

A 0.109 M Long Solenoid Contains 847 Turns And Carries A Current Of 4.49 A. What Is The Strength B Of

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Understanding the magnetic field produced by a solenoid is fundamental in electromagnetism and plays a crucial role in various technological applications, from electromagnetic relays to MRI machines. In this article, we will explore how to determine the magnetic field strength (B) of a solenoid given specific parameters: its length, number of turns, and current. By dissecting this problem step-by-step, we aim to provide a comprehensive understanding of the principles involved, the formulas used, and the practical implications of these calculations.

Introduction to Solenoids and Magnetic Fields

A solenoid is a long coil of wire wound in the form of a helix. When an electric current passes through the coil, it generates a magnetic field along the axis of the solenoid. This magnetic field can be used for various purposes, including creating magnetic environments, inductors in electrical circuits, and magnetic field sources in medical imaging.

The strength of the magnetic field inside the solenoid, denoted as (B) , depends primarily on the current flowing through the wire, the number of turns per unit length, and the physical dimensions of the coil. Understanding how to calculate (B) allows engineers and physicists to design devices with precise magnetic properties.

Fundamental Concepts and Variables

Before diving into the calculations, it's essential to understand the key variables involved:

- Length of the solenoid, (L) : The physical length of the solenoid, given as 0.109 meters.
- Number of turns, (N) : Total turns of wire wound around the coil, given as 847 turns.
- Current, (I) : The electric current passing through the wire, given as 4.49 amperes.
- Magnetic field strength, (B) : The goal is to calculate this value in teslas (T).

Additional related variables include:

- Turns per unit length, (n) : Calculated as (N / L) .

- Permeability of free space, μ_0 : A constant with a value of $4\pi \times 10^{-7} \text{ H/m}$.

Calculating the Magnetic Field (B) Inside a Solenoid

The magnetic field inside an ideal solenoid (assuming it is long relative to its diameter, so edge effects are negligible) can be calculated using the following formula:

Formula for Magnetic Field of a Solenoid

$$B = \mu_0 n I$$

Where:

- (B) = Magnetic flux density (Tesla)
- (μ_0) = Permeability of free space ($4\pi \times 10^{-7} \text{ H/m}$)
- (n) = Number of turns per unit length (N / L)
- (I) = Current in amperes

This formula assumes an ideal solenoid with uniform current distribution and negligible edge effects, which is a good approximation for long solenoids.

Step-by-Step Calculation

Let's now proceed with the calculation using the provided data.

1. Calculate (n) : Turns per unit length

$$n = \frac{N}{L} = \frac{847}{0.109 \text{ m}} \approx 7770.64 \text{ turns/m}$$

2. Use the formula $B = \mu_0 n I$

$$B = (4\pi \times 10^{-7} \text{ H/m}) \times 7770.64 \text{ turns/m} \times 4.49 \text{ A}$$

3. Calculate the product

First, multiply μ_0 and n :

$$4\pi \times 10^{-7} \times 7770.64 \approx (4 \times 3.1416) \times 10^{-7} \times 7770.64$$

$$= 12.5664 \times 10^{-7} \times 7770.64 \approx 12.5664 \times 7770.64 \times 10^{-7}$$

Calculate 12.5664×7770.64 :

$$12.5664 \times 7770.64 \approx 97561.75$$

Now, multiply by $I = 4.49 \text{ A}$:

$$97561.75 \times 4.49 \approx 438,076.87$$

Finally, account for the 10^{-7} :

$$B \approx 438,076.87 \times 10^{-7} = 4.38077 \times 10^{-2} \text{ T}$$

Or approximately:

$$B \approx 0.0438 \text{ T}$$

Final Result and Interpretation

The magnetic field strength (B) inside the solenoid under the given conditions is approximately 0.0438 Tesla.

