Experiment 4

Magnetic Force on a Current-Carrying Conductor

1. Introduction

Solenoid is constructed by winding wire in a helical coil around a cylinder. The windings are very close to each other and usually consist of many layers. When a current is carried by the wire, a magnetic field of unique properties is generated by the solenoid. If the length of a solenoid is large compared with its diameter, the magnetic field created inside the solenoid is very uniform and parallel to the axis. The magnetic field outside the solenoid is very small and decays quickly with the distance. The magnitude of the magnetic field in the center of the solenoid is proportional to the number of turns per unit length of the solenoid, n, and to the magnitude of the current, I

$$B = \mu_o \, n \, I \qquad (1)$$

where $\mu_o = 4 \pi 10^{-7}$ Webers/A m. For solenoids that are not very long, we use a more accurate formulae for the magnetic field:

$$B = \mu_o \, n \, I \, (L/2)/[(L/2)^2 + R^2]^{1/2} \qquad (2)$$

where L is the length and R is the radius of the solenoid.

When a wire carrying a current is placed in an uniform magnetic field a force is exerted on the wire. This force depends on the magnitude of the current, I, the length of the wire, d, and on the relative orientation of the wire with regard to the magnetic field, B, and can be written as

$$\mathbf{F} = I \, \mathbf{d} \times \mathbf{B} \qquad (3)$$

where x denotes the cross product of vectors **d** and **B**. When the wire is perpendicular to the magnetic field Eq. 3 simplifies to

$$F = I \, d \, B. \qquad (4)$$

The direction of the force F is given by the right hand rule. Thus, if the force F is known the magnetic field can be found from

$$B = F/I \, d \qquad (5)$$

Procedure

The air core solenoid is made of enameled copper wire wound on a phenolic core. The ends of the wire are brought out to the brass binding posts on the rigid end plates. The solenoid is about 15 cm long and its interior diameter is about 5 cm. There are five layers of turns. Measure and record the length of the loop current perpendicular to the field, the length, L, and radius, R, of the solenoid as well as the number of turns per unit length.

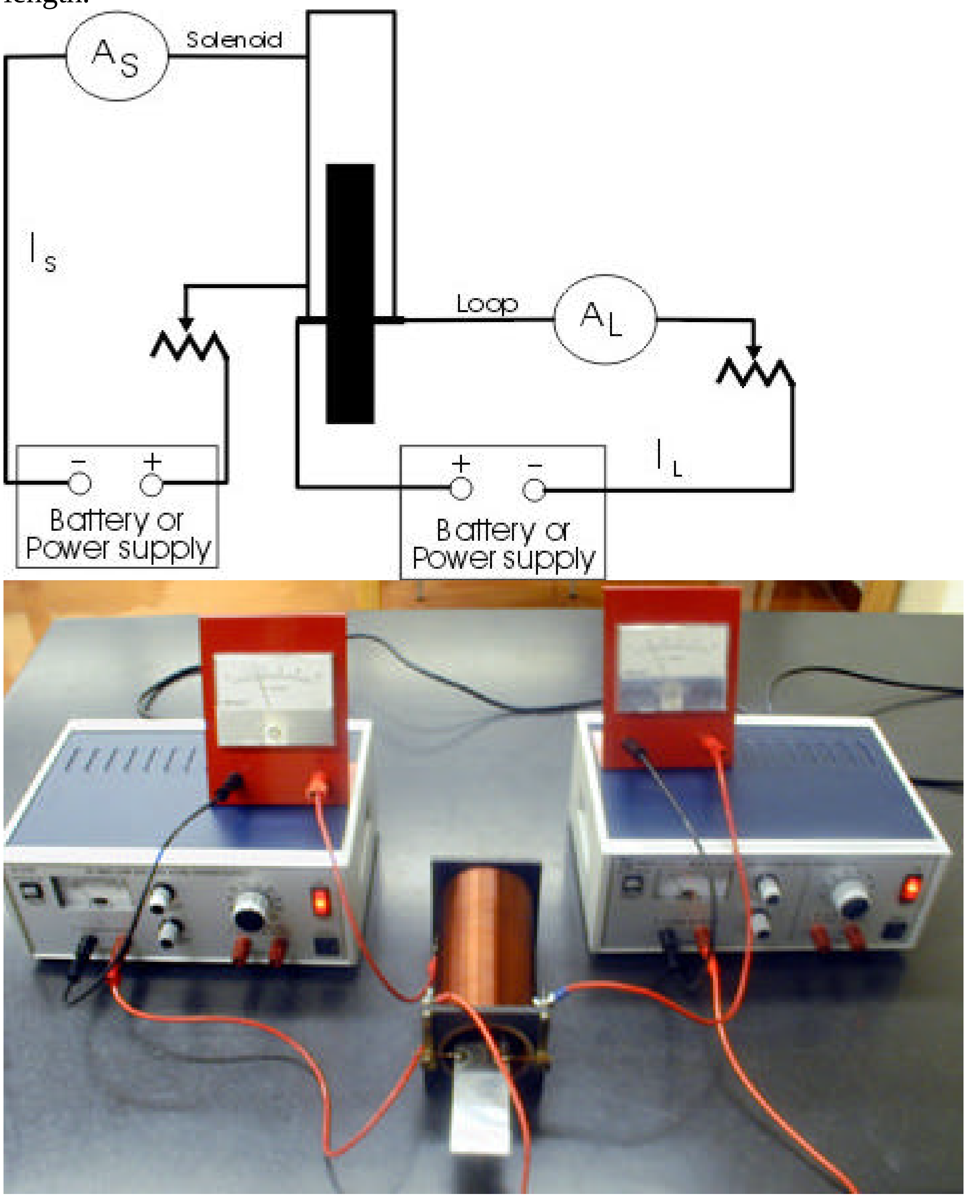

Fig. 1. A schematics (top) and a photograph (below) of the experimental setup. Your may use different equipment or use terminals **A** and **B** to get power, but the schematics will remain unchanged. [Variacs are not shown – you will use them only when the power is provided by the terminals **A** and **B** on your workbanch]

