

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

$$(0.1) \quad \mathbf{m} = I\mathbf{a}$$

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

$$(0.2) \quad \mathbf{m} = \pi IR^2 \hat{\mathbf{z}}$$

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

$$(0.3) \quad \mathbf{B}_1 = \frac{\mu_0}{4\pi r^3} [3(\mathbf{m} \cdot \hat{\mathbf{r}}) \hat{\mathbf{r}} - \mathbf{m}]$$

$$(0.4) \quad = \frac{\mu_0 \pi IR^2}{4\pi r^3} (3 \cos \theta \hat{\mathbf{r}} - \hat{\mathbf{z}})$$

$$(0.5) \quad = \frac{\mu_0 IR^2}{4r^3} (2 \cos \theta \hat{\mathbf{r}} + \sin \theta \hat{\theta})$$

For points on the z axis this becomes

$$(0.6) \quad \mathbf{B}_1 = \frac{\mu_0 IR^2}{2z^3} \hat{\mathbf{z}}$$

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

$$(0.7) \quad \mathbf{B} = \frac{\mu_0 IR^2}{2(R^2 + z^2)^{3/2}} \hat{\mathbf{z}}$$

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

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