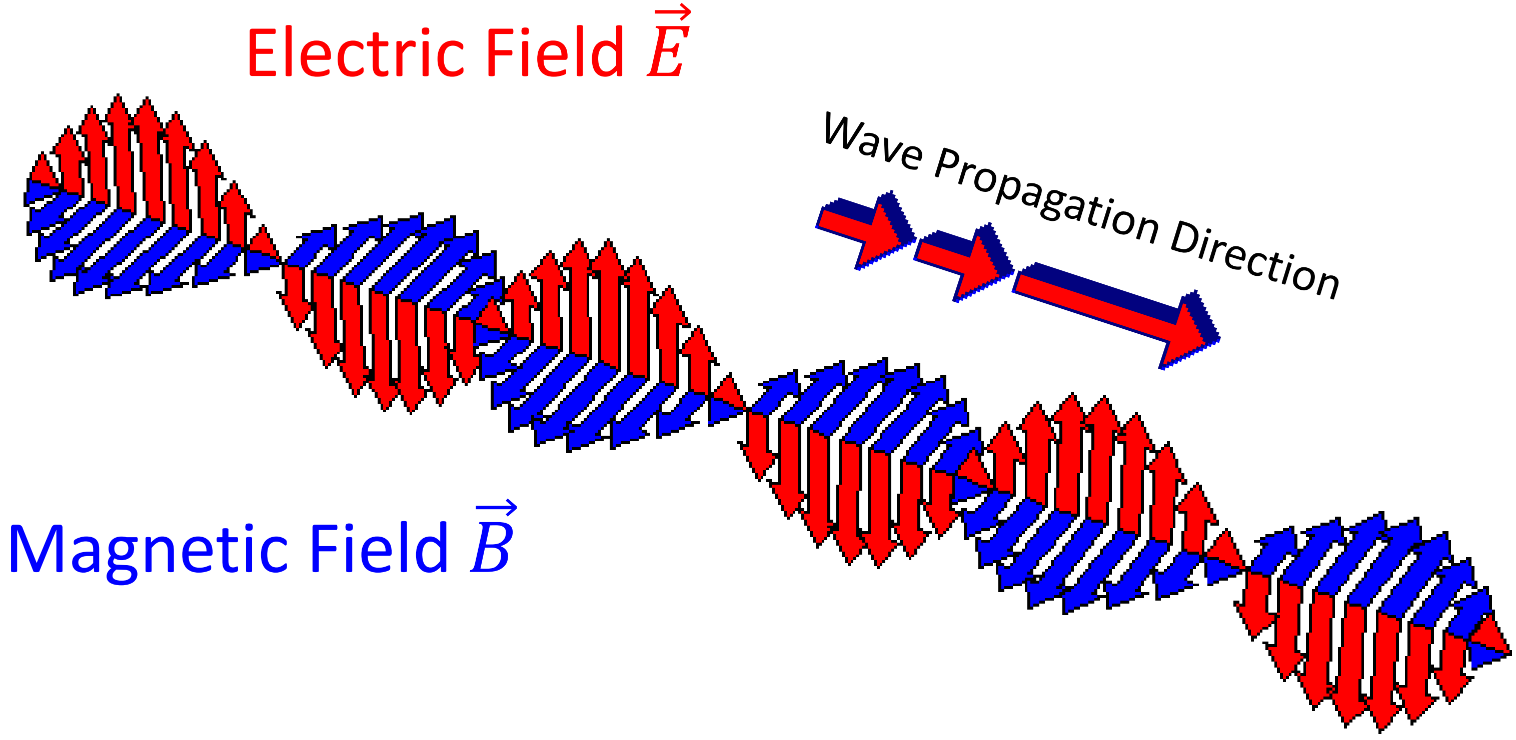
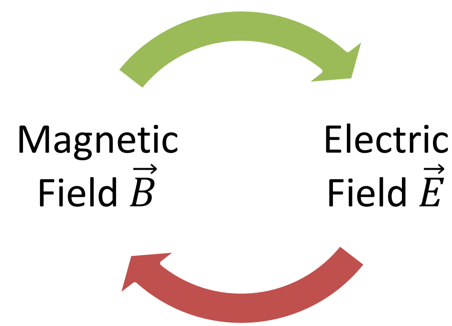
Electromagnetic Waves and Light Rays



