11-3 The Electromagnetic Spectrum

1- **Define electromagnetic waves.** Waves are composed of oscillating magnetic and electric fields that can transfer through the space and matter.

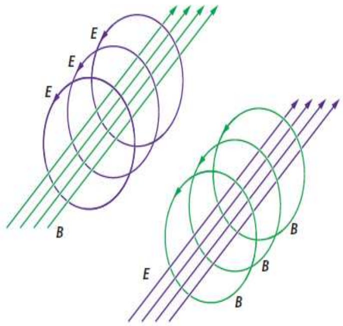
2- How to create an electromagnetic wave? By changing a magnetic field an electric field will produce or by changing an electric field a magnetic field will produce

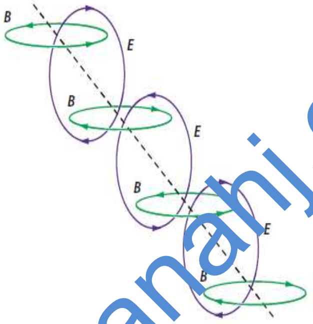
3- All electromagnetic waves travel at the speed of light.

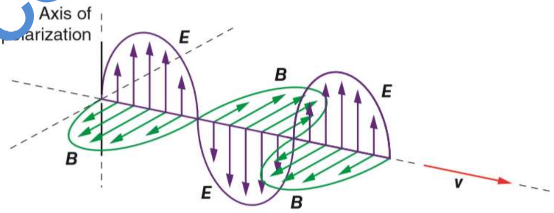
4- the wavelength and the frequency of electromagnetic waves vary dramatically.

5- The speed of light, c, the wavelength λ,, and the frequency, f, are related by

c = λ f .







Electromagnetic wave properties

1- **What are the properties of the electromagnetic waves? ➢**

2- The magnetic field oscillates at right angles to the electric field.

➢ Both the electric field and the magnetic field are at right angles to the wave propagation direction.

3- Electromagnetic waves are transverse waves and can travel through the vacuum and the matter. ➢

4- The speed of the electromagnetic field in the vacuum is equal to the speed of light $c = 3 \times 10_8\,\mathrm{m/s}$, this value change in another mediums. ➢

5- Each electromagnetic wave has a wavelength λ that inversely proportional to the frequency of the wave.

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

Questions:

11.1 Which of the following phenomena can be observed for electromagnetic waves but not for sound waves?

a) interference b) diffraction c) polarization d) absorption e) scattering

11.3 The international radio station Voice of Slobbovia announces that it is “transmitting to North America on the 49-meter band.” Which frequency is the station transmitting on?

a) 820 kHz b) 6.12 MHz c) 91.7 MHz

d) The information given tells e) nothing about the frequency.

11.33 The wavelength range for visible light is 400 nm to 700 nm (see Figure 11.10) in air. What is the frequency range of visible light?

11.34 The antenna of a cell phone is a straight rod 8.0 cm long. Calculate the operating frequency of the signal from this phone, assuming that the antenna length is 14 of the wavelength of the signal.

$9.4\text{x}10^{8}\text{Hz}$

•11.35 Suppose an RLC circuit in resonance is used to produce a radio wave of wavelength 150 m. If the circuit has a 2.0-pF capacitor, what size inductor is used?

