4.4: Electromagnetic Plane Waves

As we have seen previously, if you are far enough from a source of spherical waves, the waves flatten out into waves that can be approximated by plane waves. In the following simulation a plane electromagnetic wave is traveling in the y-direction. It's time dependent magnitude is initially in the x-direction and is given by $E(x,t) = E_x \sin(ky - \omega t + \varphi)$ where E_x is the maximum electric field in the x-direction and $E_x = 1.0 \text{ N/C}$ in this simulation. The graph below shows the electric field, $E(y = \text{slider position}, t)$ in the $x - z$ plane at the location of the magenta square. The location of the square can be changed using the slider. You can also change the viewer's perspective of the wave (top graph) by grabbing the wave with the mouse and rotating the box.

Electromagnetic Waves

Questions:

Exercise 4.4.1

Play the simulation. Grab the box on the top with the mouse to look at the wave from several orientations. Describe what is happening to the electric field in the $x - z$ plane at the location of the magenta box.

Exercise 4.4.2

Time in nanoseconds ($\times 10^9$ sec) is shown on the graph. Step through the simulation from a time when the electric field is a maximum in the plus-x direction until it is again a maximum in the plus-x direction. What is the period of this wave? What is the frequency? What part of the electromagnetic spectrum is this?

Exercise 4.4.3

Pause the simulation and use the slider to slowly move the magenta square back and forth. Describe what you see in the lower graph for various locations of the magenta square.

Exercise 4.4.4

The slider shows the position of the magenta square in a small window to the left of the slider. Slide the square from a position of maximum electric field to the next position of maximum electric field to find the wavelength of this wave. Does it match a calculation based on $v = \lambda / T$?

Exercise 4.4.5

Reset the simulation and click on the 'show B' box. The magnetic field is in red and is measured in tesla, $T = \text{Vs/m}^2$, or gauss, where $1 \text{ G} = 10^{-4} \text{ T}$. Play the simulation and look at it from several different angles. What is the relationship between the magnetic and electric field? How are they oriented? Do the have the same amplitude? The same wavelength? The same period?

The simulation represents the electric component of a wave that is **polarized** in the x-direction. In other words, the components of the electric field point in either the plus or minus x-direction and the E_z component is initially zero.

Exercise 4.4.6

Reset the simulation and add an z-component of the electric field using the slider. Play the simulation and rotate it to see what this new wave looks like. It is still polarized but no longer in the x-direction. Describe what is different about this wave than the initial case.

Exercise 4.4.7

What is the direction of polarization of this wave for the maximum z-component available using the slider?

Exercise 4.4.8

What would be the direction of polarization if the y-component was zero (instead of $1.0\ \mathrm{N/C}$) and the z-component was $1.0\ \mathrm{N/C}$?

To be consistent with Maxwell's equations, the cross product $\mathbf{E}\times\mathbf{B}$ is a vector in the direction of motion of the wave where E and B are the magnitudes of the electric and magnetic fields which are related by $E/B = c$ where c is the speed of light. In the simulation this would make B too small to be visible using the same scales so in this sense the simulation is misleading; the scales for E and B are not the same.

Exercise 4.4.9

Add the magnetic field for the previous case of a polarized wave. Play the simulation, rotate the view using the mouse, pause and slide the square. What is the relationship between the magnetic and electric field in this case? How are they oriented? Is it true that $\mathbf{E}\times\mathbf{B}$ is a vector in the direction of motion? Is this true at all times and all slider positions? Why is the magnetic field perpendicular to the electric field (Hint: Think about Ampere's law)?

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