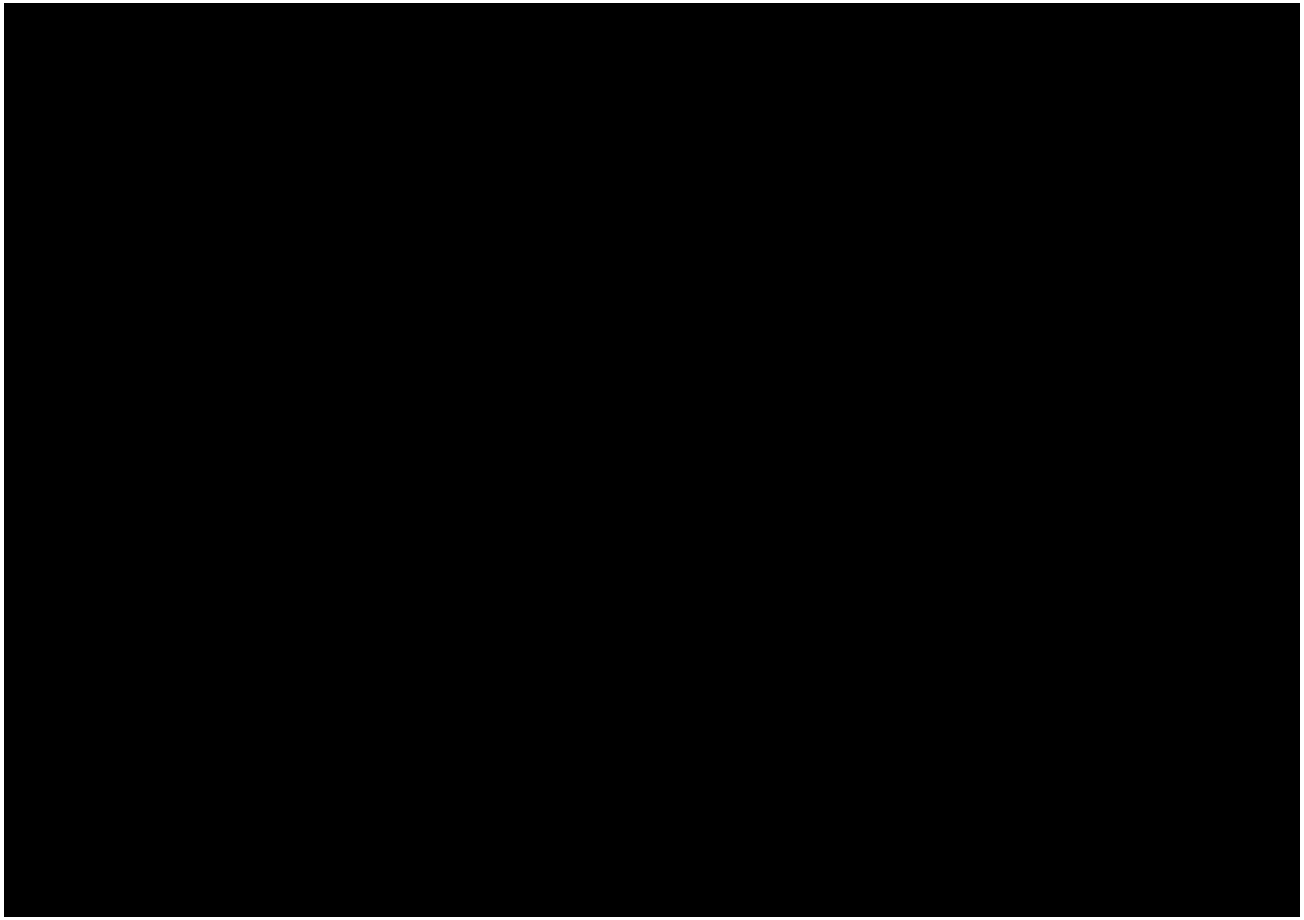
Induction Goes Both Ways

- Faraday's Law:
  - Changing a magnetic flux Φ_B induces emf
- Could we do this backwards? Could we induce a magnetic field by varying *electric* flux Φ_E?
  - Yes! It's called Ampère's Law (not covered)
  - Also, Biot-Savart's Law, which was the basis for the field formulas we've studied so far (wire, coil, solendoid)