Place the loop with pivot wires inside the solenoid and make sure that it can freely oscillate on support brackets attached to the end plate of the solenoid. If necessary adjust the balance by stretching or bending the hook attached to the plastic beam. Make sure that the loop is in the horizontal position before turning the current on. Use an aluminum block in the form of a letter T-shape to make sure that the beam is in the horizontal position.

Connect the solenoid to the ammeter, A_S, and the DC terminal of the power supply, as shown in Fig. 1. Some power supplies are equipped with ammeters and then you do not need additional meter. Alternatively, connect the solenoid to an ammeter, a variac and to the terminal **A** on your workbench.

Connect the loop to the ammeter, A_L, and to the power supply as shown in Fig. 1. Use only the DC output. Alternatively, connect the solenoid to an ammeter, a variac and to the terminal **B** on your workbench. If both ammeters do not indicate any current make sure that the power is on and ask the TA check your circuit.

You may adjust the current by rotating the voltage knob on the front panel of the power supply (or a brush of the variac). Do not increase the current above 5 A. Set both the solenoid and the loop currents to zero to see that the plastic beam is balanced. Increase both currents to about 2 A and the end of the beam close to you should move upward. If it moved downward you will have to reverse the direction of the current in either the solenoid or the loop by switching the wires. When the loop current is turned on the balance is changed because the force F given by Eq. 4 is exerted on the loop, compare Fig. 2. Note that only the part of the loop, which is perpendicular to the magnetic field produces this force. The currents flowing through the two conductive strips parallel to the symmetry axis of the solenoid do not interact with the magnetic field and can be ignored. The plastic beam has the length adjusted in such a way that the end of the beam with the conductive strip is right in the center of the solenoid, where the magnetic field can be precisely determined from Eq. 5.

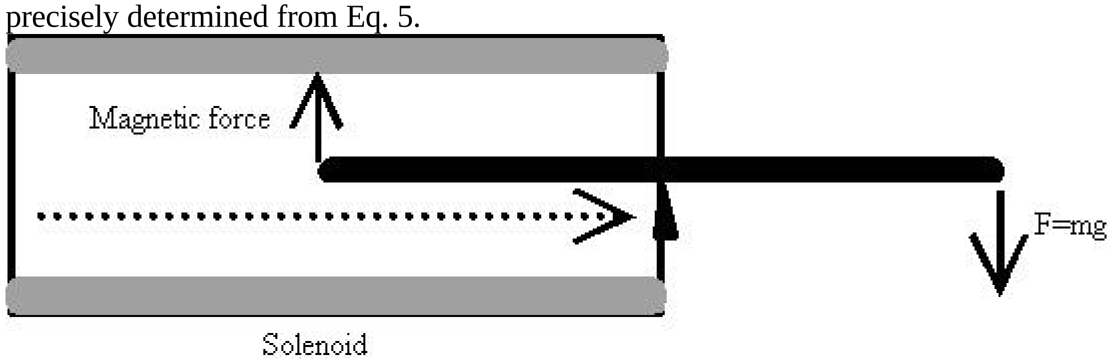

Fig. 2. The beam is the horizontal position because the two forces, magnetic and due to gravity are equal but pointed in opposite directions. The broken arrow shows the direction of the magnetic field generated by current flowing through the solenoid.

With the solenoid current set to 2 A adjust the loop current to achieve balance for each of the weights provided. The weights are in a form of the short wires that can be hang on the hook at the end of the beam. Repeat the measurements for the solenoid currents of 3, 4 and 5 A. If you cannot increase the current to the desired value, you may have to adjust the current limit by rotating the current knob on the front panel of the power supply. Write your data in the table below

Number of wires	F=mg	I_L	I_S	Magnetic field $B=F/I_L d$
	[N]	[A]	[A]	[N/A m]
1			2	
1			3	
1			4	
1			5	
2			2	
2			3	
2			4	
2			5	
3			2	
3			3	
3			4	
3			5	

The goal of this experiment is to find the magnetic field. Compute the magnetic field for each set of data in Table 1. Find the average values of B (as the ordinate) for the different loop currents, I_L, and plot these values versus the solenoid current (as the abscissa). Calculate the deviations of the mean values and mark them as vertical bars on your graph. Plot a straight line through the points on the graph in such a way that it will pass through the error bars. Compare the slope of the graph with the value obtained from Eq. 2. The slope should be given by $\{\mu_o\, n\, (L/2)/[(L/2)^2 + R^2]^{1/2}\}$. Compare both results and discuss discrepancies.

Report

Course 20481: In the introduction start with the Biot-Savart law and derive Eqs. 1 and 2.

Course 10161: In the introduction answer <u>one</u> of the following questions:

1. When the loop is placed inside the solenoid and direction of the current is reversed, the plastic beam will move in the opposite direction. Explain.
2. Two parallel conductors with currents flowing in the same direction attract each other. In the solenoid the wire windings may be treated as parallel loops, and the coil should be compressed. Is this effect important and if yes, estimate it for your experimental setup.
3. Could you use a permanent magnet to do this experiment? Explain.