Skill 51: EM Waves

135. Electromagnetic (EM Wave) – produced by the acceleration (oscillation) of a charged particle. EM waves are able to travel through a vacuum. (A place without matter.)

A charged particle has an electric field and also creates a perpendicular magnetic field. This in turn creates an electric field.

136. EM Spectrum Chart from Reference Table: Values given for a vacuum, therefore the speed of every wave on this chart is \(3.0 \times 10^8\) m/s known as “c”. If you know wavelength and speed you can find frequency.

![EM Spectrum Chart]

Frequency must be in proper scientific notation to use the EM spectrum chart.

137. When an EM wave enters a medium the speed of the wave will depend on the index of refraction “n” of the medium. The speed in the new medium can be calculated using the equation \(n = c/v\) which means \(v = c/n\).

Index of refraction and speed of EM wave in a medium have a(n) \(\text{inverse}\) relationship.

138. The frequency of an EM does not change if it enters a new medium.

139. EM Waves are photons. They behave as both \(\text{particles}\) and \(\text{waves}\).
140. A wave traveling through a vacuum has a wavelength of 100 nm. What type of wave is this?
\[ \lambda = 100 \text{ nm} = 1 \times 10^{-9} \text{ m} \]
\[ V = c = 3 \times 10^8 \text{ m/s} \]
\[ f = \frac{V}{\lambda} = \frac{3 \times 10^8 \text{ m/s}}{1 \times 10^{-9} \text{ m}} = 3 \times 10^{17} \text{ Hz} \] (Ultraviolet)

141. A wave traveling through a vacuum has a wavelength of 4.70 x 10^{-3} m. What type of wave is this?
\[ \lambda = 4.7 \times 10^{-3} \text{ m} \]
\[ V = c = 3 \times 10^8 \text{ m/s} \]
\[ f = \frac{V}{\lambda} = \frac{3 \times 10^8 \text{ m/s}}{4.7 \times 10^{-3} \text{ m}} = 6.3 \times 10^{10} \text{ Hz} \]

142. A wave has a wavelength of 50 x 10^{-6} m. What type of wave is this?
\[ \lambda = 5 \times 10^{-6} \text{ m} = 5.0 \times 10^{-5} \text{ m} \] must be in correct unit

143. An electromagnetic wave with a wavelength of 5 x 10^{-9} m is traveling through outer space.

   a. What is the speed of this wave? \(3 \times 10^8 \text{ m/s}\) (speed of light, maximum)

   b. Determine the frequency of this wave
\[ f = \frac{V}{\lambda} = \frac{3 \times 10^8 \text{ m/s}}{5 \times 10^{-9} \text{ m}} = 6 \times 10^{16} \text{ Hz} = 6 \times 10^{10} \text{ Hz} \]

   c. In what part of the electromagnetic spectrum is this wave found? UV or X-ray

144. An electromagnetic wave with a frequency of 6.2 x 10^{14} Hz is passing through unknown substance that has an index of refraction of 2.4

   a. In what part of the electromagnetic spectrum is this wave found? Blue visible light

   b. Determine the speed of the wave in this medium.
\[ n = \frac{c}{V} \]
\[ V = \frac{c}{n} = \frac{3 \times 10^8 \text{ m/s}}{2.4} = 1.25 \times 10^8 \text{ m/s} \]

   c. Calculate the wavelength of this wave in this medium.
\[ \lambda = \frac{V}{f} \]
\[ \lambda = \frac{1.25 \times 10^8 \text{ m/s}}{6.2 \times 10^{14} \text{ Hz}} = 2 \times 10^{-7} \text{ m} = 2 \times 10^{-6} \text{ m} \]

   Frequency remains the same when mediums change
   - Wavelengths do not
145. Bees have specially adapted eyes that can detect electromagnetic radiation outside of what humans refer to as 'visible light'. Some flowers that bees visit have colorations that are invisible to humans, and yet match this amazing evolutionary development in bees! Bees also use these specially adapted eyes to aid them in navigation when it is cloudy. This type of radiation has a somewhat higher frequency than that of visible light.