This value is significant in various applications:

- Electromagnetic Devices: A magnetic field of about 0.0438 T can influence magnetic materials and is useful in magnetic resonance imaging (MRI) and other scientific instruments.
- Design Considerations: Engineers can adjust parameters such as turns or current to obtain the desired magnetic field strength for specific applications.

Factors Affecting the Magnetic Field in a Real-World Solenoid

While the theoretical calculation provides a good estimate, real-world factors can influence the actual magnetic field strength:

- Edge Effects: Near the ends of the solenoid, the magnetic field is weaker due to fringing effects.
- Wire Resistance and Heating: Higher currents can lead to heating, affecting resistance and current stability.
- Material Permeability: If the solenoid core is not air or vacuum but a magnetic material, the magnetic permeability increases, further strengthening (B) .

Enhancing Magnetic Field Strength

To increase the magnetic field in a solenoid, consider the following strategies:

1. Increase the Number of Turns (N) : More turns per unit length lead to a higher (n) , directly increasing (B) .
2. Increase the Current (I) : Higher current results in a proportionally stronger magnetic field, constrained by wire resistance and thermal limits.
3. Use a Magnetic Core: Inserting a ferromagnetic core (like iron) significantly amplifies the magnetic field due to high permeability.
4. Reduce the Length (L) : Shorter solenoids with the same (N) will have a higher (n) , leading to a stronger (B) .

Practical Applications of Solenoid Magnetic Fields

Understanding how to calculate and manipulate the magnetic field in solenoids is vital across multiple fields:

- Electromagnetic Induction: Devices like transformers rely on magnetic fields generated by coils.
- Medical Imaging: MRI machines use strong, uniform magnetic fields produced by solenoids.
- Particle Accelerators: Solenoids steer and focus charged particles with magnetic fields.
- Electromechanical Devices: Solenoids act as actuators in various appliances and industrial machinery.

Conclusion

Calculating the magnetic field (B) of a solenoid involves understanding the fundamental principles of electromagnetism, applying the correct formulas, and considering the physical parameters of the coil. With the given data—a length of 0.109 meters, 847 turns, and a current of 4.49 amperes—the magnetic field inside the solenoid is approximately 0.0438 Tesla.

This calculation not only exemplifies the application of theoretical physics but also provides practical insights into designing magnetic devices for real-world applications. Whether in scientific research, medical technology, or industrial automation, mastering the calculation of magnetic fields in solenoids is essential for innovation and precision in electromagnetic systems.

Keywords: solenoid magnetic field, magnetic flux density, electromagnetism, coil design, magnetic field calculation, physics, engineering, magnetic applications

Frequently Asked Questions

What is the formula to calculate the magnetic field strength (B) inside a long solenoid?

The magnetic field strength B inside a long solenoid is given by $B = \mu_0 n I$, where μ_0 is the permeability of free space, n is the number of turns per unit length, and I is the current.

How do you determine the number of turns per unit length (n) in a solenoid?

n is calculated by dividing the total number of turns (N) by the length (L) of the solenoid: $n = N / L$.

Given N = 847 turns and I = 4.49 A, how do you find the length of the solenoid if the magnetic field strength B is known?

Rearranged from $B = \mu_0 n I$, the length L can be found using $L = N / n$, where n is derived from $B = \mu_0 (N / L) I$.

What is the permeability of free space (μ_0) used in the calculation?

The permeability of free space μ_0 is approximately $4\pi \times 10^{-7} \text{ T}\cdot\text{m/A}$.

How do you convert the given concentration 0.109 M to a magnetic field strength?

Concentration (0.109 M) is unrelated to magnetic field calculation; instead, the magnetic field depends on current, number of turns, and solenoid dimensions, not molarity.

What is the significance of the 'long' in a long solenoid for calculating B?

A 'long' solenoid allows the magnetic field to be considered uniform inside the coil, simplifying calculations using the formula $B = \mu_0 n I$.

Can the magnetic field strength B be directly calculated from the given molarity of 0.109 M?

