Section 10.4: Electromagnetic Radiation

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1. Given: f = 107.1 MHz = 1.071×10^8 Hz; $c = 3.0 \times 10^8$ m/s

Required: λ

Analysis: $c = \lambda f$; $\lambda = \dfrac{c}{f}$

Solution:
$$\begin{aligned}\lambda &= \frac{c}{f}\\ &= \frac{3.0\times10^8\ \text{m/}\cancel{\text{s}}}{1.071\times10^8\ \cancel{\text{Hz}}}\\ \lambda &= 2.8\ \text{m}\end{aligned}$$

Statement: The wavelength of the signal is 2.8 m.

2. Given: $f = 3.0\times10^{17}$ Hz; $c = 3.0 \times 10^8$ m/s

Required: λ

Analysis: $c = \lambda f$; $\lambda = \dfrac{c}{f}$

Solution:
$$\begin{aligned}\lambda &= \frac{c}{f}\\ &= \frac{3.0\times10^8\ \text{m/}\cancel{\text{s}}}{3.0\times10^{17}\ \cancel{\text{Hz}}}\\ &= 1.0\ \times10^{-9}\,\text{m}\\ \lambda &= 1.0\ \times10^{-7}\,\text{cm}\end{aligned}$$

Statement: The wavelength of the X-rays is 1.0×10^{-7} cm.

3. Given: λ = 638 nm = 6.38×10^{-7} m; $c = 3.0 \times 10^8$ m/s

Required: T

Analysis:
$$\begin{aligned}\lambda f &= c\\ f &= \frac{c}{\lambda}\\ T &= \frac{1}{f}\\ T &= \frac{\lambda}{c}\end{aligned}$$

Solution:
$$\begin{aligned}T &= \frac{\lambda}{c}\\ &= \frac{6.38\times10^{-7}\ \cancel{\text{m}}}{3.0\times10^8\ \cancel{\text{m}}/\text{s}}\\ T &= 2.1\times10^{-15}\ \text{s}\end{aligned}$$

Statement: The period of the wave is 2.1×10^{-15} s.

4. Given: $f = 60$ Hz; $x = 5.0 \times 10^3$ km $= 5.0 \times 10^6$ m; $c = 3.0 \times 10^8$ m/s
Required: n, number of wavelengths
Analysis: Calculate the wavelength of the electrical transmission using the universal wave equation, $c = \lambda f$; $\lambda = \frac{c}{f}$. Then divide the wavelength by the distance across North America; $n = \frac{\lambda}{x}$.

Solution:

$$\lambda = \frac{c}{f} = \frac{3.0\times10^8 \text{ m/s}}{60 \text{ Hz}}$$
$$\lambda = 5.0 \times 10^6 \text{m}$$

$$n = \frac{\lambda}{x} = \frac{5.0\times10^6 \text{m}}{5.0 \times10^6 \text{m}}$$
$$n = 1$$

Statement: The number of wavelengths of the electrical transmission required to cross North America is 1.

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1. Given: $f = 5.0\times10^{14}$ Hz; $c = 3.0 \times 10^8$ m/s
Required: λ
Analysis: $c = \lambda f$; $\lambda = \frac{c}{f}$

Solution:

$$\begin{aligned}\lambda &= \frac{c}{f}\\ &= \frac{3.0\times10^8 \text{ m/}\cancel{\text{s}}}{5.0\times10^{14} \ \cancel{\text{Hz}}}\\ &= 6.0 \times10^{-7}\text{m}\\ \lambda &= 6.0 \times10^{2}\text{nm}\end{aligned}$$

Statement: The wavelength of the light in the CD player is 6.0×10^2 nm.

2. Given: $\lambda = 550$ nm $= 5.50\times10^{-7}$ m; $c = 3.0 \times 10^8$ m/s
Required: f
Analysis: $\lambda f = c$

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

Solution:

$$\begin{aligned}f &= \frac{c}{\lambda}\\ &= \frac{3.0\times10^8 \ \cancel{\text{m}}\text{/s}}{5.50\times10^{-7} \ \cancel{\text{m}}}\\ f &= 5.5\times10^{14} \text{ Hz}\end{aligned}$$

Statement: The frequency of the light that is most sensitive to the human eye is 5.5×10^{14} Hz.

3. Given: $f_1 = 88\text{ MHz} = 8.8\times10^7\text{ Hz}$; $f_2 = 108\text{ MHz} = 1.08\times10^8\text{ Hz}$; $c = 3.0\times10^8\text{ m/s}$
Required: λ_1, λ_2
Analysis: $\lambda f = c$

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

Solution:

$$\lambda_1 = \frac{c}{f_1} = \frac{3.0\times10^8\ \text{m/}\cancel{\text{s}}}{8.8\times10^7\ \cancel{\text{Hz}}}$$
$$\lambda_1 = 3.4\text{ m}$$

$$\lambda_2 = \frac{c}{f_2} = \frac{3.0\times10^8\ \cancel{\text{m}}\text{/s}}{1.08\times10^8\ \cancel{\text{Hz}}}$$
$$\lambda_2 = 2.8\text{ m}$$

Statement: The wavelengths of the FM radio stations range from 3.4 m to 2.8 m.

