

Calculating the Magnetic Field Due to a Current

Figure 29-1 shows a wire of arbitrary shape carrying a current i . We want to find the magnetic field $\vec{B}$ at a nearby point P . We first mentally divide the wire into differential elements ds and then define for each element a length vector $d\vec{s}$ that has length ds and whose direction is the direction of the current in ds . We can then define a differential *current-length element* to be $i d\vec{s}$; we wish to calculate the field $d\vec{B}$ produced at P by a typical current-length element. From experiment we find that magnetic fields, like electric fields, can be superimposed to find a net field. Thus, we can calculate the net field $\vec{B}$ at P by summing, via integration, the contributions $d\vec{B}$ from all the current-length elements. However, this summation is more challenging than the process associated with electric fields because of a complexity; whereas a charge element dq producing an electric field is a scalar, a current-length element $i d\vec{s}$ producing a magnetic field is a vector, being the product of a scalar and a vector.

Magnitude. The magnitude of the field $d\vec{B}$ produced at point P at distance r by a current-length element $i d\vec{s}$ turns out to be

$$dB = \frac{\mu_0}{4\pi} \frac{i ds \sin \theta}{r^2}, \quad (29-1)$$

where θ is the angle between the directions of $d\vec{s}$ and $\hat{r}$, a unit vector that points from ds toward P . Symbol μ_0 is a constant, called the *permeability constant*, whose value is defined to be exactly

$$\mu_0 = 4\pi \times 10^{-7} \text{ T} \cdot \text{m/A} \approx 1.26 \times 10^{-6} \text{ T} \cdot \text{m/A}. \quad (29-2)$$

Direction. The direction of $d\vec{B}$, shown as being into the page in Fig. 29-1, is that of the cross product $d\vec{s} \times \hat{r}$. We can therefore write Eq. 29-1 in vector form as

$$d\vec{B} = \frac{\mu_0}{4\pi} \frac{i d\vec{s} \times \hat{r}}{r^2} \quad (\text{Biot-Savart law}). \quad (29-3)$$

This vector equation and its scalar form, Eq. 29-1, are known as the **law of Biot and Savart** (rhymes with “Leo and bazaar”). The law, which is experimentally deduced, is an inverse-square law. We shall use this law to calculate the net magnetic field $\vec{B}$ produced at a point by various distributions of current.

Here is one easy distribution: If current in a wire is either directly toward or directly away from a point P of measurement, can you see from Eq. 29-1 that the magnetic field at P from the current is simply zero (the angle θ is either 0° for *toward* or 180° for *away*, and both result in $\sin \theta = 0$)?

Magnetic Field Due to a Current in a Long Straight Wire

Shortly we shall use the law of Biot and Savart to prove that the magnitude of the magnetic field at a perpendicular distance R from a long (infinite) straight wire carrying a current i is given by

$$B = \frac{\mu_0 i}{2\pi R} \quad (\text{long straight wire}). \quad (29-4)$$

The field magnitude B in Eq. 29-4 depends only on the current and the perpendicular distance R of the point from the wire. We shall show in our derivation that the field lines of $\vec{B}$ form concentric circles around the wire, as Fig. 29-2 shows

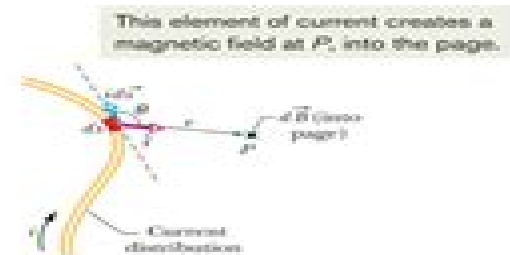


Figure 29-1 A current-length element $i d\vec{s}$ produces a differential magnetic field $d\vec{B}$ at point P . The green $\times$ (the tail of an arrow) at the dot for point P indicates that $d\vec{B}$ is directed into the page there.