No, molarity relates to concentration in chemistry and does not directly influence the magnetic field; the calculation depends on current, turns, and coil length.

If the length of the solenoid is not provided, how can you estimate B?

You need to know the length to determine n (turns per unit length). Without it, B cannot be accurately calculated; additional information is required.

What is the typical magnetic field strength inside a long

solenoid carrying 4.49 A with 847 turns?

Using the formula $B = \mu_0 (N / L) I$, and knowing the length, you can compute B. Without the length, an exact value cannot be determined, but it generally ranges from a few millitesla to several hundred millitesla depending on the coil dimensions.

How would increasing the number of turns N affect the magnetic field B in the solenoid?

Increasing N increases n (turns per unit length), which directly increases B, making the magnetic field stronger inside the solenoid.

Additional Resources

A 0.109 M Long Solenoid Contains 847 Turns And Carries A Current Of 4.49 A. What Is The Strength B Of

Understanding the magnetic field generated by a solenoid is a fundamental aspect of electromagnetism, with broad applications in electrical engineering, physics research, and various technological devices. In this article, we delve into the specifics of calculating the magnetic flux density, commonly denoted as B, for a long solenoid with given parameters. This analysis not only elucidates the underlying physics principles but also demonstrates the practical steps involved in deriving the magnetic field strength, providing a comprehensive overview suitable for students, educators, and professionals alike.

Introduction to Magnetic Fields in Solenoids

A solenoid is a cylindrical coil of wire often used to generate controlled magnetic fields. When an electric current passes through the coil, it produces a magnetic field along its axis, which can be approximated as that of a bar magnet. The magnitude of this magnetic field depends on several factors, including the number of turns, current, length, and the physical properties of the medium inside the solenoid.

The primary goal in analyzing a solenoid's magnetic field is to understand how parameters like the number of turns per unit length and current influence the magnetic flux density (B) . This understanding is essential for designing electromagnets, inductors, transformers, and other devices where magnetic fields play a critical role.

Fundamental Principles and Formulae

Magnetic Field of an Ideal Long Solenoid

For an ideal long solenoid—meaning its length is much greater than its diameter—the magnetic field inside is uniform and can be accurately described by a simplified formula:

$$B = \mu_0 n I$$

Where:

- B is the magnetic flux density in teslas (T).
- μ_0 is the permeability of free space, approximately $4\pi \times 10^{-7} \text{ T} \cdot \text{m/A}$.
- n is the number of turns per unit length (turns/m).
- I is the current passing through the solenoid (A).

This formula assumes the solenoid is sufficiently long relative to its diameter, minimizing edge effects and ensuring a nearly uniform magnetic field inside.

Calculating Turns per Unit Length (n)

Given the total number of turns N and the length L of the solenoid, the turns per unit length n is calculated as:

$$n = \frac{N}{L}$$

This parameter is critical because it determines the density of the coil windings, directly influencing the magnetic field strength.

Given Data and Initial Analysis

In the problem at hand, the following data are provided:

- Number of Turns, $N = 847$
- Length of the Solenoid, $L = 0.109 \text{ m}$
- Current, $I = 4.49 \text{ A}$

Before proceeding, it is essential to understand what the question aims to find: the magnetic flux density B inside the solenoid.

Step-by-Step Calculation of B

1. Calculate the Turns per Unit Length (n)

Using the provided data:

$$n = \frac{N}{L} = \frac{847}{0.109 \text{ m}} \approx 7779.82 \text{ turns/m}$$

This high density of turns per meter indicates a tightly wound coil, which suggests a strong magnetic field, assuming the current is sufficient.

