

MAGNETIC DIPOLE MOMENT OF A CURRENT LOOP

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Reference: Griffiths, David J. (2007) Introduction to Electrodynamics, 3rd Edition; Prentice Hall - Problem 5.34.

Here's a simple example of the magnetic dipole. We've got a circular loop of current I with radius R lying in the xy plane and centered at the origin. The dipole moment is

$$\mathbf{m} = I\mathbf{a} \quad (1)$$

where \mathbf{a} is the vector area of the loop, which is just $\mathbf{a} = \pi R^2\hat{\mathbf{z}}$. Thus

$$\mathbf{m} = \pi IR^2\hat{\mathbf{z}} \quad (2)$$

Using the dipole field as an approximation for points far from the loop, we have

$$\mathbf{B}_1 = \frac{\mu_0}{4\pi r^3} [3(\mathbf{m} \cdot \hat{\mathbf{r}})\hat{\mathbf{r}} - \mathbf{m}] \quad (3)$$

$$= \frac{\mu_0\pi IR^2}{4\pi r^3} (3\cos\theta\hat{\mathbf{r}} - \hat{\mathbf{z}}) \quad (4)$$

$$= \frac{\mu_0 IR^2}{4r^3} (2\cos\theta\hat{\mathbf{r}} + \sin\theta\hat{\theta}) \quad (5)$$

For points on the z axis this becomes

$$\mathbf{B}_1 = \frac{\mu_0 IR^2}{2z^3}\hat{\mathbf{z}} \quad (6)$$

The exact formula for points on the z axis (given as example 5.6 in Griffiths) is

$$\mathbf{B} = \frac{\mu_0 IR^2}{2(R^2 + z^2)^{3/2}}\hat{\mathbf{z}} \quad (7)$$

For $z \gg R$, this gives the same result as the dipole field.

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