Lab 11
Magnetic Force and Current Balance

Learning Goals:

- to find the magnetic force between a conductor and magnetic field.
- to measure the effect of length on magnetic force
- to measure the effect of current on magnetic force
- to measure the effect of angle on magnetic force
- to construct from the data an equation which relates the force on a current carrying wire that includes all the factors that affect its magnitude and direction.

Apparatus:

	Instrument	Instrumental Error	Instrumental Resolution
1	Ruler	± 0.1%	0.01 cm
1	Basic Current Balance		
1	Current Balance length segments		
1	Electronic Balance	± 1%	0.01 gram
1	Low Voltage AC/DC Power Supply		
1	Large Base and Support Rod		
1	Current Balance Angle Protractor	± 1%	0.5 degrees
1	Banana Plug Cord Set		
1	Experiment Resources CD		
1	Data Studio graphing Software	Curve fit ± 0.1%	

Theory:

Magnetic Forces

A current carrying wire in a magnetic field experiences a force that is usually referred to as a magnetic force. The magnitude and direction of this force depend on four variables: the magnitude and direction of the current (I); the strength of the magnetic field (B); the length of the wire (*l*); and the angle between the field and the wire (θ). The unit of force is the newton, the unit of current is the ampere, the unit of magnetic field strength is the Tesla, the unit for length is the meter and the unit for the angle θ is the degree.

Magnets are mounted on an iron yoke and placed on a balance (resolution of at least 0.01g). One of the conducting paths is suspended between the magnets. The balance is used to measure the mass of the magnets and yoke prior to any current passing through the conducting path. Current is then passed through the conducting path, producing a force. The change in reading on the balance is due to the force on the conductor in the magnetic field.

Conductors of different length are included to measure the effect of length on magnetic force. Magnetic field can be varied by changing the number of magnets in the yoke. The power source is used to change the current supplied to the conductor. The Current Balance Accessory includes all the components needed to test the effect of angle on magnetic forces.

This magnetic force can be described mathematically by the vector cross product: $\mathbf{F_m = I\mathit{l} \times B}$ Or in scalar form, $\mathbf{F_m = I\mathit{l}B\sin\theta}$. Using the equipment included in the Magnetic Forces on Wires Experiment, all four variables (I, B, L, and θ) can be varied while measuring the resulting magnetic force.

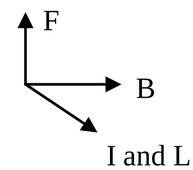
$$\textbf{(1)} \qquad \mathbf{F_m = IL} \times \mathbf{B = ILB}\sin\boldsymbol{\theta}$$

where

$\mathbf{F_m}$ ≡ “magnetic force”
$\mathbf{I}$ ≡ “current”
$\mathbf{L}$ ≡ “length of wire”
$\mathbf{B}$ ≡ “magnetic field strength”
$\boldsymbol{\theta}$ ≡ “angle between magnetic field and current”

Equation **(1)** uses the *cross-product*, which means you must use the *right hand rule* to determine the direction of the magnetic force.

Study the vector diagram at the right: it describes the direction of the force on a current carrying wire in a magnetic field. The direction of the force is dependent upon both the direction of the magnetic field and the direction of the current flowing through the wire. For the directions indicated in the drawing, the north pole of the magnet is at the left, the direction of positive electric flow is through the wire of length L out of the page and the force on the wire is upward. Because the magnet supplying the magnetic field is resting on a movable balance platform and because the wire is fixed, as current flows through the wire, the magnet will be pushed downward, indicating a larger force on the balance than the weight of the magnet.



