Chapter 32

Electromagnetic Waves

32.1 Creating EM Waves

8/10:

- Quizzes and tests are open notebook, open notes, open textbook.
  - You can use a TI-84 type calculator, but nothing fancier.
- Reviews that a charge at rest generates an electric field and that a charge moving with constant velocity v generates a magnetic field in addition to its electric field.
  - Relativity says that you can't tell whether a charge is moving relative to you or whether you're moving relative to the charge, so a charge at rest and a moving charge have identical field lines, when appropriate frames of reference are taken.
- However, when a charge accelerates for a brief time, kinks will be generated in the field lines that correspond to exactly what was going on during the acceleration.

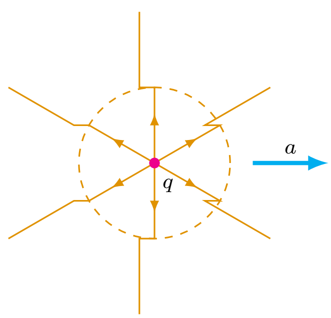

Figure 32.1: An accelerating charge.

  - The field lines are radial before and after the acceleration, but not radial during it (these are the kinks).
  - The kinks are perpendicular to the field lines, and generate a transverse electric field.
  - The transverse electric field then propagates at the speed of light.

32.2 Defining EM Waves

- **Electromagnetic wave**: The propagation of the transverse electric field.
- According to Faraday's Law, changing magnetic fields induce changing electric fields.

- According to Ampere's Law, currents induce magnetic fields.
  - Maxwell adjusts this.
  - You can have currents that are real, but also currents that are not technically currents.

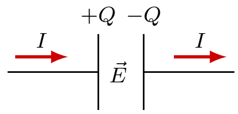

Figure 32.2: Generating a displacement current.

    - For example, between the plates of a charging capacitor, the changing electric field still produces a magnetic field.
    - This **displacement current** is induced by the changing electric flux $\mathrm{d}\Phi_E/\mathrm{d}t$, which is the root cause of the magnetic field.
    - Mathematically, $I_{\text{displacement}} = \epsilon_0 \cdot \mathrm{d}\Phi_E/\mathrm{d}t$.
  - Thus, according to the Maxwell-Ampere law, changing electric fields induce changing magnetic fields.
- As the transverse electric field approaches you, the changing magnetic field induces a planar displacement current going in one direction at the front end and the opposite direction at the other end.

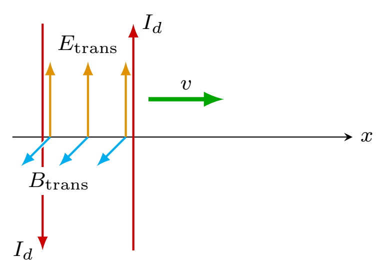

Figure 32.3: An idealized wave with a planar wavefront.

  - As the front passes you, a magnetic field is induced, too, by the Maxwell-Ampere law.
  - The two interchanging pulses create a self-sustaining wave.
- Essentially, Maxwell's conclusion is that changing transverse electric fields and changing transverse magnetic fields induce each other.
  - The speed that this occurs at is

$$v = \frac{1}{\sqrt{\mu_0 \epsilon_0}} = 3 \times 10^8 \text{ m/s}$$

  - To derive this speed, Maxwell used his observation that in one dimension, the transverse electric field obeys the equation, $\frac{\partial^2 E_{\text{trans}}}{\partial x^2} = \mu_0 \epsilon_0 \frac{\partial^2 E_{\text{trans}}}{\partial t^2}$.
  - By comparison with the wave equation, $\mu_0 \epsilon_0 = \frac{1}{v^2}$, which can be solved for the above.

32.3 EM Waves in the World

- Accelerating charges are commonly seen in

1. Orbiting electrons in an atom;
2. LC circuits.

- For an LC circuit,

$$f_{\text{EM wave}} = f_{\text{LC}} = \frac{1}{2\pi} \cdot \frac{1}{\sqrt{LC}}$$

- Homemade circuits can make frequencies between 1×10^4 - $1 \times 10^{11}\,\mathrm{s}^{-1}$, and thus since $c = f\lambda$, wavelengths between 1×10^4 - 1×10^{-3} m (waves from kilometers to millimeters in length).
- Orbiting electrons give frequencies between 1×10^{11} - $1 \times 10^{18}\,\mathrm{s}^{-1}$, and wavelengths between 1×10^{-3} - 1×10^{-10} m (waves from millimeters down to angstroms in length).
  - Thus, we can cover 14 orders of magnitude in total.
  - Visible is only 4000-7000 angstroms!