallel rays, reflecting according to the law of reflection and parallel, to produce a clear image from a perfectly smooth reflective surface.

c. incoming parallel rays, reflecting according to the law of reflection but not parallel, to produce a blurry image after total internal reflection.

d. incoming parallel rays, reflecting according to the law of reflection but not parallel, to produce a blurry image from a less-than-smooth reflective surface.

see first page of activity 5.3 for a diagram

I will explain the nature and behavior of EMR using the wave model.