What part of the electromagnetic spectrum are these bee eyes able to see?

Ultra-Violet

145. An electromagnetic wave traveling through a vacuum has a wavelength of $1.5 \times 10^3$ meter. What is the period of this electromagnetic wave?

(1) $5.0 \times 10^{10}$ s
(2) $1.5 \times 10^4$ s
(3) $4.5 \times 10^7$ s
(4) $2.0 \times 10^9$ s

$\lambda = \frac{c}{v} \quad T = \frac{\lambda}{v} = \frac{1.5 \times 10^3}{5 \times 10^8} = 3 \times 10^{-6} \quad \text{OR} \quad v = \frac{c}{T} = \frac{3 \times 10^8}{5 \times 10^{-6}} = 6 \times 10^4$

147. The speed of a ray of light traveling through a substance having an absolute index of refraction of 1.1 is

(1) $1.1 \times 10^8$ m/s
(2) $2.7 \times 10^8$ m/s
(3) $3.0 \times 10^8$ m/s
(4) $3.3 \times 10^8$ m/s

$n = \frac{c}{v} \quad v = \frac{c}{n = \frac{3 \times 10^8}{1.1}} = 2.7 \times 10^8$

148. A microwave and an x-ray are traveling in a vacuum. Compared to the wavelength of the microwave, the x-ray has a wavelength that is

(1) longer and a period that is shorter
(2) longer and a period that is longer
(3) shorter and a period that is longer
(4) shorter and a period that is shorter

As $\lambda$ decreases, frequency increases; frequency and period are inversely proportional, so $\lambda \cdot T$ are direct.

149. Which wavelength is in the infrared range of the electromagnetic spectrum?

(1) 100 nm
(2) 100 mm
(3) 100 m
(4) 100 μm

$100 \text{ nm} = 10^7 \text{ m}
100 \text{ mm} = 10^3 \text{ m}
100 \text{ m} = 1 \times 10^8 \text{ m}
100 \mu \text{ m} = 1 \times 10^{-4 \text{ m}}$

$\frac{c}{T} = \lambda \quad v = \frac{c}{\lambda}$

150. To determine the type or category of a wave on the EM spectrum you can use either the wavelength or frequency if traveling in a vacuum unless it is visible light. If the wave is traveling through a substance you must solve for frequency, because it does not change when an EM wave enters a new medium.

Radio waves are categorized as electromagnetic because they can travel through the vacuum of space. The type of particle vibration for radio waves is transverse which means the particles move perpendicular to the motion of the wave. Visible light (such as Red, Orange...) is similar to a radio wave in type of wave and type of particle vibration but it has a higher energy, a smaller wavelength and a higher frequency. In a vacuum the speed of a radio wave and a visible light are the same (which is $3 \times 10^8 \text{ m/s}$).

Sound waves are categorized as mechanical because they cannot travel through a vacuum. The type of particle vibration for sound waves is longitudinal. Mechanical waves other than sound can also have transverse particle vibration. The speed of a sound wave in air at STP is $331 \text{ m/s}$. The speed of sound in air is less than water because the particles are less dense.
<table>
<thead>
<tr>
<th>Sound Waves</th>
<th>Electromagnetic Waves</th>
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</thead>
<tbody>
<tr>
<td><strong>What do they do?</strong></td>
<td>Transfer energy, not mass.</td>
</tr>
<tr>
<td><strong>Where do they come from?</strong></td>
<td>Vibration within a medium. (Sound is a pressure wave)</td>
</tr>
<tr>
<td><strong>Types of Vibration</strong></td>
<td><img src="image" alt="Longitudinal Vibration" /></td>
</tr>
<tr>
<td><strong>Speed</strong></td>
<td>Speed of sound at STP: ( \frac{331 \text{ m/s}}{1} )</td>
</tr>
<tr>
<td><strong>How speed changes with medium</strong></td>
<td>Can only move (propagate) through a medium. Speed up with density. CANNOT propagate through a vacuum</td>
</tr>
<tr>
<td><strong>Energy of a propagating wave is related to...</strong></td>
<td>Amplitude</td>
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<tr>
<td><strong>To compare the energy of two different types of wave consider</strong></td>
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<td><strong>Amplitude is related to...</strong></td>
<td>Loudness</td>
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<td><strong>Increasing frequency is related to...</strong></td>
<td>Increasing pitch</td>
</tr>
<tr>
<td><strong>Wavelength is the distance</strong></td>
<td>Between two compressions or rarefactions</td>
</tr>
</tbody>
</table>
152. Which color of light has a wavelength of 5.0 \times 10^{-7} \text{ meter in air?}