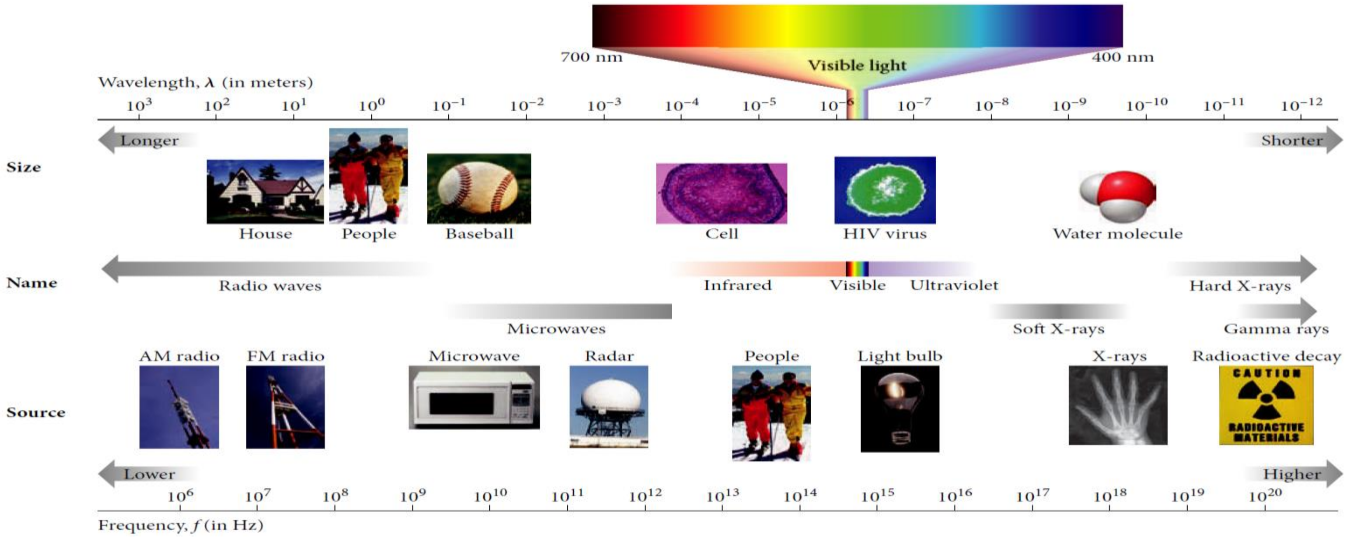
$3.2\text{x}10^{-3}\text{H}$

•11.36 Three FM radio stations covering the same geographical area broadcast at frequencies 91.1, 91.3, and 91.5 MHz, respectively. What is the maximum allowable wavelength width of the band-pass filter in a radio receiver such that the FM station 91.3 can be played free of interference from FM 91.1 or FM 91.5? Use c = 3.00 x10^8 m/s, and calculate the wavelength to an uncertainty of 1 mm.

14mm

Electromagnetic Spectrum

Radio waves	have frequencies ranging from several hundred kHz (AM radio) to 100 MHz (FM radio). They are also widely used in astronomy because they can pass through clouds of dust and gas that block visible light utilize radio waves.
Microwaves	used to popcorn in microwave ovens and transmit phone messages through relay towers or satellites, have frequencies around 10 GHz. Radar uses waves with wavelengths between those of radio waves and microwaves, which enable them to travel easily through the atmosphere and reflect off objects from size of a baseball to the size of a storm cloud.
Infrared waves	With wavelengths just longer than visible up to around 10^{-4} m) are felt as warmth. Detectors of infrared waves can be used to measure heat leaks in homes and offices, as well as locate brewing volcanoes. Many animals have developed the ability to see infrared waves, so they can see in the dark. Infrared beams are also used in automatic faucets in public restrooms and in remote control units for TV and DVD players.
Visible light	refers to electromagnetic waves that we can see with our eyes, with Wavelengths from 400 nm (blue) to 700 nm (red). The response of the human eye peaks at around 550 nm (green) and drops off quickly away from that wavelength. Other wavelengths of electromagnetic waves are invisible to the human eye. However, we can detect them by other means
Ultraviolet rays	with wavelengths just shorter than visible down to a few nanometers (10^{-9} m) can damage skin and cause sunburn. Fortunately, Earth's atmosphere, particularly its ozone layer, prevents most of the Sun's ultraviolet rays from reaching Earth's surface. Ultraviolet rays are used in hospitals to sterilize equipment and also produce optical properties such as fluorescence.
X-rays	used to produce medical images, such the one shown in Figure 31.9c, have Wavelengths on the order of 10^{-10} m. This length is about the same as the distance between atoms in a solid crystal, so X-rays are used to determine the detailed molecular structure of any material that can be crystallized.
Gamma rays	emitted in the decay of radioactive nuclei have very short wavelengths, on the order of 10–12 m, and can cause damage to human cells. They are often used in medicine to destroy cancer cells or other malignant tissues that are hard to reach.