This experiment involves placing your magnets on a scale while running a current carrying wire between them. Since the magnetic field of the magnets will exert a force on the charges in the wire (and the wire is held stationary), the magnet should feel a reaction force due to Newton’s third law. This reaction force will cause the scale to read either a smaller or bigger mass for the magnet, depending on whether the force is attractive or repulsive. You will use this difference in mass to determine the magnetic force felt by the magnet using Newton’s second law. The equation you will use is:

$$\textbf{(2)} \qquad \mathbf{F_m = (m - m_i)g}$$

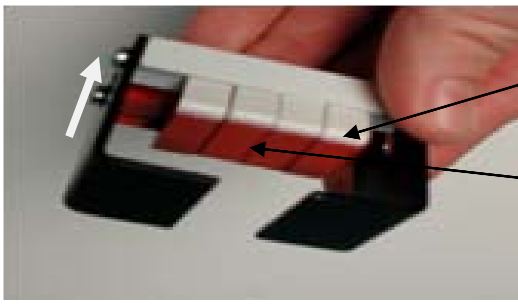
where

$\mathbf{F_m}$ ≡ “force on magnets”
$\mathbf{m_i}$ ≡ “initial mass of magnets and holder”
$\mathbf{m}$ ≡ “mass of magnets with current turned on”

Prelab:

#1 In the picture below a rack contains four horseshoe magnets which form a magnetic field which points from the back toward the front. A wire is inserted between the magnet poles so that the field is perpendicular to current flowing through the wire, either right to left or left to right dependence on the connection to the power supply

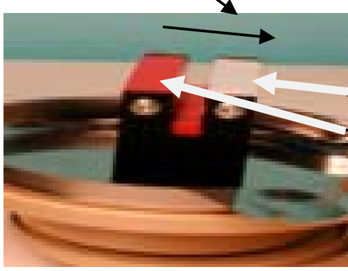
The arrow at the left below indicates the direction of the magnetic field strength B



This arrow points toward the front or white or South pole of four horseshoe magnets.

This arrow points toward the rear or red or North pole of four horseshoe magnets.

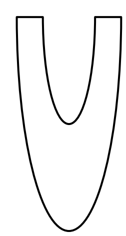
The horizontal black arrow points in the direction of the magnetic field strength B



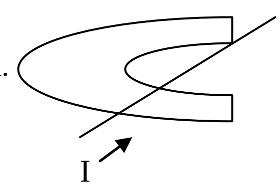
This arrow points toward the right or white or South pole of four horseshoe magnets.

This arrow points toward the left or red or North pole of four horseshoe magnets.

#2 In the drawing at the right a magnet is represented by a horseshoe. Label on the left branch of the horseshoe magnet the pole face South. Label on the right branch of the horseshoe magnet the pole face North. Draw between the branches an arrow representing the direction of the magnetic field between the two poles of the magnet. Label it B.