A) blue  \quad \underline{\text{B) green}}  \quad \text{C) orange}  \quad \text{D) violet}

\begin{align*}
\lambda &= \frac{c}{\nu} \\
\lambda &= \frac{3 \times 10^8 \text{ m/s}}{5 \times 10^{14} \text{ Hz}} = 6 \times 10^{-7} \text{ m}
\end{align*}

153. An electromagnetic AM-band radio wave could have a wavelength of

A) 0.005 \text{ m} \quad \frac{5 \times 10^3 \text{ m}}{} \quad \text{B) 5 m} \quad \frac{5 \times 10^1 \text{ m}}{} \quad 
C) 500 \text{ m} \quad \frac{5 \times 10^2 \text{ m}}{} \quad \text{D) 5 000 000 m} \quad \frac{5 \times 10^6 \text{ m}}{}

154. A microwave and an x-ray are traveling in a vacuum. Compared to the wavelength and period of the microwave, the x-ray has a wavelength that is

A) longer and a period that is shorter  \quad \text{B) longer and a period that is longer}
C) shorter and a period that is longer  \quad \underline{\text{D) shorter and a period that is shorter}}

\begin{align*}
\frac{\lambda_x}{\lambda_m} &= \frac{c}{v} \\
\frac{v}{v} &= \frac{5 \times 10^8 \text{ m/s}}{3 \times 10^8 \text{ m/s}} = \frac{5}{3}
\end{align*}

155. Which wavelength is in the infrared range of the electromagnetic spectrum?

A) 100 \text{ nm} \quad \underline{\text{B) 100 mm} \quad \frac{1 \times 10^{-3} \text{ m}}{}} \quad \text{C) 100 \text{ m} \quad \frac{1 \times 10^{-1} \text{ m}}{}} \quad \text{D) 100 \mu \text{m} \quad \frac{1 \times 10^{-6} \text{ m}}{}}

156. Electromagnetic radiation having a wavelength of 1.3 \times 10^{-7} \text{ meter would be classified as}

A) infrared  \quad \underline{\text{B) orange}}  \quad \text{C) blue}  \quad \text{D) ultraviolet}

\begin{align*}
\frac{v}{c} &= \frac{3 \times 10^8 \text{ m/s}}{1.3 \times 10^{-7} \text{ m}} = 3 \times 10^{15} \text{ Hz}
\end{align*}

157. Radio waves are propagated through the interaction of

A) nuclear and electric fields  \quad \text{B) electric and magnetic fields}
C) gravitational and magnetic fields  \quad \text{D) gravitational and electric fields}

158. Compared to the period of a wave of red light the period of a wave of green light is

A) less  \quad \underline{\text{B) greater}}  \quad \text{C) the same}

\begin{align*}
\frac{v}{c} &= \frac{3 \times 10^8 \text{ m/s}}{5 \times 10^{14} \text{ Hz}} = 6 \times 10^{10} \text{ Hz}
\end{align*}

159. Which pair of terms best describes light waves traveling from the Sun to Earth?

A) electromagnetic and transverse  \quad \underline{\text{B) electromagnetic and longitudinal}}
C) mechanical and transverse  \quad \text{D) mechanical and longitudinal}