Communication Frequency Bands:

The frequency ranges assigned to radio and television broadcasts are shown in Figure 11.11. The range of frequencies assigned to:

AM (amplitude modulation)	radio is from **535 kHz to 1705 kHz**
FM (frequency modulation)	radio use the frequencies between **88.0 MHz and 108.0** MHz
VHF (very high frequency)	television operates in two ranges: **54.0 MHz to 88.0 MHz** for **channels 2 through 6,**
	and **174.0 MHz to 216.0 MHz** for **channels 7 through 13**
UHF (ultra-high frequency)	television channels 14 through 83 broadcast in the range from **512.0 MHz to 698.0 MHz**
Most high-definition television (HDTV)	broadcasts use the UHF band and channels 14 through 83. A radio or television station transmits a carrier signal on a given frequency

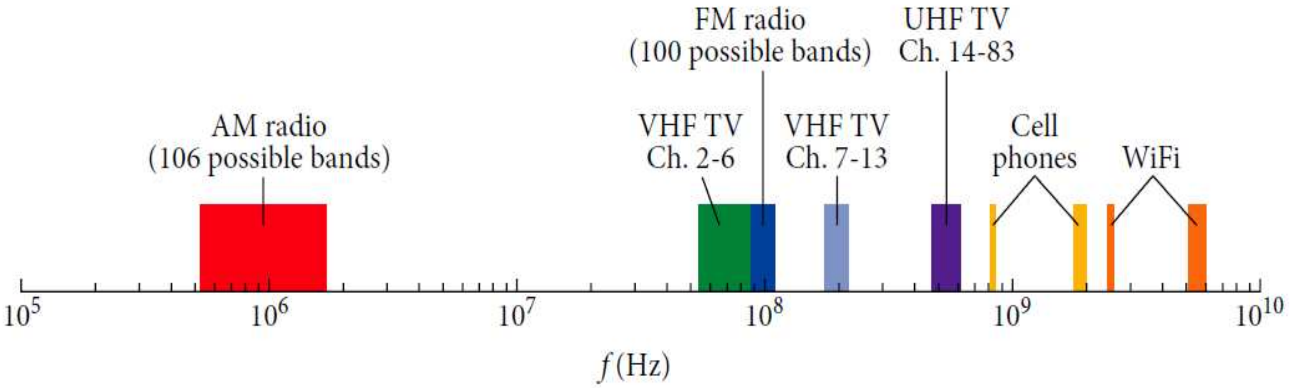


FIGURE 31.11 The frequency bands assigned to radio broadcasts, television broadcasts, cell phones, and WiFi computer connections in the United States.

The carrier signal is a sine wave with a frequency equal to the frequency of the broadcasting station. In the case of AM broadcasts, the amplitude of the carrier wave is modified by the information being transmitted, as illustrated in Figure 31.12a. The modulation of the amplitude of the carrier signal carries the transmitted message. Figure 31.12a shows a simple sine wave, indicating that a simple tone is being transmitted. The signal is received by a tuned RLC circuit whose resonant frequency is equal to the frequency of the carrier signal. The current induced in the circuit is proportional to the message being transmitted.

a. AM transmission **535kHz-1705kHZ**	is vulnerable to noise and signal loss because the message is proportional to the amplitude of the signal, which can change if conditions vary.
FM transmission **88MHz-108MHZ**	the frequency of the carrier signal is modified by the message to produ modulated signal, as shown in Figure 31.12b. This type of transmission less affected by noise and signal loss because the message is extracted frequency shifts of the carrier signal, rather than from changes in the amplitude of the carrier signal

