Magnetic Field Inside A Solenoid

Principles:
In 1814 Hans Oersted demonstrated the presence of a magnetic field around a current carrying wire. The field, B at a distance, R from the wire can be calculated according to Ampere's Law with the equation:

$$B = \frac{\mu_o I}{2\pi R}$$

If the wire is bent into a loop, the field will be the integral of the magnetic fields produced along the circumference of the wire, and concentrated at the center of the loop. The equation becomes:

$$B = \oint B_{ll} dl = B\oint dl \qquad \text{or} \qquad B = (2\pi R)\frac{\mu_o I}{2\pi R} = \mu_o I$$

An **electromagnet** or **solenoid** is made of a conducting wire wound into a coil of several, closely spaced loops. The magnetic fields around each loop overlap inside the coil, forming a strong field inside the solenoid and parallel to its length. The magnetic field outside the loops is opposite in direction to the field inside, and much weaker. The magnetic field inside the loop is directly proportional to the current and the number of loops in the wire and can be calculated as:

$$B = \frac{N\mu_o I}{l} \qquad \text{or} \qquad B = n\mu_o I$$

where N = # loops

μ_o = permeability of free space = $4\pi x10^{-7}$ Tm/A

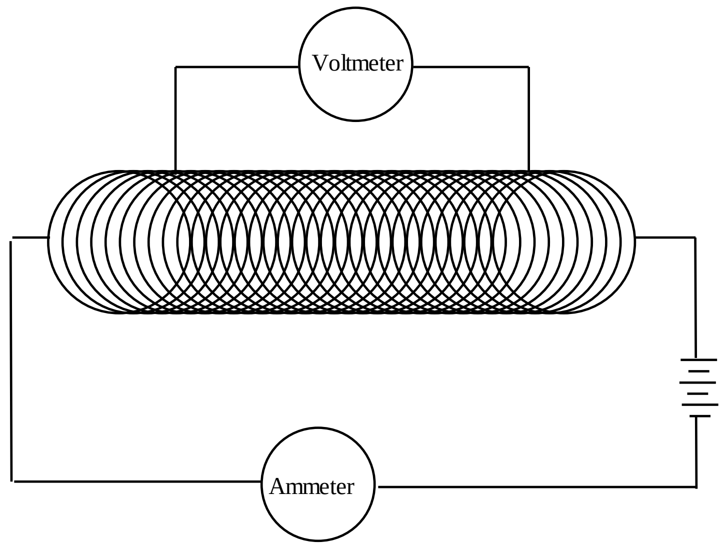
I = current

l = length of solenoid

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

Purpose:
The purpose of this lab is to determine the permeability of free space by graphing the magnetic field produced by a varying current through a Slinky® toy vs the current, and finding the slope of the line.

Materials:
1 metal Slinky®
3 wire leads with alligator clips
Ammeter
35 Ω - 50Ω resistor
6, D-Cell batteries in battery holders
Pasco magnetic Field sensor (PS2112) with Xplorer Data logger



Procedure:

1. Connect an ammeter and one D-cell battery in series with a metal Slinky® stretched to a length of about 20 cm. Record the length and number of loops of the Slinky® in the space provided under Table I.

2. Connect an ammeter in series with the Slinky® and one battery. Connect a voltmeter in parallel across the Slinky®, and not the batteries.

3. Turn on the Pasco Magnetic Field Probe and hold it away from any known magnetic fields. If it records a magnetic field, record the initial field and use it as a tare: that is, subtract that field from the measured average magnetic field.

4. Place the Pasco Magnetic Field Probe inside the slinky and turn it on. Record the voltage, current and magnetic field in Table I.

5. Continue to add batteries one at a time in series with the first and record your measurements after each battery is added until there are six batteries in series.

6. Using Ohm's Law, calculate total resistance with each battery and record your answer in the space provided in Table I.

7. On the graphs provided, plot the data in Table I in a voltage versus current graph and a magnetic field vs. current graph. For each graph, the horizontal axis is current (I). Include 0,0 as your first data point for both graphs . Draw a best-fit line through the data points.

8. Find the slope of the Magnetic Field vs. Current graph and compare that to the permeability of free space constant. Determine the factor by which the slope of the magnetic field vs. current differs from the permeability of free space, and test your conclusion with a % error.

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Name______________________________

Partners ______________________________

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Data Page

Table I

Current (A)	Voltage (V)	Resistance (Ω)	Measured Magnetic Field (T)	Calculated Magnetic Field (T)	% error
average resistance (Ω)					

Length of Slinky ____________________ cm

Calculations for *n*:

Number of loops ____________________

Resistance @	**Magnetic Field**	**% Error**
1.5V		
3.0V		
4.5 V		
6.0 V		
7.5 V		
9.0 V		

Graph of Magnetic Field vs. Current

Calculations for Slope:

Graph of Voltage vs. Current

Magnetic Field Inside a Solenoid

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Questions:

1. From your graph of voltage vs. current, how would you classify the resistance of a Slinky? Justify your answer:________________________________

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2. Why was it important to connect the voltmeter across the Slinky® and not the batteries, even though they are in parallel ?__________________________