160. Electrons oscillating with a frequency of 2.0 \times 10^{10} \text{ hertz produce electromagnetic waves. These waves would be classified as}

A) infrared  \quad \underline{\text{B) visible}}  \quad \text{C) microwave}  \quad \text{D) x-ray}

\begin{align*}
\frac{v}{c} &= \frac{3 \times 10^8 \text{ m/s}}{2 \times 10^{10} \text{ Hz}} = 1.5 \times 10^{-2} \text{ m}
\end{align*}
Topic 6B: Electromagnetic Waves

161. A photon of which electromagnetic radiation has the most energy?
A) ultraviolet  B) x-ray  C) infrared  D) microwave

162. Compared to the wavelength of red light, the wavelength of yellow light is
A) shorter  B) longer  C) the same

163. A beam of green light may have a frequency of
A) $5.0 \times 10^{-7}$ Hz  B) $1.5 \times 10^2$ Hz  C) $3.0 \times 10^8$ Hz  D) $6.0 \times 10^{14}$ Hz

164. A monochromatic beam of light has a frequency of $6.5 \times 10^{14}$ hertz. What color is the light?
A) yellow  B) orange  C) violet  D) blue

165. Which electromagnetic radiation has the shortest wavelength?
A) infrared  B) radio  C) gamma  D) ultraviolet

166. Which of the following electromagnetic waves has the lowest frequency?
A) violet light  B) green light  C) yellow light  D) red light

167. Which of the following electromagnetic radiations has the shortest wavelength?
A) radio  B) infrared  C) visible  D) ultraviolet

168. Which is not in the electromagnetic spectrum?
A) light waves  B) radio waves  C) sound waves  D) x-rays

169. Which color of light has the greatest period?
A) violet  B) green  C) orange  D) red

170. To which part of the electromagnetic spectrum will a photon belong if its wavelength in a vacuum is $5.6 \times 10^{-7}$ meters?
A) X-ray  B) ultraviolet  C) visible light  D) infrared

\[
f = \frac{c}{\lambda} = \frac{3 \times 10^8}{5.6 \times 10^7} \approx 5.3 \times 10^4 \text{ Hz}
\]
171. The color of visible light is determined by its
   A) frequency  B) amplitude
   C) intensity  D) speed

172. Which statement best describes a proton that is being accelerated?
   A) It produces electromagnetic radiation.
   B) The magnitude of its charge increases.
   C) It absorbs a neutron to become an electron.
   D) It is attracted to other protons.

173. The diagram below shows an antenna emitting an electromagnetic wave.

   Antenna  Direction of wave motion
   [Diagram of antenna and wave motion]

   In what way did the electrons in the antenna produce the electromagnetic wave?
   A) by remaining stationary
   B) by moving at constant speed upward, only
   C) by moving at constant speed downward, only
   D) by accelerating alternately upward and downward

174. Electromagnetic waves can be generated by accelerating
   A) a hydrogen atom  B) a photon
   C) a neutron  D) an electron

   An electron has a charge.

175. An accelerating particle that does not generate electromagnetic waves could be
   A) a neutron  B) a proton
   C) an electron  D) an alpha particle

176. When electrical charges are accelerated in a vacuum, they may generate
   A) sound waves  B) water waves
   C) light waves  D) torsional waves

177. Radiations such as radio, light, and gamma are propagated by the interchange of energy between
   A) magnetic fields, only
   B) electric fields, only
   C) electric and gravitational fields
   D) electric and magnetic fields

178. Orange light has a frequency of $5.0 \times 10^{14}$ hertz in a vacuum. What is the wavelength of this light?
   A) $1.5 \times 10^{-3}$ m  B) $1.7 \times 10^{-6}$ m
   C) $6.0 \times 10^{-7}$ m  D) $2.0 \times 10^{-15}$ m

   \[ \lambda = \frac{c}{f} = \frac{3 \times 10^8 \text{ m/s}}{5 \times 10^{14} \text{ Hz}} = 6 \times 10^{-7} \text{ m} \]
179. What is the wavelength of X-rays with a frequency $1.5 \times 10^{18}$ hertz traveling in a vacuum?