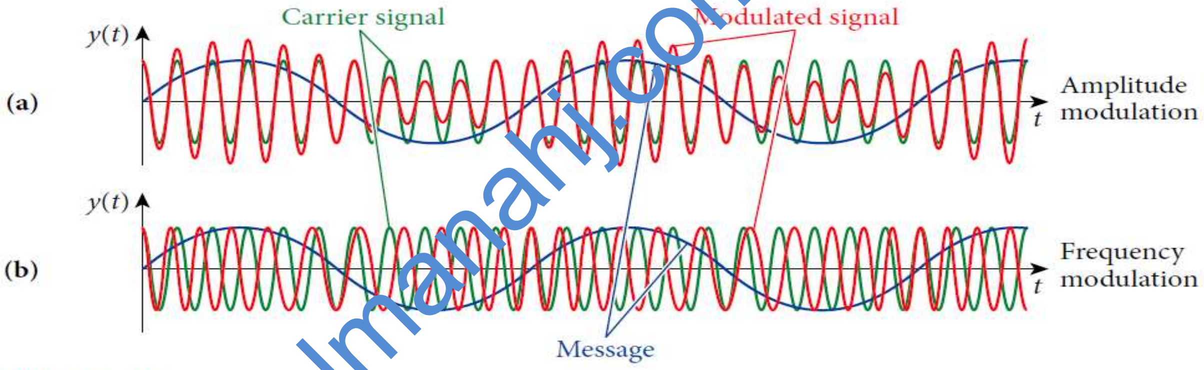


FIGURE 31.12 (a) Amplitude modulation. (b) Frequency modulation. For both cases, the green curve represents the carrier signal, the red curve represents the modulated signal, and the blue curve signifies the information being transmitted.

Q: If you know The FM frequency is higher than AM frequency complete the following table:

Which band contain more energy FM band or AM band. Explain.	
Compere between the velocity between FM band and FM band	

A Foster-Seeley discriminator :

FM radio receivers commonly use a Foster-Seeley discriminator to demodulate the FM signal. A Foster-Seeley discriminator uses an RLC circuit tuned to the frequency of the carrier signal and connected to two diodes, resembling the full wave rectifier discussed in Chapter 30. If the input equals the carrier frequency, the two halves of the tuned circuit produce the same rectified voltage and the output is zero. As the frequency of the carrier signal changes, the balance between the two halves of the rectified circuit changes, resulting in a voltage proportional to the frequency deviation of the carrier signal. A Foster-Seeley discriminator is sensitive to amplitude variations and is usually coupled with a limiter amplifier stage to desensitize it to variations in the strength of the carrier wave by allowing lower power signals to pass through it unaffected while removing the peaks of the signals that exceed a certain power level. HDTV transmitters broadcast information digitally in the form of zeros and ones. One byte of information contains eight bits, where a bit is a zero or a one. The screen is subdivided into picture elements (pixels) with digital representations of the red, green, and blue color of each pixel. Currently, the highest resolution for HDTV is 1080i, which has 1920 pixels in the horizontal direction and 1080 pixels in the vertical direction. Half the picture (every other horizontal line) is updated 60 times every second, and the two halves of the image are interlaced to form the complete image. (See Section 31.10 for more information on video formats.) HDTV is broadcast using a compression-decompression (codec) technique, typically the standard known as MPEG-2, to reduce the amount of data that must be transmitted. A typical HDTV station broadcasts about 17 megabytes of information per second. Cell phone transmissions occur in the frequency bands from 824.04 to 848.97 MHz and 1.85 to 1.99 GHz. WiFi wireless data connections for computers operate in the ranges from 2.401 to 2.484 GHz (for the international standard; the U.S. standard band has an upper limit of 2.473 GHz) and from 5.15 to 5.85 GHz. These frequencies are in the micro- wave range, and some people worry about prolonged exposure to electromagnetic waves emitted by cell phones and WiFi. However, the relatively low power of these devices com- bined with the fact that the energy of these waves is much lower than that of other waves that are commonly encountered, such as visible light, argue that there is little danger from cell phones and WiFi. Chapter 37 on quantum mechanics will discuss the energy of the photons associated with electromagnetic waves.