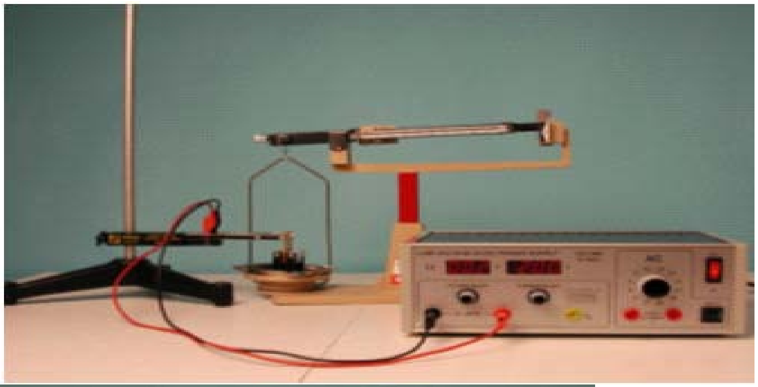


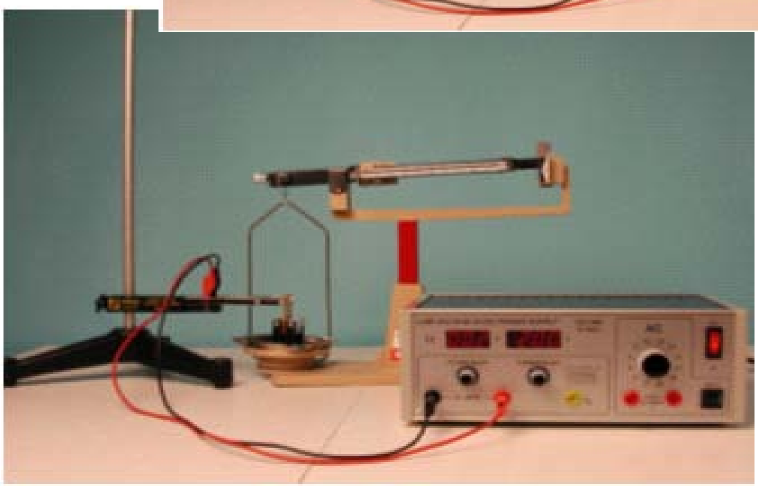
#3 In the drawing at the right a magnet is represented by a horseshoe. Label on the top branch of the horseshoe magnet, the pole face South. Label on the bottom branch of the horseshoe magnet, the pole face North. Draw between the branches an arrow representing the direction of the Magnetic field between the two poles of the magnet. Label it B. Current flows through the wire from left to right (+ charges). If the magnet is held fixed and the wire is free to move, will it move left or right?



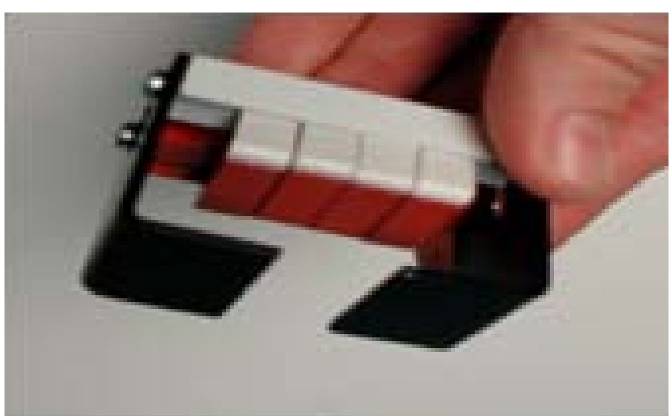
______.

Part I : Force vs. Current   Procedure





1. Mount the Current Balance Unit on a lab stand.
2. Select a Current Loop, and plug it into the ends of the arms of the Unit with the foil extending down.
3. Place the Magnet Assembly on a digital balance with at least 0.01 gram sensitivity. Position the lab stand so the horizontal portion of the conductive foil on the Current Loop passes through the pole region of the magnets. The Current Loop shouldn't touch the magnets.
4. Connect the power supply and ammeter as shown above.
5. Insert between 4 – 6 magnets into the magnet holder to provide a constant magnetic field.



6. Record the number of magnets used in the Data table in the notebook.

7. Choose one of the current loops to use throughout the experiment and record the length of the current loop in the Data Table in the notebook.
8. Setup the current balance as shown.
9. Determine the mass of the magnet holder and magnets with no current flowing. Record this value as $Mass_{C.OFF}$ in the Data table.
10. Turn on the power supply and set the current to 0.5 A. Determine the new mass of the magnet assembly. Record this value under $Mass_{C.ON}$ in the Data table.
11. Increase the current in 0.5 A increments to a maximum of 5.0 A, each time measuring the new "mass" of the magnet assembly and recording this value as $Mass_{C.ON}$ in the Data table.
12. Subtract $Mass_{C.OFF}$ from $Mass_{C.ON}$ to determine the net Mass due to the current alone and convert this value to newtons of force, recording these values in the Data table.

13. Open the Data Studio selection "Table" and enter the Current (x values) from smallest to largest and Force (y) values used into the table.
14. Make a graph of Force vs. Current and include a title and curve fit with equation on the graph. Note the slope of the graph in the title. Print the graph and tape it in the notebook.
15. Describe in the notebook the relationship that exists between the magnetic force and current through the conductor.

Part I : Force vs. Current Data (record in notebook)

A.