A) $4.5 \times 10^{26}$ m  
B) $2.0 \times 10^{-10}$ m  
C) $5.0 \times 10^{-10}$ m  
D) $5.0 \times 10^9$ m

$$\lambda = \frac{c}{f} = \frac{3 \times 10^8 \text{m/s}}{1.5 \times 10^{18} \text{Hz}} = 2 \times 10^{-10} \text{m}$$

180. The time required for light to travel a distance of $1.5 \times 10^{11}$ meters is closest to

A) $5.0 \times 10^{-2}$ s  
B) $2.0 \times 10^{-3}$ s  
C) $5.0 \times 10^{-1}$ s  
D) $4.5 \times 10^{19}$ s

$$\lambda = \frac{c}{f} = \frac{3 \times 10^8 \text{m/s}}{1.5 \times 10^{18} \text{Hz}} = 2 \times 10^{-10} \text{m}$$

181. The distance from the Moon to Earth is $3.9 \times 10^8$ meters. What is the time required for a light ray to travel from the Moon to Earth?

A) 0.65 s  
B) 1.3 s  
C) 2.6 s  
D) 3.9 s

$$\lambda = \frac{c}{f} = \frac{3 \times 10^8 \text{m/s}}{1.5 \times 10^{18} \text{Hz}} = 2 \times 10^{-10} \text{m}$$

182. A typical microwave oven produces radiation at a frequency of $1.0 \times 10^{10}$ hertz. What is the wavelength of this microwave radiation?

A) $3.0 \times 10^{-1}$ m  
B) $3.0 \times 10^{-2}$ m  
C) $3.0 \times 10^0$ m  
D) $3.0 \times 10^{18}$ m

$$\lambda = \frac{c}{f} = \frac{3 \times 10^8 \text{m/s}}{1.0 \times 10^{10} \text{Hz}} = 3 \times 10^{-2} \text{m}$$

183. How long will it take a light wave to travel a distance of 100 meters?

A) $3.00 \times 10^{10}$ s  
B) $3.00 \times 10^8$ s  
C) $3.33 \times 10^{-7}$ s  
D) $3.33 \times 10^7$ s

$$\lambda = \frac{c}{f} = \frac{3 \times 10^8 \text{m/s}}{1.0 \times 10^{10} \text{Hz}} = 3 \times 10^{-2} \text{m}$$

184. When x-ray radiation and infrared radiation are traveling in a vacuum, they have the same

A) speed  
B) frequency  
C) wavelength  
D) energy per photon

185. Which characteristic is the same for every color of light in a vacuum?

A) energy  
B) frequency  
C) speed  
D) period

186. How much time does it take light from a flash camera to reach a subject 6.0 meters across a room?

A) $5.0 \times 10^{-9}$ s  
B) $2.0 \times 10^{-8}$ s  
C) $5.0 \times 10^{-8}$ s  
D) $2.0 \times 10^{-7}$ s

$$\lambda = \frac{c}{f} = \frac{3 \times 10^8 \text{m/s}}{1.0 \times 10^{10} \text{Hz}} = 3 \times 10^{-2} \text{m}$$

187. Base your answer to the following question on the information below.

A 2.00 $\times 10^6$-hertz radio signal is sent a distance of $7.30 \times 10^6$ meters from Earth to a spaceship orbiting Mars.

Approximately how much time does it take the radio signal to travel from Earth to the spaceship?

A) $4.11 \times 10^{-3}$ s  
B) $2.43 \times 10^2$ s  
C) $2.19 \times 10^8$ s  
D) $1.46 \times 10^17$ s

$$\lambda = \frac{c}{f} = \frac{3 \times 10^8 \text{m/s}}{2 \times 10^6 \text{Hz}} = 1.5 \times 10^{-2} \text{m}$$
188. As the wavelength of a visible light beam is increased from violet to red, the speed of the light in a vacuum
   A) decreases  B) increases  C) remains the same
   Speed in a vacuum is $c = 3 \times 10^8 \text{ m/s}$ for all EM waves.