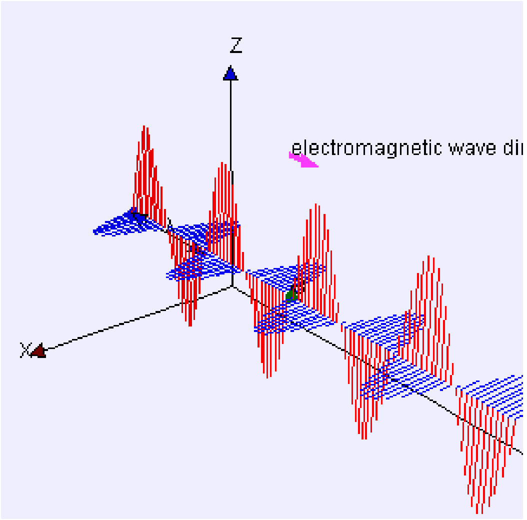
Generating Electromagnetic Waves

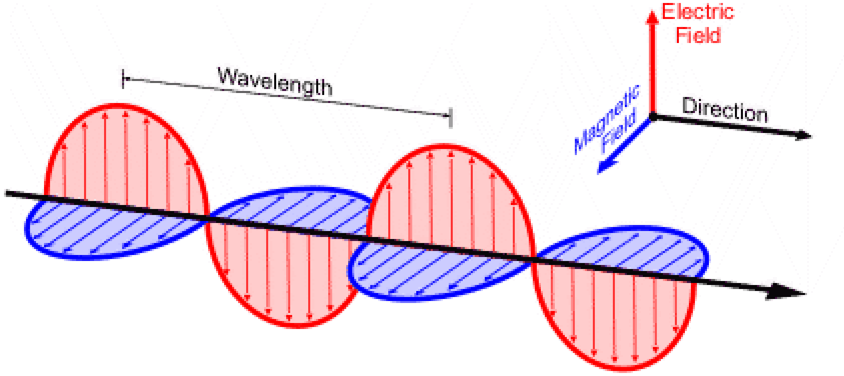
http://math.ucr.edu/~jdp/Relativity/EM_Propagation.html



Features of EM Waves

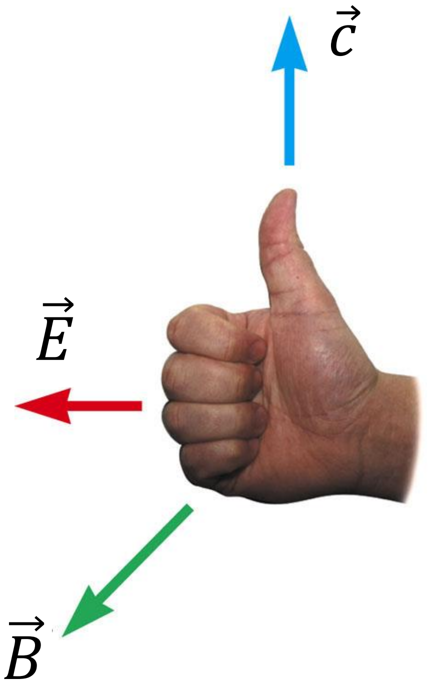
- Electric and magnetic fields oscillate in mutually perpendicular planes.
- Both the magnetic and electric field are perpendicular to the direction of wave propagation.