# of magnets Used	Length of Current Loop Used (m)	Current **x-axis** (Amps)	$Mass_{C.OFF}$ (grams)	$Mass_{C.ON}$ (grams)	Force **y-axis** (Newtons)
6					
6	↓		↓		
6	↓		↓		
6	↓		↓		
6	↓		↓		
6	↓		↓		
6	↓		↓		
6	↓		↓		

B. The relationship that exists between the magnetic force **F** and current **I** through the conductor can be expressed in sentence form as__________________________________ and in the form of an equation from the graph as ____________________________.

C. The physical meaning of the slope of the Force vs. Current graph is________________.

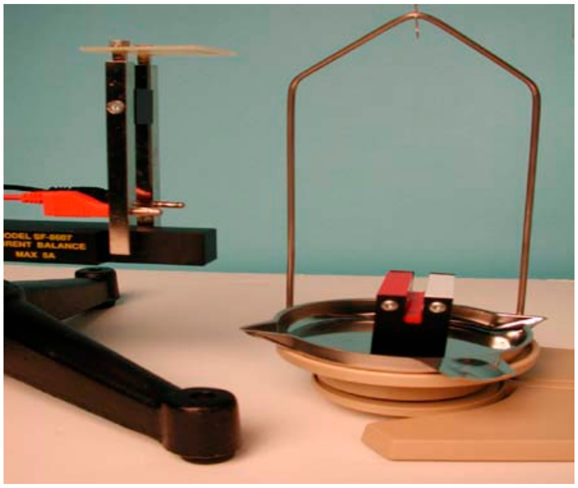
D. The physical meaning of the vertical intercept of the Force vs. Current graph is ______.

E. Can the vertical intercept be attributed to measurement error?__________.

Part II: FORCE VS. LENGTH OF WIRE Procedure

16. Insert between 4 – 6 magnets into the magnet holder to provide a constant magnetic field. Be sure to center the magnets in the holder.
17. Record the number of magnets used in the Data Section.
18. Choose the shortest current loop to begin the experiment.
19. Use a ruler to measure the length of the conductor in meters that will be perpendicular to the magnetic field between the pole faces of the magnets in the holder.
20. Setup the current balance as shown above. Determine the mass of the magnet holder and magnets with no current flowing. Record this value as $Mass_{C.OFF}$ in the Data section below.

21. Turn on the power supply and set the current between 2.0 and 3.0 Amps. Record this value in the Data Section.
22. Determine the new mass of the magnet assembly. Record this value under $Mass_{C.ON}$ in Table 2 in the Data Section below.
23. Subtract $Mass_{C.OFF}$ from $Mass_{C.ON}$ to determine the net Mass due to the current alone and convert this value to newtons of force, recording these values in the table.
24. Swing the arm of the main unit up, to raise the present current loop out of the magnetic field gap.page



25. Pull the current loop gently from the arms of the base unit. Replace it with the next current loop and carefully lower the arm to reposition the current loop in the magnetic field. Reset the current so that it is the same value as in procedure 21.
26. Repeat procedures 19 to 25 for each of the current loops and enter the appropriate data in the Data table in the notebook.
27. Open the Data Studio "table" file and enter the Lengths used (x values) from smallest to largest into the Force vs. Length table. Enter the "Force" (y values) into the Force vs. Length table.
28. Make a graph of Force vs. Length including a curve fit with equation. Print or sketch in detail the graph and include in the title the slope of the graph. Tape the graph to the notebook.

Part II FORCE VS. LENGTH OF WIRE Data (record in notebook)

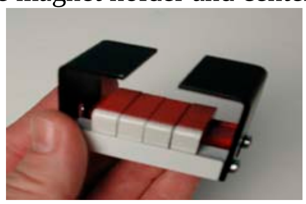
F.