Traveling electromagnetic Waves

Subatomic processes can produce electromagnetic waves such as gamma rays, X-rays, and light. Electromagnetic waves can also be produced by an RLC circuit connected to an antenna (Figure 31.13). The connection between the RLC circuit and the antenna occurs through a transformer. A dipole antenna is used to approximate an electric dipole. The voltage and current in the antenna vary sinusoidally with time and cause the flow of charge in the antenna to oscillate with the frequency, ω_0, of the RLC circuit. The accelerating charges create traveling electromagnetic waves. These waves travel from the antenna at speed c and frequency $f = \omega_0/(2\pi)$. The traveling electromagnetic waves propagate as wave fronts spreading out spherically from the antenna. However, at a large distance from the antenna, the wave fronts appear to be almost flat, or planar. Thus, such a traveling wave is described by equation 31.8. If a second RLC circuit tuned to the same frequency, ω_0, as the emitting circuit is placed in the path of these electromagnetic waves, voltage and current will be induced in this second circuit. These induced oscillations are the basic idea of radio transmission and reception. If the second circuit has $\omega_0 = 1/(LC)^{1/2}$ different from ω_0, much smaller voltages and currents will be induced. Only if the resonant frequency of the receiving circuit is the same as or very close to the transmitted frequency will any signal be induced in the receiving circuit. Thus, the receiver can select a transmission with a given frequency and reject all others. The principle of transmission of electromagnetic waves was discovered by Heinrich Hertz in 1888, as described in Section 31.3, and was used by the Italian physicist Guglielmo Marconi (1874-1937) to transmit wireless signals

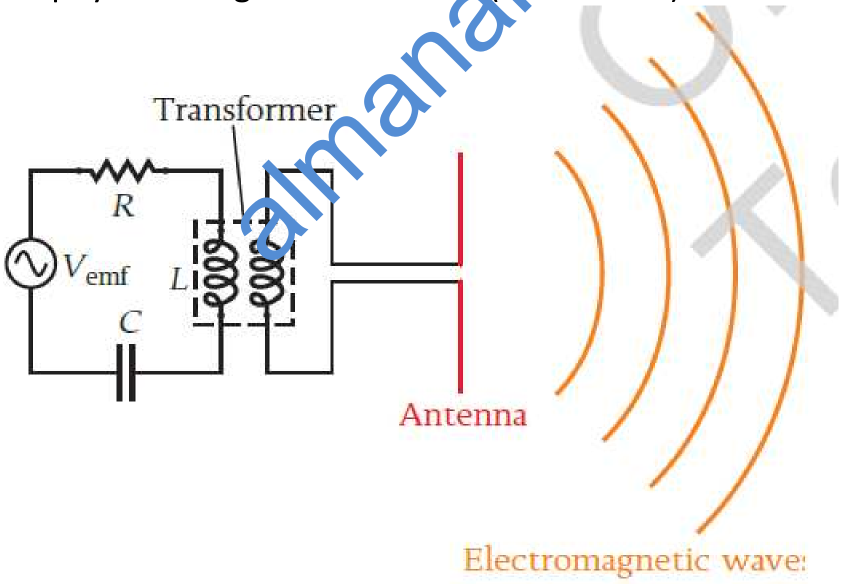


FIGURE 11.13 An RLC circuit coupled to an antenna that emits traveling electromagnetic waves.

11-4 Poynting Vector and Energy Transport

The rate at which energy is transported by an electromagnetic wave is usually defined in terms of a vector, **S**, given by

$$\vec{S} = \frac{1}{\mu_0}\vec{E}\times\vec{B}.$$

This quantity is called the **Poynting vector**.

The magnitude of **S,** is related to the instantaneous rate at which energy is transported by an electromagnetic wave over a given area, or more simply, the instantaneous power per unit area:

$$S = \left|\vec{S}\right| = \left(\frac{\text{power}}{\text{area}}\right)_{\text{instantaneous}}.$$

The units of the Poynting vector are thus watts per square meter (W/m^2).

For an electromagnetic wave, where $\vec{E}$ is perpendicular to $\vec{B}$, equation 31.23 yields

$$S = \frac{1}{\mu_0}EB.$$

$$C = \frac{E}{B} = \frac{1}{\sqrt{\mu_o \pounds_o}}$$

Boynting Vector magnitude

$S = \dfrac{1}{\mu_o}EB$	$S = \dfrac{1}{c\mu_o}E^2$	$S = \left\lvert\vec{s}\right\rvert = \left(\dfrac{\text{القدرة } P}{\text{المساحة } A}\right)_{\text{اللحظية}}$

