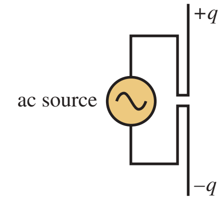
Topic 11 | Radiation from an Antenna

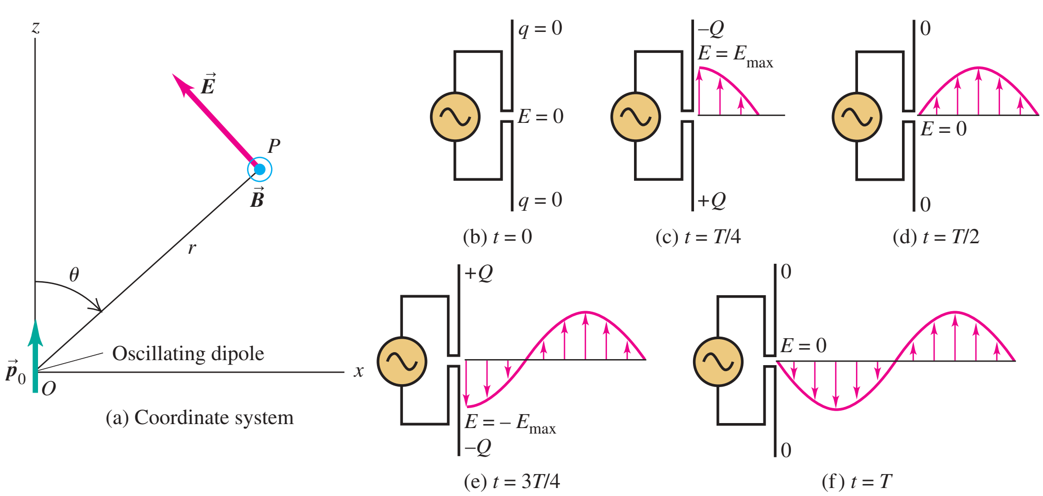


T11.1 An oscillating electric dipole antenna. Each terminal of an ac source is connected to a straight conductor; the two conductors together comprise the antenna. As the voltage across the source oscillates, the charges on the two conductors also oscillate. The charges are always equal in magnitude and opposite in sign.

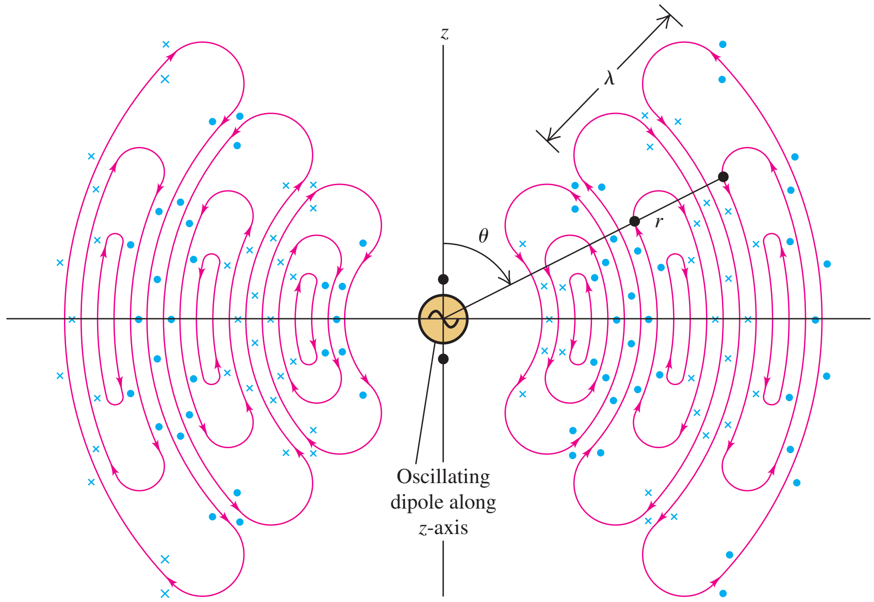
Our discussion of electromagnetic waves in Chapter 32 has centered mostly on *plane waves,* which propagate in a single direction. In any plane perpendicular to the direction of propagation of the wave, the $\vec{E}$ and $\vec{B}$ fields are uniform at any instant of time. Though easy to describe, plane waves are by no means the simplest to produce experimentally. Any charge or current distribution that oscillates sinusoidally with time, such as the oscillating point charge in Fig. T11.1, produces sinusoidal electromagnetic waves, but in general there is no reason to expect them to be plane waves.

A device that uses an oscillating distribution to produce electromagnetic radiation is called an *antenna.* A simple example of an antenna is an **oscillating electric dipole,** a pair of electric charges that vary sinusoidally with time such that at any instant the two charges have equal magnitude but opposite sign. One charge could be equal to $Q \sin \omega t$ and the other to $-Q \sin \omega t$. An oscillating dipole antenna can be constructed in various ways, depending on frequency. One technique that works well for radio frequencies is to connect two straight conductors to the terminals of an ac source, as shown in Fig. T11.1.