189. As the frequency of an electromagnetic wave increases, its speed in a vacuum
   A) decreases  B) increases  C) remains the same
   Speed in a vacuum is $c = 3 \times 10^8 \text{ m/s}$ for all EM waves.

190. All frequencies of light have the same speed when traveling through
   A) a vacuum  B) glass  C) water  D) alcohol

191. A change in the speed of a wave as it enters a new medium produces a change in
   A) frequency  B) period  C) wavelength  D) phase

   Frequency comes from the source of the wave and does not change after created.

   Period depends on frequency so it follows the same rules.

192. What happens to the frequency and the speed of an electromagnetic wave as it passes from air into glass?
   A) The frequency decreases and the speed increases.
   B) The frequency increases and the speed decreases.
   C) The frequency remains the same and the speed increases.
   D) The frequency remains the same and the speed decreases.

   Frequency remains the same.
   $V = C/n$
   $n$ of air = 1
   $n$ of glass = 1.52 or 1.60 $\Rightarrow n^2$

193. What is the speed of light ($f = 5.09 \times 10^{14} \text{ Hz}$) in ethyl alcohol?
   A) $4.53 \times 10^{-9} \text{ m/s}$  B) $2.43 \times 10^2 \text{ m/s}$
   C) $1.24 \times 10^8 \text{ m/s}$  D) $2.21 \times 10^8 \text{ m/s}$
   $V = \frac{C}{n} = \frac{3 \times 10^8 \text{ m/s}}{1.36}$

194. The wavelength of a wave doubles as it travels from medium $A$ into medium $B$. Compared to the wave in medium $A$, the wave in medium $B$ has
   A) half the speed  B) twice the speed  C) half the frequency  D) twice the frequency

   Frequency remains the same.
   $V = f \lambda$ direct so speed doubles.

195. As a wave travels into a different medium with a change in direction, there will be a change in the wave's
   A) speed  B) frequency  C) period  D) phase

   Frequency and period are linked, frequency does not change.
   $V = C/n$
196. What is the speed of light \((f = 5.09 \times 10^{14} \, \text{Hz})\) in flint glass?

(A) \(1.81 \times 10^8 \, \text{m/s}\)  
(B) \(1.97 \times 10^8 \, \text{m/s}\)  
(C) \(3.00 \times 10^8 \, \text{m/s}\)  
(D) \(4.98 \times 10^8 \, \text{m/s}\)

\[ \text{can't be greater than } \frac{c}{n} \]

197. What is the speed of a ray of light \((f = 5.09 \times 10^{14} \, \text{hertz})\) traveling through a block of sodium chloride?

(A) \(1.54 \times 10^8 \, \text{m/s}\)  
(B) \(1.95 \times 10^8 \, \text{m/s}\)  
(C) \(3.00 \times 10^8 \, \text{m/s}\)  
(D) \(4.62 \times 10^8 \, \text{m/s}\)

\[ \frac{c}{n} = \frac{3 \times 10^8 \, \text{m/s}}{1.54} \]

198. Which quantity is equivalent to the product of the absolute index of refraction of water and the speed of light in water?

A) wavelength of light in a vacuum  
B) frequency of light in water  
C) sine of the angle of incidence  
D) speed of light in a vacuum

\[ n = \frac{c}{v} \quad \text{C} = nv \]

199. If the speed of light in a medium is \(2.0 \times 10^8 \, \text{meters per second}\), the index of refraction for the medium is

A) 1.0  
B) 2.0  
C) \(\frac{3}{2}\)  
D) 0.67

\[ \frac{c}{v} = \frac{2 \times 10^8 \, \text{m/s}}{3 \times 10^8 \, \text{m/s}} \]

200. In which of the following materials is the speed of light the greatest?

A) quartz  
B) alcohol  
C) glycerol  
D) lucite

\[ \frac{c}{n} \quad \text{inverse} \]