Intesity (I)= |S| Boynting Vector magnitude

$$I = \frac{P}{A} = \frac{1}{c\mu}E_{r\,m\,s}^2 = \frac{E_{max}^2}{2c\mu}$$

the energy density

كثافة الطاقة تعطى بالعلاقات التالية :

$$u_E = \frac{1}{2}\varepsilon_\circ E^2$$

(للمجال الكهربائي)

For electric field

$$u_B = u_E$$

$$u_B = \frac{1}{2}\frac{B^2}{\mu_\circ}$$

(للمجال المغناطيسي)

For magnetic field

$$A = 4\pi r^2\ (in\ case\ spher) = 2\pi r^2 (in\ case\ half\ spher) = \pi r^2 (\ in\ case\ laser)$$

Important Question :

Because the magnitudes of the electric and magnetic fields of an electromagnetic wave are related by

$E = cB$ and C is such a large number, you might conclude that the energy transported by the electric field is much larger than the energy transported by the magnetic field.

How to proof that these energies are *the same. By using* the energy density of an electric field is given by

$$u_E = \frac{1}{2}\epsilon_0 E^2,$$

If we substitute $E = cB$ and $c = 1/\sqrt{\mu_0\epsilon_0}$ into the expression for the energy density of the electric field, we get

$$u_E = \frac{1}{2}\epsilon_0 (cB)^2 = \frac{1}{2}\epsilon_0 \left(\frac{B}{\sqrt{\mu_0\epsilon_0}}\right)^2 = \frac{1}{2\mu_0}B^2 = u_B. \qquad \textbf{(31.27)}$$

Thus, the energy density of the electric field is the same as the energy density of the magnetic field everywhere in the electromagnetic wave.

EXAMPLE 11.1 Using Solar Panels to Charge an Electric Car

Suppose that photovoltaic (solar power to electric power) solar panels (Figure 11.14a) can be mounted on the roof of your house at a cost per area of η = AED1420/m^2. You have an electric car (Figure 11.14b) that requires a charge corresponding to an energy of U = 10.0 kWh for a day of local driving. The solar panels convert solar power to electricity with an efficiency ε = 14.1% and have an area A. Suppose that sunlight is incident on your solar panels for Δt = 4.00 h a day with an average intensity of Save = 600. W/m^2.

ε :The efficiency of convert solar power to electricity

PROBLEM

How much do you need to spend on solar panels to give your electric car its daily ch

SOLUTION

We equate the total amount of energy produced by the solar panels to the en required to charge the car:

$$U_{\text{produced}} = P\Delta t = U.$$

The amount of power produced by the solar panels is the average intensity of the light times the area of the solar panels times the efficiency of the solar panels:

$$P = \varepsilon A S_{\text{ave}}.$$

Thus, the total area required is

$$A = \frac{P}{\varepsilon S_{\text{ave}}} = \frac{(U/\Delta t)}{\varepsilon S_{\text{ave}}} = \frac{U}{\varepsilon S_{\text{ave}}\Delta t}.$$

The total cost will then be

$$\text{Cost} = \eta A = \frac{\eta U}{\varepsilon S_{\text{ave}}\Delta t}.$$

Putting in the numerical values gives us

$$\text{Cost} = \frac{\eta U}{\varepsilon S_{\text{ave}}\Delta t} = \frac{(\text{AED}1420/\text{m}^2)(10.0\text{ kWh})}{(0.141)(0.600\text{ kW/m}^2)(4.00\text{ h})} = \text{AED } 42\,000.$$

Problem:

Photovoltaic (solar power to electric power) solar panels (Figure 31.14a) can be mounted on the roof of your house at a cost per area of $\eta = \$1430/\text{m}^2$. You have an electric car (Figure 31.14b) that requires a charge corresponding to an energy of $U = 8.0$ kW h for a day of local driving. The solar panels convert solar power to electricity with an efficiency $\epsilon = 10.7\%$ and have an area A. Suppose that sunlight is incident on your solar panels for $\Delta t = 8.0$ h with an average intensity of $S_{\text{ave}} = 600\ \text{W/m}^2$.

PROBLEM

How much do you need to spend on solar panels to give your electric car its daily charge?

$22,000.