4. Given: $\lambda = 0.10\text{ nm} = 1.0\times10^{-10}\text{ m}$; $c = 3.0\times10^8\text{ m/s}$
Required: f
Analysis: $c = \lambda f$; $f = \dfrac{c}{\lambda}$
Solution:

$$f = \frac{c}{\lambda} = \frac{3.0\times10^8\ \cancel{\text{m}}\text{/s}}{1.0\times10^{-10}\ \cancel{\text{m}}}$$
$$f = 3.0\times10^{18}\text{ Hz}$$

Statement: The frequency of the X-ray is 3.0×10^{18} Hz.

5. (a) Given: $\lambda = 12.24\text{ cm} = 1.224\times10^{-1}\text{ m}$; $c = 3.0\times10^8\text{ m/s}$
Required: f
Analysis: $\lambda f = c$

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

Solution:

$$f = \frac{c}{\lambda} = \frac{3.0\times10^8\ \cancel{\text{m}}\text{/s}}{1.224\times10^{-1}\ \cancel{\text{m}}}$$
$$f = 2.5\times10^9\text{ Hz}$$

Statement: The frequency of the X-ray wave is 2.5×10^9 Hz.

(b) Most microwave ovens contain rotating carousels to heat the food evenly. By rotating the food, the nodes cannot heat the same spot all the time, so the food cooks more evenly. With a microwave wavelength of 12 cm, the nodes are located within the oven itself.

6. Given: f = 2.4 GHz = 2.4×10^9 Hz; c = 3.0×10^8 m/s
Required: λ
Analysis: $c=\lambda f$

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

Solution: $\lambda=\frac{c}{f}$

$$=\frac{3.0\times10^8\ \text{m}/\cancel{\text{s}}}{2.4\times10^9\ \cancel{\text{Hz}}}$$

$$=1.25\ \times10^{-1}\text{m}$$

$$\lambda=12\text{ cm}$$

Statement: The wavelength of the radio waves in the cordless phone is 12 cm.
7. Given: f = 680 kHz = 6.80×10^5 Hz; c = 3.0×10^8 m/s
Required: λ
Analysis: $\lambda f=c$

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

Solution: $\lambda=\frac{c}{f}$

$$=\frac{3.0\times10^8\ \text{m}/\cancel{\text{s}}}{6.80\times10^5\ \cancel{\text{Hz}}}$$

$$=4.4\ \times10^2\ \text{m}$$

$$\lambda=440\text{ m}$$

Statement: The wavelength of the broadcasting frequency used by 680 News is 440 m.
8. Given: w = 6.0 cm = 6.0×10^{-2} m; f = 7.5 GHz = 7.5×10^9 Hz; c = 3.0×10^8 m/s; m = 1
Required: θ
Analysis: First calculate the wavelength using the universal wave equation, $c=\lambda f$; $\lambda=\frac{c}{f}$. Then use the equation $m\lambda=w\sin\theta_m$ to calculate the angle; $\sin\theta_m=\frac{m\lambda}{w}$.

Solution: $\lambda=\frac{c}{f}$

$$=\frac{3.0\times10^8\ \cancel{\text{m}}/\text{s}}{7.5\times10^9\ \cancel{\text{Hz}}}$$

$$\lambda=4.0\ \times10^{-2}\ \text{m}$$

$$\sin\theta = \frac{m\lambda}{w}$$

$$\sin\theta = \frac{(1)(4.0\times10^{-2}\ \cancel{\text{m}})}{6.0\times10^{-2}\ \cancel{\text{m}}}$$

$$\theta = 42°$$

Statement: The angle from the central maximum to the first diffraction minimum is $42°$.

9. Some of the radiation in the electromagnetic spectrum is only detectable in deep space because Earth's atmosphere absorbs the radiation at several different wavelengths, so it does not pass through the atmosphere to the surface. To be able to detect these portions of the electromagnetic spectrum, the detectors have to be in space, above Earth's atmosphere. Some examples of electromagnetic radiation from space that does not reach Earth's surface are some wavelengths of infrared radiation from distant objects, X-rays, and gamma rays.

Additional information: All objects emit infrared radiation. To avoid interfering with very faint astronomical objects emitting infrared radiation, the detectors (telescopes) need to be kept extremely cold. That is only possible in deep space.

10. Television correspondents in a distant part of the world are so far away that their responses are delayed due to the travel time of the signal. There is also the time required to process the signal.

11. (a) Given: f = 75 MHz = 75 × 10^6 Hz; d = 134 m; c = 3.0 × 10^8 m/s

Required: type of interference

Analysis: Calculate the wavelength of the signal, $c = \lambda f$; $\lambda = \frac{c}{f}$. Divide the distance by wavelength.

Solution:

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

$$= \frac{3.0\times10^{8}\ \text{m}/\cancel{\text{s}}}{75\times10^{6}\ \cancel{\text{Hz}}}$$

$$\lambda = 4\ \text{m}$$

$$\frac{134\ \text{m}}{4\ \text{m}} = 33\frac{1}{2}\ \text{wavelengths}$$

The interference is constructive interference because the path difference is a half-whole-number multiple of the wavelength, and there is a 180° phase change from the reflection.

Statement: The kind of interference that results is constructive interference.

(b) The signal is now being reflected from 134 m – 42 m = 92 m, which is exactly 23 wavelengths. This is now destructive interference because the path difference is a whole-number multiple of wavelengths, and there is a 180° phase change from the reflection.

12. Answers may vary. The report should explain how an antenna converts electrical currents into electromagnetic radiation and that an antenna can be either a transmitter or a receiver. The size of the antenna will depend on the type of signals being transmitted. For example, the wavelengths of FM signals are 2 m to 4 m. Generally, the length of the antenna should be about half the wavelength of the radio waves you are trying to send or receive.