Current (amps)	# of magnets Used	Length **x-axis** (meters)	$Mass_{C.OFF}$ (grams)	$Mass_{C.ON}$ (grams)	Force **y-axis** (Newtons)
	6				
↓	↓		↓		
↓	↓		↓		
↓	↓		↓		
↓	↓		↓		
↓	↓		↓		
↓	↓		↓		
↓	↓		↓		

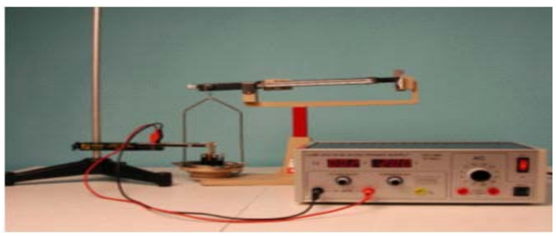
G. The relationship that exists between the magnetic force **F** and length of conductor ***l*** in the magnetic field expressed in a sentence is _______________________ and expressed in mathematical form is __________________________.
H. The physical meaning of the slope of the Force vs. Length graph is _________________..
I. The physical meaning of the vertical intercept of the Force vs. Length graph is ________.
J. Can the vertical intercept can be attributed to measurement error? _________________.

Part III: FORCE VS. MAGNETIC FIELD Procedure

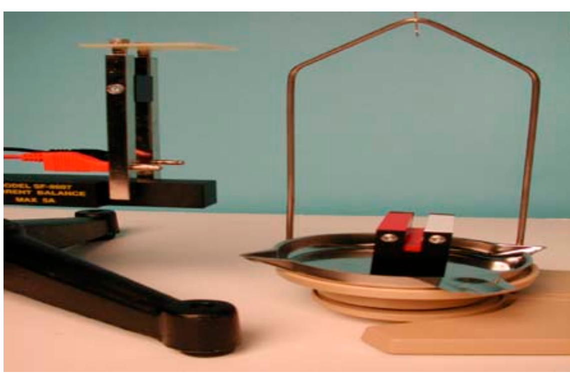
28. Insert one magnet into the magnet holder and center the magnet in the holder.

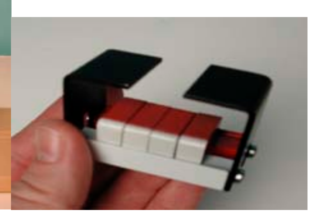


29. Choose one of the current loops to use throughout the experiment and record the length *l* of the current loop in the Data Section



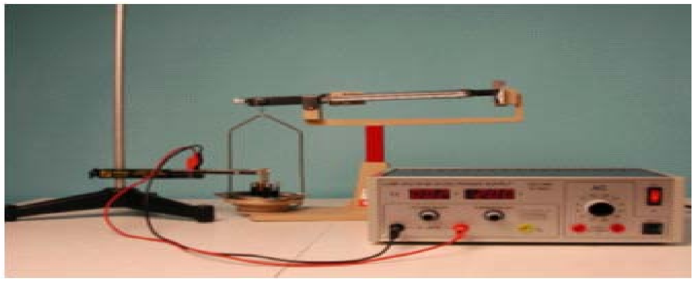
30. Setup the current balance as shown above.
31. Determine the mass of the magnet holder and magnets with no current flowing. Record this value in the Mass$_{C.OFF}$, I = 0 column in Table 3.
32. Turn on the power supply and set the current between 2.0 and 3.0 Amps. Record this value in the Data section
33. Determine the new mass of the magnet assembly. Record this value under Mass$_{C.ON}$, I > 0 in Table 3 below.
34. Turn off the power supply to change the current to zero.
35. Swing the arm of the main unit up, to raise the current loop out of the magnetic field gap.





36. Place an additional magnet into the magnet holder aligning the like poles of the magnets.
37. Place the holder in the back on the balance pan with the North and South poles in the same orientation as the last measurement.
38. Lower the arm of the main unit and reposition the current loop inside the magnetic

field gap. Be certain the current loop isn't touching the magnet holder.



