A Quantitative Lenz's Law Demonstration

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Outline

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- The Coil
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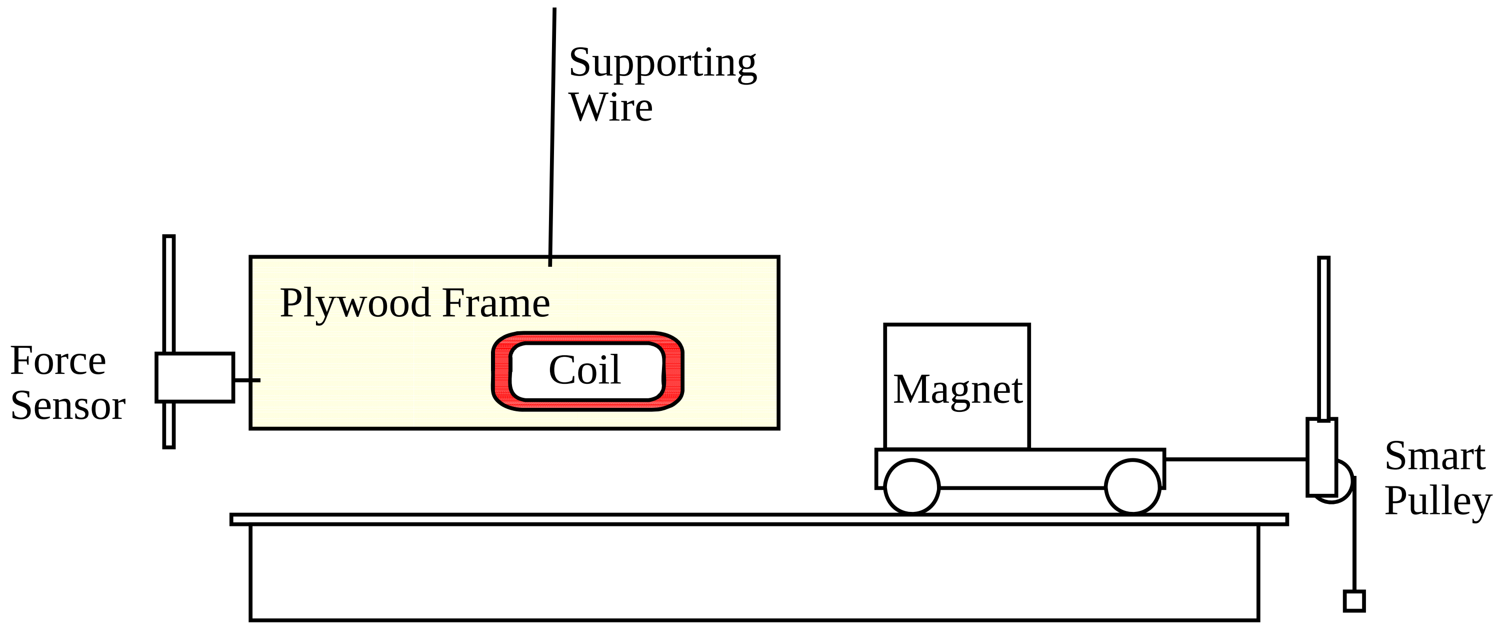
- Conclusion