EXAMPLE 11.2 The Root-Mean-Square Electric and Magnetic Fields from Sunlight

The average intensity of sunlight at the Earth's surface is approximately $1400\ \text{W/m}^2$, if the Sun is directly overhead.

PROBLEM

What are the root-mean-square electric and magnetic fields of these electromagnetic waves?

$$E_{rms} = 726.5\ V/m$$
$$B_{rms} = 2.4\ \mu T$$

11.2 Which of the following statements concerning electromagnetic waves are incorrect? (Select all that apply.)

a) Electromagnetic waves in vacuum travel at the speed of light.

b) The magnitudes of the electric field and the magnetic field are equal.

c) Only the electric field vector is perpendicular to the direction of the wave's propagation.

d) Both the electric field vector and the magnetic field vector are perpendicular to the direction of propagation.

e) An electromagnetic wave carries energy only when E = B.

11.37 A monochromatic point source of light emits 1.5 W of electromagnetic power uniformly in all directions. Find the Poynting vector at a point situated at each of the following locations:

a) 0.30 m from the source

$1.3\ \mathrm{W/m^2}$

b) 0.32 m from the source

$1.2\ \mathrm{W/m^2}$

c) 1.00 m from the source

$0.12\ \mathrm{W/m^2}$.

11.38 Consider an electron in a hydrogen atom, which is 0.050nm from the proton in the nucleus.

a) What electric field does the electron experience?

$5.8 \cdot 10^{11}\ \mathrm{V/m}$

b) In order to produce an electric field whose root-mean-square magnitude is the same as that of the field in part (a), what intensity must a laser light have

$8.8 \cdot 10^{20}\ \mathrm{W/m^2}$

11.39 A 3.00 kW carbon dioxide laser is used in laser welding. If the beam is 1.00 mm in diameter, what is the amplitude of the electric field in the beam?

$1.70 \cdot 10^{6}$ V/m.

11.40 Suppose that charges on a dipole antenna oscillate slowly at a rate of 1.00 cycle/s, and the antenna radiates electromagnetic waves in a region of space. If someone measured the time-varying magnetic field in the region and found its maximum to be 1.00 mT, what would be the maximum electric field, E, in the region, in units of volts per meter? What is the period of the charge oscillation? What is the magnitude of the Poynting vector?

$2.39 \cdot 10^{8}$ W/m^2

11.41 Calculate the average value of the Poynting vector, Save, for an electromagnetic wave having an electric field of amplitude 100. V/m.

a) What is the average energy density of this wave in J/m3?

$4.43 \cdot 10^{-8}$ J/m^3

b) How large is the amplitude of the magnetic field?

$3.33 \cdot 10^{-7}$ T

11.42 The most intense beam of light that can propagate through dry air must have an electric field whose maximum amplitude is no greater than the breakdown value for air: E3.010V/m, maxair6= assuming that this value is unaffected by the frequency of the wave.

a) Calculate the maximum amplitude the magnetic field of this wave can have.

$1.0\cdot10^{-2}\ \mathrm{T}$

b) Calculate the intensity of this wave.

$1.19\cdot10^{10}\ \mathrm{W/m^2}$

c) What happens to a wave more intense than this?

••11.43 A continuous-wave argon-ion laser beam has an aver-age power of 10.0 W and a beam diameter of 1.00 mm. Assume that the intensity of the beam is the same throughout the cross section of the beam (which is not true, as the actual distribution of intensity is a Gaussian function).

a) Calculate the intensity of the laser beam. Compare this with the average intensity of sunlight at Earth's surface (1400. W/m2).

$1.2732\cdot10^{7}\ \mathrm{W/m^2}$

b) Find the root-mean-square electric field in the laser beam.

$6.932809\cdot10^{4}\ \mathrm{V/m}$

c) Find the average value of the Poynting vector over time.

11.73 A radio tower is transmitting 30.0 kW of power equally in all directions. Assume that the radio waves that hit the Earth are reflected.

a) What is the magnitude of the Poynting vector at a distance of 12.0 km from the tower?

3.3157×10^{-5} W/m^2

b) What is the root-mean-square value of the electric force on an electron at this location?

1.26649×10^{-20}N