39. Determine the mass of the magnet holder and magnets with no current flowing. Record this value in the $Mass_{C.OFF}$, I = 0 column in Table 3.
40. Turn the power supply on to provide current through the loop.
41. Measure the new mass of the magnet assembly and record this value in the $Mass_{C.ON}$, I > 0 in Table 3 below.
42. Subtract $Mass_{C.OFF}$ from $Mass_{C.ON}$ to determine the net Mass due to the current alone and convert this value to newtons of force, recording these values in the table.
43. Repeat steps 31-42 for 3, 4, 5 and 6 magnets.
44. Open the DataStudio "table" file and enter the number of magnets (x values) from smallest to largest and Force (y values) used into the Force vs. Magnetic Field table.
45. Make a graph of Force vs. Magnetic Field and include a curve fit and equation. Print or sketch in detail the graph and include in the title the slope of the graph and tape it to notebook.

Part III FORCE VS. MAGNETIC FIELD Data (record in notebook)

K.

# of magnets Used **x-axis**	Current Used (amps)	Length of Current Loop Used (m)	$Mass_{C.OFF}$ I = 0 (grams)	$Mass_{C.ON}$ I > 0 (grams)	Force **y-axis** (Newtons)
none					
1	↓	↓			
2	↓	↓			
3	↓	↓			
4	↓	↓			
5	↓	↓			
6	↓	↓			

L. The relationship that exists between the magnetic force **F** and the magnetic field **B** expressed in a sentence is ________________________ and expressed in mathematical form is _______.

M. The physical meaning of the slope of the Force vs. magnetic field graph is _______________.

N. The physical meaning of the vertical intercept of the Force vs. magnetic field graph is _____.

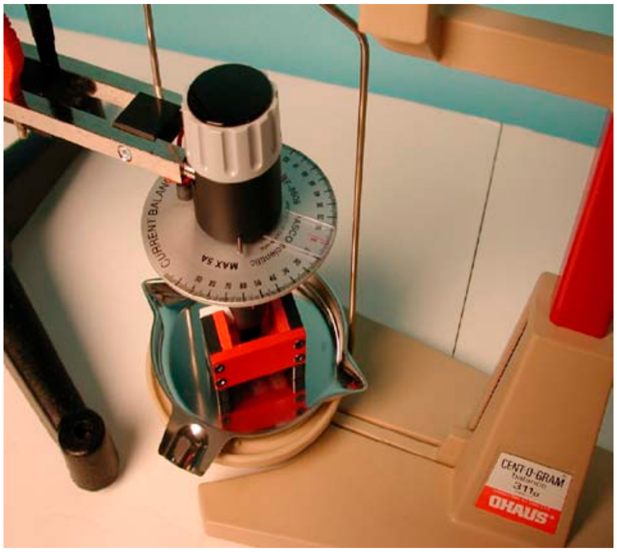
O. Can the vertical intercept can be attributed to measurement error? ___________________.

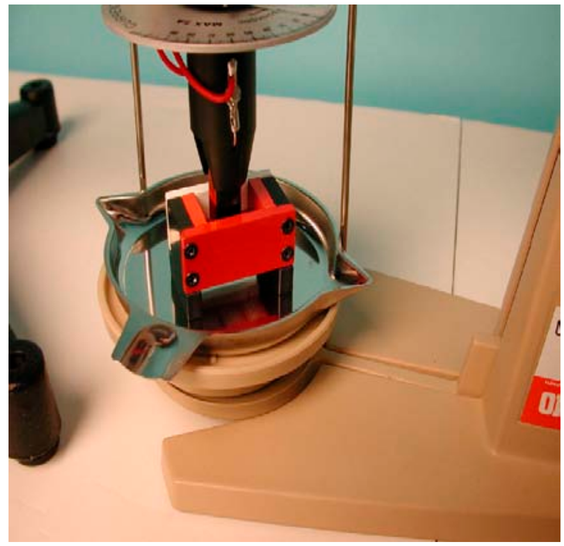
Part IV: FORCE VS. ANGLE Procedure

46. Place the smaller magnet holder from the Current Balance Accessory on the mass tray of the balance.
47. Measure the length of the coil with a ruler (this value is 1.0 cm) and record it in meters in the Data section.
48. Count the number of turns of wire in the coil and record it in the Data section.
49. Attach the Current Balance Accessory to the arm of the current balance and lower the coil

into the magnetic field of the magnet holder. The coil should not be touching the magnet holder.

