CH 20-3 – Electromagnetic Waves

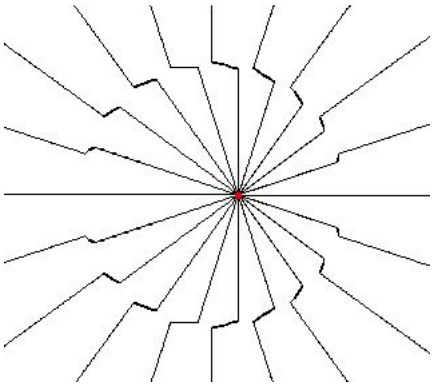
Important Ideas

- We have seen so far that:

  1. A charged particle creates an electric field because it has charge. (That's what charge does!)
  2. A moving charged particle creates a magnetic field because it has charge and because it is moving. (That's what moving charge does!)

  Today, we will see that an accelerating charged particle creates a propagating "disturbance" in the electric and magnetic field. This "disturbance" in the electric and magnetic fields travels at the speed of light.

- If a charged particle has an acceleration $\vec{a}$, then there will be a "kink" in the electric field that is tangent to a circle around the charged particle. This "kink" travels radially away from the particle. The electric field at the "kink" will be called the *radiative* electric field. It is zero along the direction of the acceleration and is a maximum perpendicular to the acceleration.



- The radiative electric field travels at the speed of light (in a vacuum). The speed of light is

$$c = \frac{1}{\sqrt{\varepsilon_0 \mu_0}} \tag{1}$$

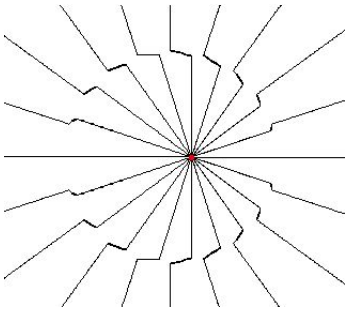
- There is also a radiative magnetic field. Its magnitude is

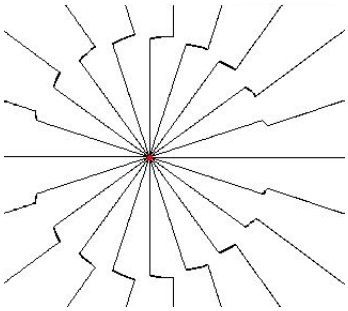
$$B_{rad} = \frac{E_{rad}}{c} \tag{2}$$

- The direction of the electric and magnetic fields in an electromagnetic wave are related by the right-hand rule. Point your fingers in the direction of $\vec{E}$, face your palm in the direction of $\vec{B}$. Your thumb points in the direction of propagation of the wave.

Examples

1. Figure 1 (left) and Figure 2 (right) show a proton at rest that is briefly accelerated ("kicked") by an external electric field and then moves at constant velocity. The electric field lines are shown (and point away from the particle). The direction of the brief acceleration of the proton is different in the two cases.





   (a) In which case was the proton briefly accelerated to the left?

      i. Figure 1
      ii. Figure 2
      iii. in both cases
      iv. in neither case

   (b) In which case was the proton briefly accelerated to the right?

      i. Figure 1
      ii. Figure 2
      iii. in both cases
      iv. in neither case

   (c) Suppose that "electric field detectors" are placed around a sphere at the same distance r from the source particle when the electromagnetic pulse is emitted (as a result of the brief kick). Which detector would measure the largest radiative (or transverse) electric field as the pulse passes the detector?

      i. the detector on the x-axis
      ii. the detector on the y-axis
      iii. the detector on the z-axis
      iv. Detectors on the y and z axes would both measure the largest radiative electric field.
      v. All of the detectors would measure the same magnitude of radiative electric field.

   (d) Which detector would measure zero radiative (or transverse) electric field?

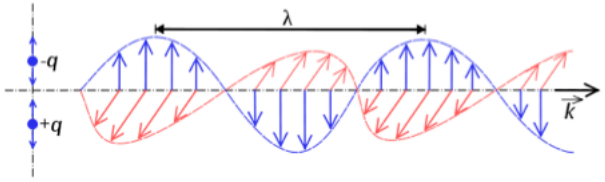
      i. the detector on the x-axis
      ii. the detector on the y-axis
      iii. the detector on the z-axis
      iv. Detectors on the x and z axes would both measure zero radiative electric field.
      v. All of the detectors would measure zero radiative electric field.

(e) Suppose that at t=0, the particle received the "kick" that changed its momentum during a very short time interval. At what time would a detector 1 km away from the particle detect the radiative (i.e. transverse) electric field?

i. 3.00×10^5 s
ii. 3.00×10^8 s
iii. 3.33×10^{-9} s
iv. 3.33×10^{-6} s
v. 1000 s

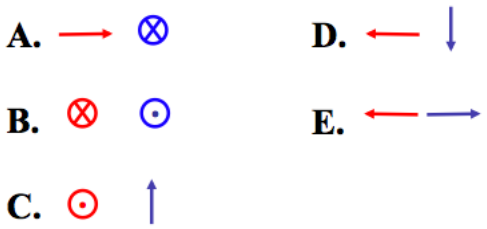
2. Using the constants μ_0 and ϵ_0, calculate the speed of an electromagnetic wave.

3. What does the vector in the $\pm y$ direction represent?



4. How long does it take for light to travel from Sun to Earth, if Earth is 1.5×10^{11} m from Sun?

5. If an electromagnetic wave is traveling directly out of the page, which of the following shows possible directions of the electric (red, on left) and magnetic (blue, on right) fields at a point P along its path at a particular instant? (Assume there are no background fields present.)



6. A certain FM radio station broadcasts at 88.5 MHz. What is the wavelength of the radio wave that it broadcasts?