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3. How can the motion of a charged particle be used to distinguish between a magnetic field and an electric field in a certain region? ________________________

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4. Find the velocity necessary for a proton to orbit a distance 1000 km above the Earth's magnetic equator where the field is directed horizontally with magnitude 4.0×10^{-8}T

answer ________________

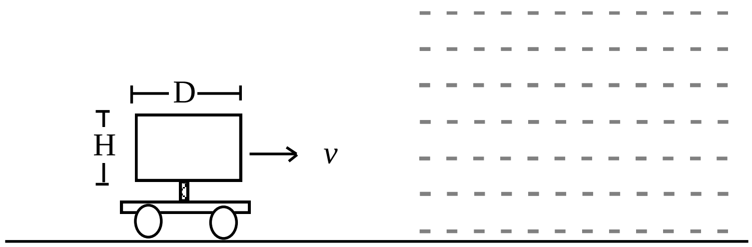
5. A solenoid with a radius of 5.0 cm consists of 150 turns over a length of 20.0 cm. Determine the following when it is given a current of 5.0 A,

a) the magnetic field inside the solenoid

answer ________________

b) The momentum of a proton orbiting inside with a radius of 2.0 cm. The axis of the solenoid is perpendicular to the plane of the orbit.

answer ________________



6. The rectangular loop of wire shown above has vertical height H, length D, and resistance R. The loop is mounted on an insulated stand attached to a cart, which moves on a frictionless horizontal track with an initial speed of v_o to the right. The loop and cart have a combined mass, m. The loop enters a region of uniform magnetic field B, directed out of the page toward the reader. Express your answers to the parts below in terms of B, D, H, R, m, and v_o.

a. What is the magnitude of the initial induced emf in the loop as the front end of the loop begins to enter the region containing the field?

answer______________________

b. What is the magnitude of the initial induced current in the loop?

answer______________________

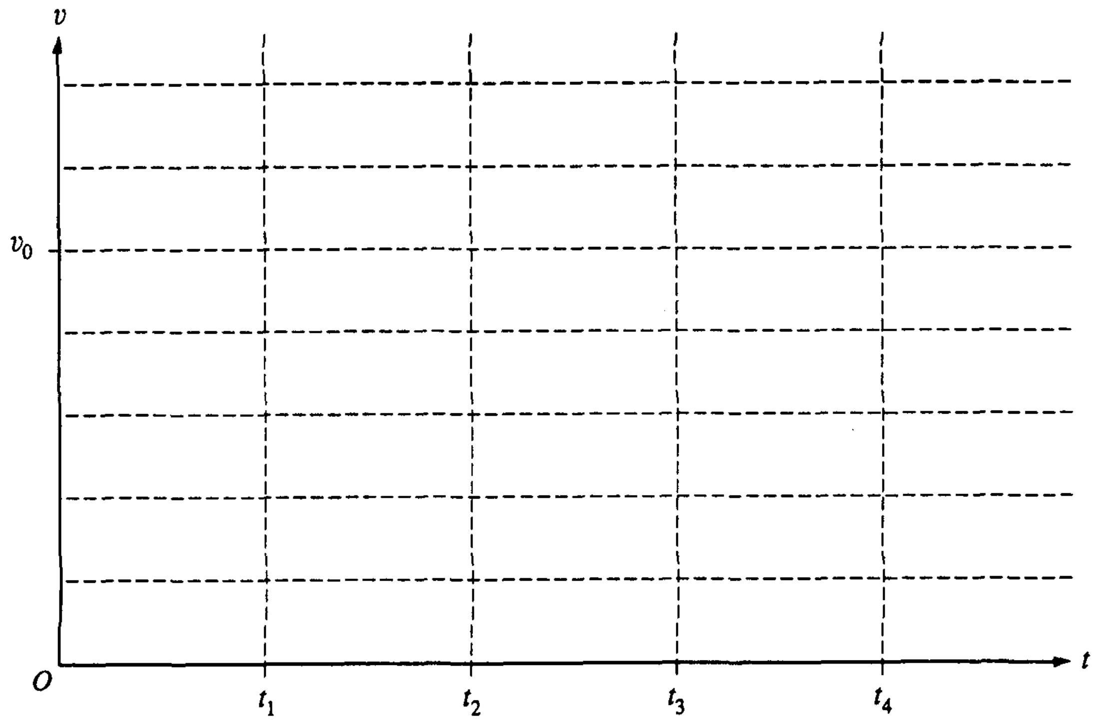
c. State whether the initial induced current in the loop is clockwise or counterclockwise around the loop.

answer______________________

d. Derive an expression for the acceleration of the glider for the interval after the front edge of the loop has entered the magnetic field until the rear edge has entered the field.

Name________________________

e. Using the axes below, sketch qualitatively a graph of speed v versus time t for the glider. The front end of the loop enters the field at t = 0. At t_1 the back end has entered and the loop is completely inside the field. At t_2 the loop begins to come out of the field. At t_3 it is completely out of the field. Continue the graph until t_4, a short time after the loop is completely out of the field. These times may not be shown to scale on the t-axis below.



Conclusion:

Insight: ____

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Errors: ____

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