The magnetic field vector at any point is tangent to a circle.

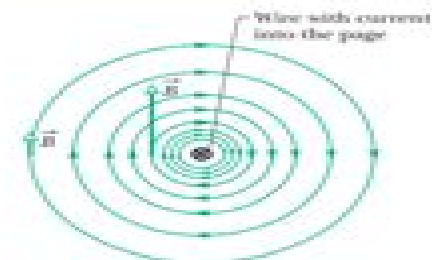


Figure 29-2 The magnetic field lines produced by a current in a long straight wire form concentric circles around the wire. Here the current is into the page, as indicated by the $\times$.

Answers For Magnetic Fundamentals Conceptual Physics

Paul G. Hewitt



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1. Understanding the eBook Answers For Magnetic Fundamentals Conceptual Physics
 - The Rise of Digital Reading Answers For Magnetic Fundamentals Conceptual Physics
 - Advantages of eBooks Over Traditional Books
2. Identifying Answers For Magnetic Fundamentals Conceptual Physics
 - Exploring Different Genres
 - Considering Fiction vs. Non-Fiction
 - Determining Your Reading Goals
3. Choosing the Right eBook Platform
 - Popular eBook Platforms
 - Features to Look for in an Answers For Magnetic Fundamentals Conceptual Physics
 - User-Friendly Interface
4. Exploring eBook Recommendations from Answers For Magnetic Fundamentals Conceptual Physics
 - Personalized Recommendations
 - Answers For Magnetic Fundamentals Conceptual Physics User Reviews and Ratings
 - Answers For Magnetic Fundamentals Conceptual Physics and Bestseller Lists
5. Accessing Answers For Magnetic Fundamentals Conceptual Physics Free and Paid eBooks
 - Answers For Magnetic Fundamentals Conceptual Physics Public Domain eBooks
 - Answers For Magnetic Fundamentals Conceptual Physics eBook Subscription Services
 - Answers For Magnetic Fundamentals Conceptual Physics Budget-Friendly Options

6. Navigating Answers For Magnetic Fundamentals Conceptual Physics eBook Formats
 - ePub, PDF, MOBI, and More
 - Answers For Magnetic Fundamentals Conceptual Physics Compatibility with Devices
 - Answers For Magnetic Fundamentals Conceptual Physics Enhanced eBook Features
7. Enhancing Your Reading Experience
 - Adjustable Fonts and Text Sizes of Answers For Magnetic Fundamentals Conceptual Physics
 - Highlighting and Note-Taking Answers For Magnetic Fundamentals Conceptual Physics
 - Interactive Elements Answers For Magnetic Fundamentals Conceptual Physics
8. Staying Engaged with Answers For Magnetic Fundamentals Conceptual Physics
 - Joining Online Reading Communities
 - Participating in Virtual Book Clubs
 - Following Authors and Publishers Answers For Magnetic Fundamentals Conceptual Physics
9. Balancing eBooks and Physical Books Answers For Magnetic Fundamentals Conceptual Physics
 - Benefits of a Digital Library
 - Creating a Diverse Reading Collection Answers For Magnetic Fundamentals Conceptual Physics
10. Overcoming Reading Challenges
 - Dealing with Digital Eye Strain
 - Minimizing Distractions
 - Managing Screen Time
11. Cultivating a Reading Routine Answers For Magnetic Fundamentals Conceptual Physics
 - Setting Reading Goals Answers For Magnetic Fundamentals Conceptual Physics
 - Carving Out Dedicated Reading Time
12. Sourcing Reliable Information of Answers For Magnetic Fundamentals Conceptual Physics
 - Fact-Checking eBook Content of Answers For Magnetic Fundamentals Conceptual Physics
 - Distinguishing Credible Sources
13. Promoting Lifelong Learning
 - Utilizing eBooks for Skill Development
 - Exploring Educational eBooks
14. Embracing eBook Trends
 - Integration of Multimedia Elements

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