2. Apply the Magnetic Field Formula

Using the fundamental formula for an ideal long solenoid:

$$B = \mu_0 n I$$

Plugging in the known values:

$$\mu_0 = 4\pi \times 10^{-7} \text{ T} \cdot \text{m/A}$$

$$n \approx 7779.82 \text{ turns/m}$$

$$I = 4.49 \text{ A}$$

Calculating step-by-step:

$$B = (4\pi \times 10^{-7}) \times 7779.82 \times 4.49$$

First, compute $(4\pi \times 10^{-7})$:

$$4\pi \times 10^{-7} \approx 1.25663706 \times 10^{-6} \text{ T} \cdot \text{m/A}$$

\]

Now multiply:

\[

$$B \approx 1.25663706 \times 10^{-6} \times 7779.82 \times 4.49$$

\]

Calculate (7779.82×4.49) :

\[

$$7779.82 \times 4.49 \approx 34894.85$$

\]

Finally, multiply:

\[

$$B \approx 1.25663706 \times 10^{-6} \times 34894.85 \approx 0.0438 \, \mathrm{T}$$

\]

Result:

\[

\boxed{

$$B \approx 0.0438 \, \mathrm{T}$$

}

\]

Implications and Contextual Analysis

Magnitude of the Magnetic Field

The calculated magnetic flux density $(B \approx 0.0438 \, \mathrm{T})$ (or about 43.8 milliteslas) indicates a relatively strong magnetic field, suitable for many practical electromagnetic applications. For comparison, Earth's magnetic field ranges from approximately 25 to 65 microteslas, so this solenoid produces a magnetic field several orders of magnitude stronger.

Influence of Parameters on Magnetic Field Strength

Understanding the relationships involved helps in designing solenoids tailored to specific magnetic field requirements:

- Number of Turns (N) : Increasing (N) increases (n) and thus enhances (B) .

Doubling the number of turns roughly doubles the magnetic field, assuming other factors remain constant.

- Length of the Solenoid (L): Shorter solenoids with the same N have higher n , leading to stronger B . However, shorter length also introduces edge effects, making the uniformity of the field less ideal.
- Current (I): Increasing the current proportionally increases B . Material limitations and heat dissipation considerations must be accounted for when scaling current.

Limitations and Real-World Considerations

While the ideal formula provides a solid estimate, real-world factors can influence the actual magnetic field:

- Finite Length Effects: Edge effects reduce the uniformity of B near the ends of the solenoid.
- Material Properties: The presence of magnetic materials inside or near the solenoid can increase or decrease B .
- Resistance and Heating: High currents induce resistive heating, which can affect the coil's performance and safety.
- Core Material: Using a ferromagnetic core (like iron) significantly amplifies B by increasing the permeability μ , potentially beyond the vacuum permeability μ_0 .

Applications of Solenoid Magnetic Fields

The magnitude of magnetic fields generated by solenoids is pivotal in various disciplines:

- Electromagnetic Induction: Solenoids are at the heart of transformers and inductors.
- Magnetic Resonance Imaging (MRI): Strong, uniform magnetic fields are essential for image clarity.
- Particle Accelerators: Magnetic fields steer and focus charged particles.
- Electromagnetic Actuators: Used in relays and electric motors.
- Scientific Experiments: Precise magnetic fields are necessary for research in physics and materials science.

Understanding how to accurately compute B enables engineers and scientists to optimize device performance, ensuring safety, efficiency, and effectiveness.

Conclusion

The calculation of the magnetic flux density B in a solenoid provides insight into the

fundamental principles of electromagnetism and practical design considerations. For a long solenoid with 847 turns and a length of 0.109 meters carrying a current of 4.49 amperes, the magnetic field inside is approximately 0.0438 teslas. This value underscores the influence of the number of turns, current, and solenoid length on magnetic field strength.

Mastery of these calculations is essential for designing electromagnetic devices, understanding magnetic phenomena, and advancing technological innovations. While ideal formulas offer a strong foundation, real-world applications necessitate considering additional factors such as material properties, finite size effects, and thermal management to ensure that theoretical predictions align with actual performance.

In sum, the ability to accurately determine the magnetic field in a solenoid not only deepens our understanding of electromagnetism but also empowers engineers and scientists to harness magnetic fields effectively across a multitude of applications.

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