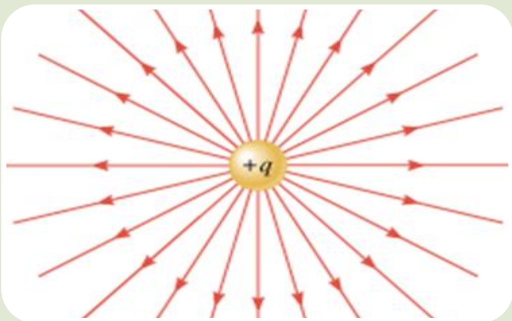


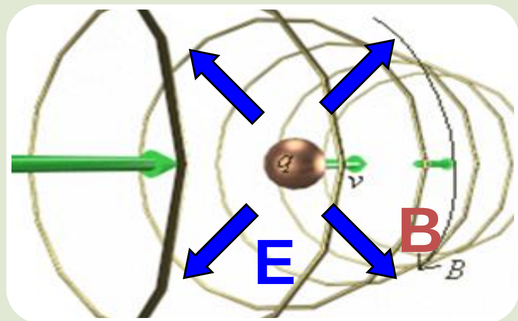
Right-hand-rule Once More

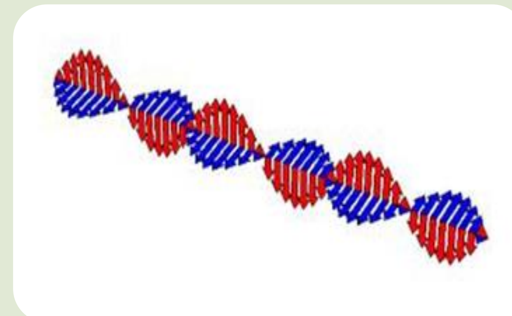
- Point your fingers in the direction of the electric field $\vec{E}$
- Curl the fingers in the direction of the magnetic field $\vec{B}$,
- Your thumb points in the direction of the wave propagation, $\vec{c}$



Accelerated charges produce electromagnetic waves







Stationary charges produce an electric field, but no magnetic field

Moving charges (with **constant velocity**) produce an electric field and a magnetic field

Accelerating charges produce an electric field, a magnetic field, and a self-sustaining electromagnetic wave

Quickuiz

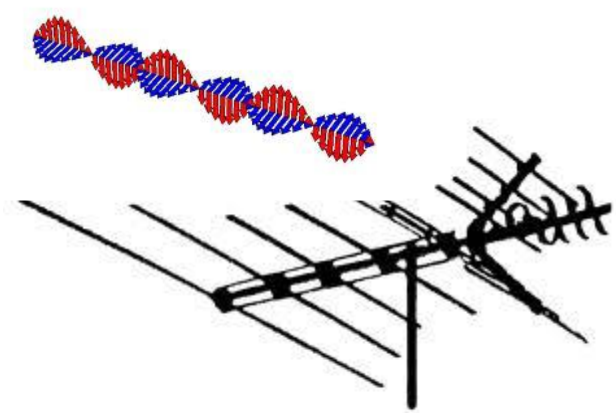
When an antenna receives a signal in the form of an electromagnetic (EM) wave, the EM wave causes which of the following to be generated inside the antenna:

A. A direct current (DC)

B. An alternating current (AC)

C. A constant force on all charges within the antenna

D. A constant magnetization within the antenna



Simulation: http://phet.colorado.edu/en/simulation/radio-waves

Quickuiz

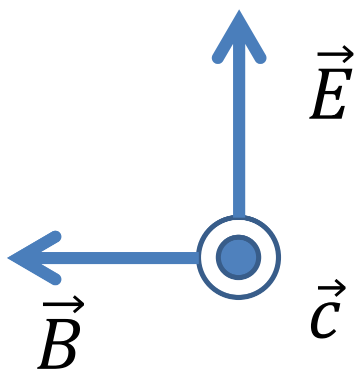
An electromagnetic plane wave is coming directly toward you. If the magnetic field points to the left at a given time and at a given point in space, in what direction does the electric field point at that same time and same point in space?

A. Left

B. Right

C. Up

D. Down



Wavefronts and light rays, wave equation

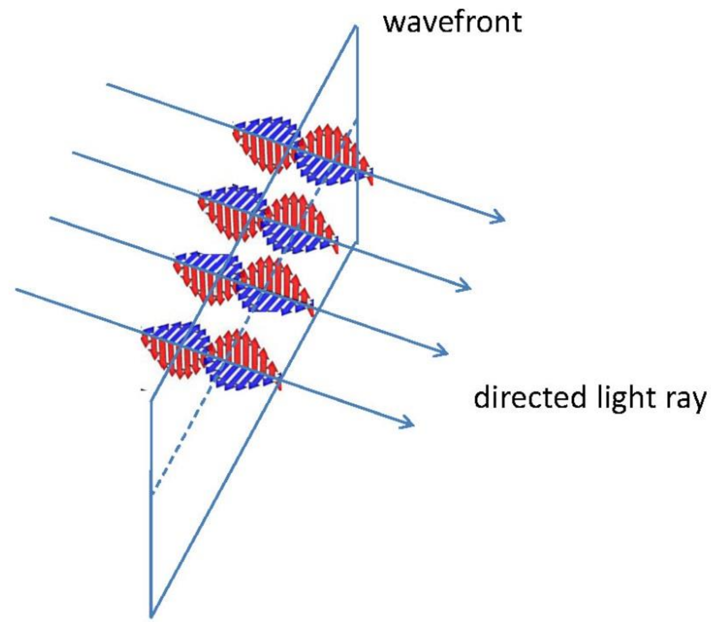
- Speed of light in vacuum $c = 3.00 \times 10^8 \mathrm{m/s}$ is related to the wavelength λ and the frequency f:

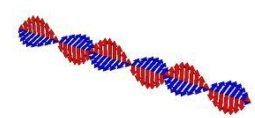
$$c = \lambda f \quad \text{(vacuum)}$$

- In other media besides vacuum, frequency remains the same, but speed and therefore wavelength decrease!