50. Setup the current balance as shown above.
51. Set the angle to 0º such that the coils are facing the shorter dimension of the magnet holder (see photo below but use an electronic gram balance rather than a mechanical gram balance).





52. Determine the mass of the magnet holder and magnets with no current flowing. Record this value as $Mass_{C.OFF}$, I = 0 in the Data Section.
53. Turn on the power supply and set the current between 2.0 and 3.0 Amps. With the angle indicator set to zero degrees, the weight of the magnets and holder should not change with current. If the electronic balance indicates a new weight when the current is on, turn the magnet holder slightly until turning the current on and off does not affect the electronic balance. Set the current between 2.0 and 3.0 amps and record the current value in the Data Section.
54. Set the angle indictor (clockwise) to negative 90 degrees and record the new mass of the magnet assembly under $Mass_{C.ON}$ $I > 0$ in Table 4 in the Data section below.
55. Subtract $Mass_{C.OFF}$ from $Mass_{C.ON}$ to determine the net Mass due to the current alone and convert this value to newtons of force, recording these values in the Table 4 for the angle -90 degrees.
56. Change the angle by 10º increments up to +90º, each time repeating steps 48 – 49. Record the measurements in Table 4.
57. Open the Data Studio file "table" and Enter the angles (x-axis values) used from smallest to largest and "Force" (y axis) values into the Force vs. Angle table.
58. Graph Force vs. Angle and include a curve fit and equation. (try a trigonometric fit) Print or sketch the graph in detail and include in the title the equation of its best fit and tape the graph to the notebook.

Part IV FORCE VS. ANGLE Data (record in notebook)

P. $Mass_{C.OFF}$, I = 0: ____________grams
Q. Current Used: ______amps
R. Length of Coil: _______m
S. Number of turns of wire in coil _____.
T.

Angle **x-axis** (degrees)	$Mass_{CON}$ I > 0 (grams)	Force **y-axis** (newtons)		Angle **x-axis** (degrees)	$Mass_{CON}$ I > 0 (grams)	Force **y-axis** (newtons)
-90				10		
-80				20		
-70				30		
-60				40		
-50				50		
-40				60		
-30				70		
-20				80		
-10				90		
0				x	x	x

U. Explain why the trigonometric function sine would be a valid choice for a curve fit.________.

V. The relationship that exists between the magnetic force **F** and the angle **θ** expressed in a sentence is ________________________ and expressed in mathematical form is _______.

W. The physical meaning of the slope of the Force vs. sin **θ** graph is ______________.

X. The physical meaning of the vertical intercept of the Force vs. sin **θ** graph is _____.

Y. Can the vertical intercept can be attributed to measurement error? ___________________.

Part V: Summary of Parts I to IV. **Procedure**

59. Combine the proportionality expressions for all four experiments into one expression. Force should be on the left side of the expression and the other variables on the right side of the expression. To find this combined proportionality constant, divide the proportionality constant of any one graph by the product of the constants used in generating the y-axis values.
60. Write a few sentences explaining the relationship between Magnetic Force, Length, Current, Magnetic Field and Angle.
61. Convert the relationship into an equation.
62. Indicate the constant of proportionality for this equation and explain its significance.
63. Describe how such an equation could be used.

Part V Summary of Parts I to IV Data (record in notebook)

Z.

x	Table 1	Table 2	Table 3	Table 4
current	Variable = I	Constant =	Constant =	Constant =
length	Constant =	Variable = *l*	Constant =	Constant =
# of magnets	Constant =	Constant =	Variable = B	Constant =
angle	Constant =	Constant =	Constant =	variable = Sinθ
fit	Slope =	Slope =	Slope =	Scale =

AA. The constant of proportionality for this summary equation is __________________and its significance is ___________________________________.

BB. The relationship between force and all the other variables studied in all four parts (i.e., Length, Current, Magnetic Field and Angle) expressed in a sentence is _____and expressed in a mathematical relationship is __________________.

CC. A description of how such an equation could be used i