Problem Set 12
Physics, summer 2020/21

1) **(2p.)** What is the maximum strength of the B-field in an electromagnetic wave that has a maximum E-field strength of 1000 V/m?

<u>*Answer:*</u>
To find the B-field strength, we rearrange the above equation to solve for B, yielding

$B = \frac{E}{c}$.

<u>*Solution*</u>
We are given E, and c is the speed of light. Entering these into the expression for B yields

$$B = \frac{E}{c} = \frac{1000\ V/m}{3.00\ \times 10^{8}\ m/s} = 3.33\ \times 10^{-6}\ T$$

The B-field strength is less than a tenth of the Earth's admittedly weak magnetic field. This means that a relatively strong electric field of 1000 V/m is accompanied by a relatively weak magnetic field. Note that as this wave spreads out, say with distance from an antenna, its field strengths become progressively weaker.

2) **(3p.)** Calculate the wavelengths of:
   a) a 1530-kHz AM radio signal,
   b) a 105.1-MHz FM radio signal,
   c) and a 1.90-GHz cell phone signal.

<u>*Answer:*</u>
The relationship between wavelength and frequency is $c=f\lambda$, where $c=3.00\times10^{8}m/s$ is the speed of light (the speed of light is only very slightly smaller in air than it is in a vacuum). We can rearrange this equation to find the wavelength for all three frequencies.

<u>*Solution*</u>

a) for f =1530 kHz AM radio signal, then

$$\lambda = \frac{3.00\ \times 10^{8}\ m/s}{1530\ \times 10^{3}\ 1/s} = 196\ m.$$

b) for f =105.1 MHz AM radio signal, then

$$\lambda = \frac{3.00\ \times 10^{8}\ m/s}{105.1\ \times 10^{6}\ 1/s} = 2.85\ m.$$

c) for f =1.9 GHz AM radio signal, then

$$\lambda = \frac{3.00\ \times 10^{8}\ m/s}{1.9\ \times 10^{9}\ 1/s} = 0.158\ m.$$

3) **(3p.)** During laser vision correction, a brief burst of 193-nm ultraviolet light is projected onto the cornea of a patient. It makes a spot 0.80 mm in diameter and evaporates a layer of cornea 0.30μm thick. Calculate the energy absorbed, assuming the corneal tissue has the same properties as water; it is initially at 34ºC . Assume the evaporated tissue leaves at a temperature of 100ºC.

Answer:

The energy from the laser light goes toward raising the temperature of the tissue and also toward evaporating it. Thus we have two amounts of heat to add together. Also, we need to find the mass of corneal tissue involved.

Solution

To figure out the heat required to raise the temperature of the tissue to 100°C , we can apply concepts of thermal energy. We know that

$Q=mc\Delta T,$

where Q *is the heat required to raise the temperature,* ΔT *is the desired change in temperature,* m *is the mass of tissue to be heated, and* c *is the specific heat of water equal to 4186 J/kg/K.*

Without knowing the mass m *at this point, we have*

$Q=m*(4186\ J/kg/K)*(100°C-34°C)=m(276{,}276\ J/kg)=m(276\ kJ/kg).$

The latent heat of vaporization of water is 2256 kJ/kg, so that the energy needed to evaporate mass m *is*

$Q_v=mL_v=m*(2256\ kJ/kg).$

To find the mass m *, we use the equation* $\rho=m/V$ *, where* ρ *is the density of the tissue and* V *is its volume. For this case,*

$m=\rho V=(1000\ kg/m^3)(area\times thickness(m^3))=$
$=(1000\ kg/m^3)(\pi(0.80\times10^{-3}m)^2/4)(0.30\times10^{-6}m)=$
$=0.151\times10^{-9}kg.$

Therefore, the total energy absorbed by the tissue in the eye is the sum of Q *and* Q_v*:*

$Q_{tot}=m(c\Delta T+L_v)=(0.151\times10^{-9}kg)(276\ kJ/kg+2256\ kJ/kg)=382\times10^{-9}kJ.$

4) **(2p.)** Determine the amount of time it takes for X-rays of frequency 3×1018Hz to travel

a) 1 mm and

b) 1 cm.

Answer:

The relationship between distance and time is $t=s/c$ *, where* $c=3.00\times10^8 m/s$ *is the speed of light (the speed of light is only very slightly smaller in air than it is in a vacuum).*

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