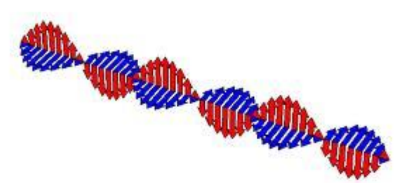
$$v = \lambda f \quad \text{(medium)}$$

- Frequency measures the number of oscillations per unit time. Its unit is Hertz ($1\ \mathrm{Hz} = 1/s$)

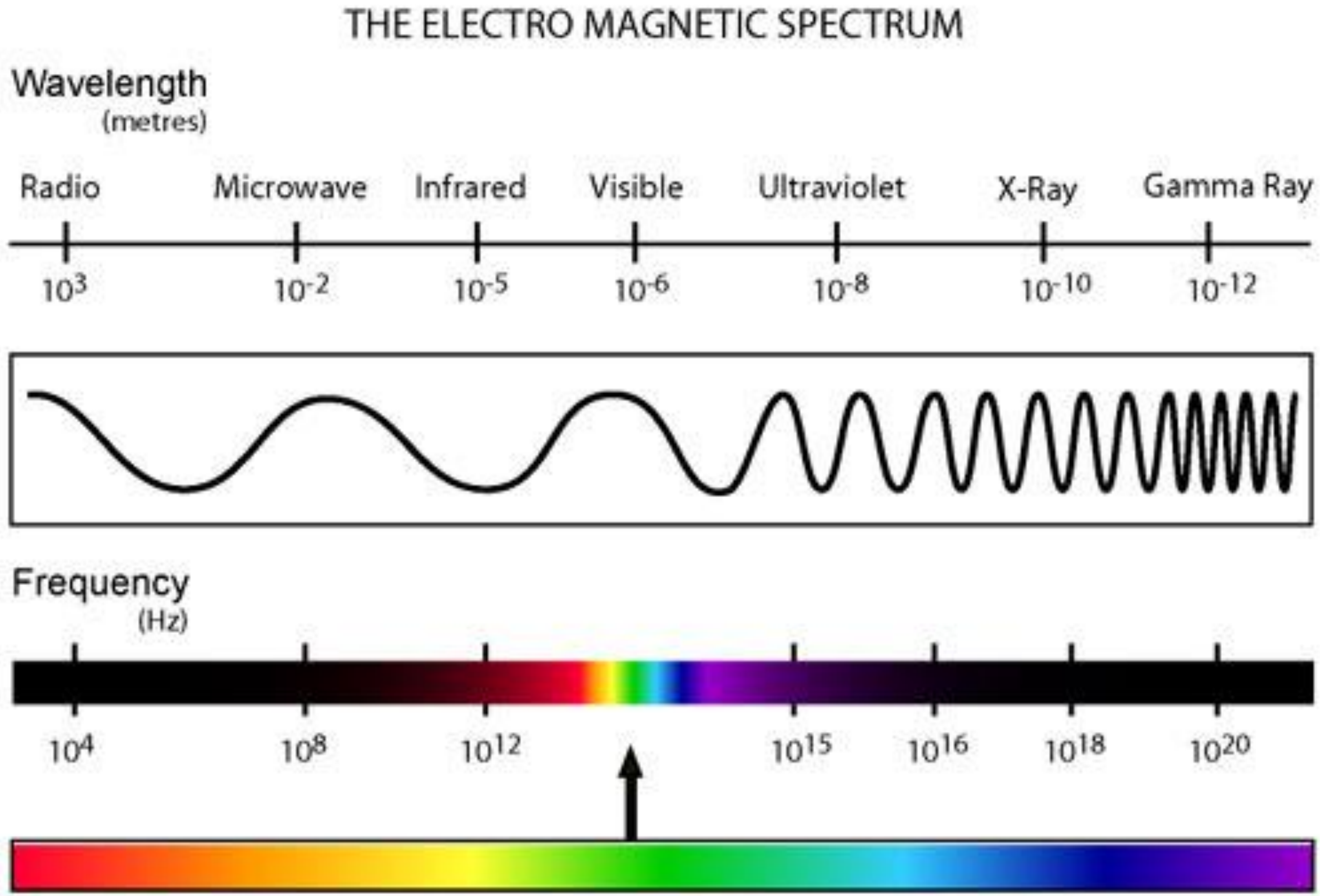




Small wavelength,
High frequency



Large wavelength,
Lower frequency


THE ELECTRO MAGNETIC SPECTRUM
Wavelength
(metres)
Radio
Microwave
Infrared
Visible
Ultraviolet
X-Ray
Gamma Ray
10^3
10^{-2}
10^{-5}
10^{-6}
10^{-8}
10^{-10}
10^{-12}
Frequency
(Hz)
10^4
10^8
10^{12}
10^{15}
10^{16}
10^{18}
10^{20}

http://www.astro.washington.edu/users/nms/teaching/a101_2012/applets/IF_05_02_EMSPectrum.swf

Demo Problem

- You are a starship captain on a long space mission to Alpha Centauri. But you still like to watch your favorite TV show from back on Earth. Fortunately, you have an antenna that is capable of picking up the TV signals from Earth. You are currently 7.95×10^{11} m from Earth. Your show comes on at $7:30$ PM on Earth, and your starship has a clock that is synchronized to Earth EST (Eastern Standard Time zone). The TV signal is carried on an electromagnetic wave with a frequency of 6.75×10^8 Hz. Remember, $c = 3.00 \times 10^8 \mathrm{m/s}$, $c = \lambda f$
- At what time will you be able to start watching your show?

$$v = \frac{d}{t} \Rightarrow t = \frac{d}{v} = \frac{7.95 \times 10^{11}\ \mathrm{m}}{3.00 \times 10^{8} \mathrm{m/s}} = 2.65 \times 10^3 s = 44.2\, min.$$

- Time you'll watch your show is $7:30\ \mathrm{PM} + 44.2\ \mathrm{min} \approx 8:14\ \mathrm{PM}$

Demo Problem

- You are a starship captain on a long space mission to Alpha Centauri. But you still like to watch your favorite TV show from back on Earth. Fortunately, you have an antenna that is capable of picking up the TV signals from Earth. You are currently 7.95×10^{11} m from Earth. Your show comes on at $7:30$ PM on Earth, and your starship has a clock that is synchronized to Earth EST (Eastern Standard Time zone). The TV signal is carried on an electromagnetic wave with a frequency of 6.75×10^8 Hz. Remember, $c = 3.00 \times 10^8 \mathrm{m/s}$, $c = \lambda f$
