Because of the duality of results, the properties of the magnetic dipole and the electric dipole are the same, with the exception of the directions of the fields: These, of course, are perpendicular to one another; that is, the directions of the electric field intensity of the electric dipole and that of the magnetic dipole are at right angles. The time-averaged power density in the far field may be written directly as

$$\mathcal{P}_{av} = \frac{1}{2}\text{Re}\{\mathbf{E} \times \mathbf{H}^*\} = \hat{\mathbf{R}}\,\frac{\omega^2\mu^2\beta^2 m^2}{32\pi^2\eta R^2}\sin^2\theta \quad \left[\frac{\text{W}}{\text{m}^2}\right] \tag{18.78}$$

The time-averaged Poynting vector in the far field is again in the R direction, indicating outward propagation of energy. Also, by direct comparison with **Eq. (18.32)**, we note that **Eq. (18.78)** may be obtained from **Eq. (18.32)** by replacing $I_0\Delta l'$ with βm.

18.6.3 Properties of the Magnetic Dipole

Now that we have the electric and magnetic fields in the far field, we can calculate the basic properties of the magnetic dipole by starting with the definition of radiated power in **Eq. (18.33)**. Since the steps are identical to those for the electric dipole, we merely list these in **Table 18.1**. The properties of the magnetic dipole may also be obtained from those of the electric dipole in the first column of **Table 18.1** by replacing $I_0\Delta l'$ by βm or $\Delta l'$ by $\beta\pi a^2$ as indicated above.

Note also that although the relative power and field antenna patterns are the same for both antennas, the absolute antenna patterns are not. Also, the E-field pattern for the magnetic dipole corresponds to the H-field pattern for the electric dipole and vice versa.

Table 18.1 Properties of electric and magnetic dipoles as antennas

	Electric dipole	Magnetic dipole
$\mathcal{P}_{av}$ (average power density) $\left[\frac{\text{W}}{\text{m}^2}\right]$	$\hat{\mathbf{R}}\,\frac{\eta I_0^2\beta^2(\Delta l')^2}{32\pi^2R^2}\sin^2\theta$	$\hat{\mathbf{R}}\,\frac{m^2\beta^4\eta}{32\pi^2R^2}\sin^2\theta = \hat{\mathbf{R}}\,\frac{\omega^2\mu^2m^2\beta^2}{32\pi^2\eta R^2}\sin^2\theta$
P_{rad} (radiated power) [W]	$\frac{\eta I_0^2\beta^2(\Delta l')^2}{12\pi}$	$\frac{m^2\beta^4\eta}{12\pi} = \frac{\omega^2\mu^2m^2\beta^2}{12\pi\eta}$
R_{rad} (radiation resistance) [Ω]	$\frac{2\eta\pi}{3}\left(\frac{\Delta l'}{\lambda}\right)^2$	$\frac{\beta^4\pi a^4\eta}{6} = \frac{\omega^2\mu^2\beta^2\pi a^4}{6\eta}$
R_{rad} in air (radiation resistance in air) [Ω]	$80\pi^2\left(\frac{\Delta l'}{\lambda}\right)^2$	$20\pi^2\beta^4a^4 = \frac{\omega^2\mu^2\beta^2a^4}{720}$
$\lvert f_l(\theta)\rvert$ (normalized field radiation pattern)	$\lvert\sin\theta\rvert$	$\lvert\sin\theta\rvert$
$f_p(\theta)$ (normalized power radiation pattern)	$\sin^2\theta$	$\sin^2\theta$
$U(\theta)$ (radiation intensity) $\left[\frac{\text{W}}{\text{sr}}\right]$	$\frac{\eta I_0^2}{8}\left(\frac{\Delta l'}{\lambda}\right)^2\sin^2\theta$	$\frac{\beta^2\eta m^2}{8\lambda^2}\sin^2\theta = \frac{\omega^2\mu^2m^2}{8\eta\lambda^2}\sin^2\theta$
U_{av} (average radiation intensity) $\left[\frac{\text{W}}{\text{sr}}\right]$	$I_0^2\frac{\eta}{12}\left(\frac{\Delta l'}{\lambda}\right)^2$	$\frac{\beta^2\eta m^2}{12\lambda^2}$
$D(\theta)$ (directivity) [dimensionless]	$\frac{3}{2}\sin^2\theta$	$\frac{3}{2}\sin^2\theta$
D_0 (maximum directivity) [dimensionless]	1.5	1.5
eff. (radiation efficiency) [dimensionless]	$\frac{R_{rad}}{R_{rad}+R_d}$	$\frac{R_{rad}}{R_{rad}+R_d}$

Note: $\beta^2\eta^2 = \omega^2\mu^2$, $\beta = 2\pi/\lambda$.