The radiation pattern from an oscillating electric dipole is fairly complex, but at points far away from the dipole (compared to its dimensions and the wavelength of the radiation) it becomes fairly simple. We'll confine our description to this far region. A key feature of the radiation in the far region is that it is *not* a plane wave, but a wave that travels out radially in all directions from the source. The wave fronts are not planes; in the far region they are expanding concentric spheres centered at the source. Figure T11.2 shows an oscillating electric dipole aligned with the z-axis, with maximum dipole moment p_0. The $\vec{E}$ and $\vec{B}$ fields at a point described by the spherical coordinates (r, θ, ϕ) have the directions shown in Fig. T11.2a during half the cycle and the opposite direction during the other half.



T11.2 (a) An oscillating electric dipole oriented along the z-axis. The electric and magnetic fields at a point P are given by Eqs. (T11.1). (b)–(f) One cycle in the production of an electromagnetic wave by an oscillating electric dipole antenna. The red curve and arrows depict the $\vec{E}$ field at points on the x-axis (where $\theta = \pi/2$); the magnetic field is not shown. The figure is not to scale.



T11.3 Representation of the electric field (red lines) and the magnetic field (blue dots and crosses) in a plane containing an oscillating electric dipole. During one period the loop of $\vec{E}$ shown closest to the source moves out and expands to become the loop shown farthest from the source. You can use Eq. (32.28) and the right-hand rule to find the direction of the Poynting vector $\vec{S}$ at each point within the pattern. No energy is radiated along the axis of the dipole.

Their magnitudes in the far region are

$$E(r, \theta, \phi, t) = \frac{-p_0 k^2}{4\pi\epsilon_0} \frac{\sin\theta}{r} \sin(kr - \omega t)$$

$$B(r, \theta, \phi, t) = \frac{-p_0 k^2}{4\pi\epsilon_0 c} \frac{\sin\theta}{r} \sin(kr - \omega t) \qquad \text{(T11.1)}$$

One distinctive feature of the oscillating-dipole fields given by Eqs. (T11.1) is that their magnitudes are proportional to $1/r$. This is in contrast to the $\vec{E}$ field of a *stationary* point charge or the $\vec{B}$ field of a point charge moving with *constant* velocity, both of which are proportional of $1/r^2$. In fact, the complete expressions for the $\vec{E}$ and $\vec{B}$ fields of an oscillating dipole also include terms that are proportional to $1/r^2$; we haven't included these in Eqs. (T11.1), since our interest is in the behavior of the fields in the far region, and the $1/r^2$ terms become negligible at greater distances r from the dipole.

Figure T11.3 shows a cross section of the radiation pattern at one instant. At each point, $\vec{E}$ is in the plane of the section and $\vec{B}$ is perpendicular to that plane. The electric field lines form closed loops, as is characteristic of *induced* electric fields; in the far region the electric field is induced by the variation of $\vec{B}$, and the magnetic field is induced by the variation of $\vec{E}$, forming a self-sustaining wave. The field magnitudes are greatest in the directions perpendicular to the dipole, where $\theta = \pi/2$; there is *no* radiation along the axis of the dipole, where $\theta = 0$ or π. We saw a similar result for a single oscillating electric charge in Fig. T32.2. The key difference is that Fig. T11.3 shows only the fields that are proportional to $1/r$ in the far region of an oscillating electric dipole, while Fig. T32.2 shows the field in the *near* region of a single oscillating charge; in this near region the $1/r^2$ terms must also be included.

At points very far from the oscillating dipole, $\vec{E}$ and $\vec{B}$ are perpendicular to each other, and the direction of the Poynting vector $\vec{S} = (\vec{E} \times \vec{B})/\mu_0$ is radially outward from the source. Because each field magnitude is proportional to $1/r$, the intensity I (the average value of the magnitude of $\vec{S}$) is proportional to $1/r^2$. The net average power radiated by the oscillating dipole through a spherical surface of radius r centered on the dipole is the integral of the intensity over this surface. Since the area of this surface is proportional to r^2, the net average power is proportional to $(1/r^2)(r^2) = 1$; that is, the power radiated by the dipole in all directions is independent of r. This means that the radiated energy does not "get lost" as it spreads outward but continues on to arbitrarily great distances from the source. The intensity is also proportional to $\sin^2\theta$, which vanishes on the axis of the dipole ($\theta = 0$ or $\theta = \pi$). No energy is radiated along the dipole axis.

Oscillating *magnetic* dipoles also act as radiation sources; an example is a circular loop antenna that uses a sinusoidal current. At sufficiently high frequencies a magnetic dipole antenna is more efficient at radiating energy than is an electric dipole antenna of the same overall size.