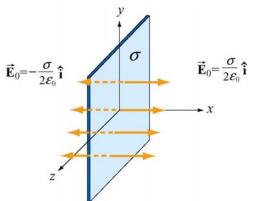**Topics**:   Generating EM Radiation
Related Reading:
        Course Notes (Liao et al.):   Chapter 13
Experiments: (8) Microwave Generator
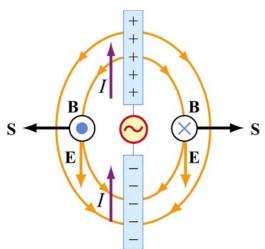
Topic Introduction

Today we will talk about how to generate electromagnetic waves. We will also discuss and do a lab using a spark-gap transmitter.

Polarization
As mentioned in the last class, EM waves are transverse waves – the E & B fields are both perpendicular to the direction of propagation $\hat{\mathbf{p}}$ as well as to each other. Given $\hat{\mathbf{p}}$, the E & B fields can thus oscillate along an infinite number of directions (any direction perpendicular to $\hat{\mathbf{p}}$). We call the axis that the E field is oscillating along the polarization axis (often a "polarization direction" is stated, but since the E field oscillates, sometimes E points along the polarization direction, sometimes opposite it). When light has a specific polarization direction we say that it is polarized. Most light (for example, that coming from the sun or from light bulbs) is unpolarized – the electric fields are oscillating along lots of different axes. However, in certain cases light can become polarized. A very common example is that when light scatters off of a surface only the polarization which is parallel to that surface survives. This is why Polaroid sunglasses are useful. They stop all light which is horizontally polarized, thus blocking a large fraction of light which reflects off of horizontal surfaces (glare). If you happen to own a pair of Polaroid sunglasses, you can find other situations in which light becomes polarized. Rainbows, for example, are polarized. So is the sky under the right conditions (can you figure out what the conditions are?) This is because the blue light that you see in the sky is scattered sun light.

Generating Plane Electromagnetic Waves: How do we generate plane electromagnetic waves? We do this by shaking a sheet of charge up and down, making waves on the electric field lines of the charges in the sheet. We discuss this process quantitatively in this lecture, and show that the work that we do to shake the sheet up and down provides exactly the amount of energy carried away in electromagnetic waves.

Antenna: How do we generate electric dipole radiation? Again, by shaking charge, but this time not an infinite plane of charge, but a line of charge on an antenna. At left is an illustration of an antenna. It is quite simple in principle. An oscillator drives charges back and forth from one end of the antenna to the other (at the moment pictured the top is positive the bottom negative, but this will change in half a period). This separation of charge creates an electric field that points from the positive to the negative side of the antenna. This field also begins to propagate away from the antenna (in the direction of the Poynting vector **S**). When the charge changes sides the field will flip directions – hence you have an oscillating electric field that is propagating away from the antenna. This changing E field generates a changing B field, as pictured, and you thus have an electromagnetic wave. The length of each part of the antenna above (e.g. the top half) is about equal in length to ¼ of the wavelength if the radiation that it produces. Why is that? The charges move at close to the speed of light in the antenna so that in making one complete oscillation of the wave (by moving from the top to the bottom and back again) they move about as far as the wave has itself (one wavelength).

Important Equations

Maxwell's Equations:

$$(1) \oiint_S \vec{E} \cdot d\vec{A} = \frac{Q_{in}}{\varepsilon_0} \qquad (2) \oiint_S \vec{B} \cdot d\vec{A} = 0$$

$$(3) \oint_C \vec{E} \cdot d\vec{s} = -\frac{d\Phi_B}{dt} \qquad (4) \oint_C \vec{B} \cdot d\vec{s} = \mu_0 I_{enc} + \mu_0 \varepsilon_0 \frac{d\Phi_E}{dt}$$

EM Plane Waves:

$$\vec{E}(\vec{r},t) = E_0 \sin(k\hat{\mathbf{p}} \cdot \vec{r} - \omega t)\hat{\mathbf{E}}$$
$$\vec{B}(\vec{r},t) = B_0 \sin(k\hat{\mathbf{p}} \cdot \vec{r} - \omega t)\hat{\mathbf{B}}$$

with $E_0 = cB_0$; $\hat{\mathbf{E}} \times \hat{\mathbf{B}} = \hat{\mathbf{p}}$; $\omega = ck$

Experiment 8: Microwaves
Preparation: Read pre-lab and answer pre-lab questions

In today's lab you will create microwaves (EM radiation with a wavelength of several centimeters) using a spark gap transmitter. This is a type of quarter wavelength antenna that works on the principles described above. You will measure the polarization of the produced EM waves, and try to understand the intensity distribution created by such an antenna (where is the signal the strongest? The weakest?) You will also measure the wavelength of the radiation by creating a standing wave by reflecting the waves off of a metal wall and allowing them to interfere with the waves created by the antenna.