- What is the wavelength of the electromagnetic wave that carries the TV signal?

$$\lambda = \frac{c}{f} = \frac{3.00 \times 10^8 \mathrm{m/s}}{6.75 \times 10^8 \text{ Hz}} = 0.444 \text{ m}$$

Demo Problem

- You are a starship captain on a long space mission to Alpha Centauri. But you still like to watch your favorite TV show from back on Earth. Fortunately, you have an antenna that is capable of picking up the TV signals from Earth. You are currently 7.95×10^{11} m from Earth. Your show comes on at $7{:}30$ PM on Earth, and your starship has a clock that is synchronized to Earth EST (Eastern Standard Time zone). The TV signal is carried on an electromagnetic wave with a frequency of 6.75×10^{8} Hz. Remember, $c = 3.00 \times 10^{8}$m/s, $c = \lambda f$
- What type of electromagnetic radiation is this?
- According to the table in Section 20.4 providing a classification of the different ranges of wavelength (and frequency) in the electromagnetic spectrum, an EM wave with a wavelength of 0.444 m would indeed be classified as a TV wave

Demo Problem

- You are a starship captain on a long space mission to Alpha Centauri. But you still like to watch your favorite TV show from back on Earth. Fortunately, you have an antenna that is capable of picking up the TV signals from Earth. You are currently 7.95×10^{11} m from Earth. Your show comes on at $7{:}30$ PM on Earth, and your starship has a clock that is synchronized to Earth EST (Eastern Standard Time zone). The TV signal is carried on an electromagnetic wave with a frequency of 6.75×10^{8} Hz. Remember, $c = 3.00 \times 10^{8}\,\mathrm{m/s}$, $c = \lambda f$
- As you watch the EM wave coming toward you, the electric field points to the right. What is the direction of the magnetic field?
- Magnetic field points upward