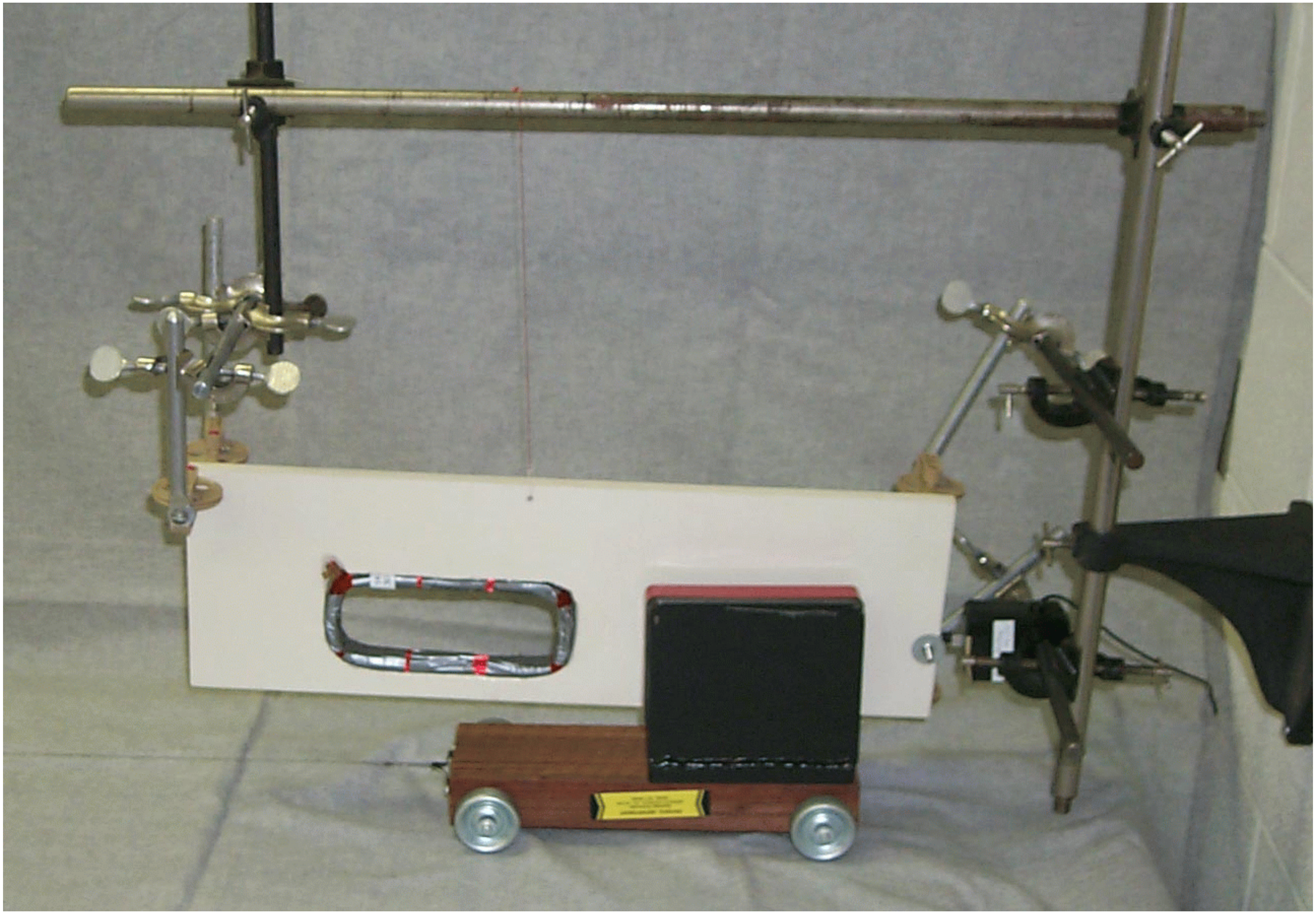
Motivation

Lenz's law is often illustrated with qualitative demonstration experiments such as dropping a button magnet through a conducting pipe. Computer data acquisition makes it possible to measure the force on a coil as the secondary effect opposing its motion through a magnetic field.

Experimental Setup



Experimental Setup



Equipment

- Pasco Science Workshop 750 Interface
- Dell Optiplex Pentium III 550 MHz
- Coil and Plywood Frame
- Magnet
- Dual Range Force Sensor
- Pasco Smart Pulley
- F. W. Bell 4048 Gauss Meter
- Low Friction Pulleys
- Dial Calipers

Voltage Induced in the Coil

$$V = v\, N\, w\, B$$

Current Induced in the Coil

$$I = \frac{V}{R} = \frac{v\, N\, w\, B}{R}$$

Force on the Coil because of the Induced Current

$$F = I\, N\, w\, B = \frac{(N\, w\, B)^2}{R} v$$

where v is the coil velocity, N is the number of coil turns, w is the width of the coil, B is the magnetic field strength and R is the resistance of the coil.

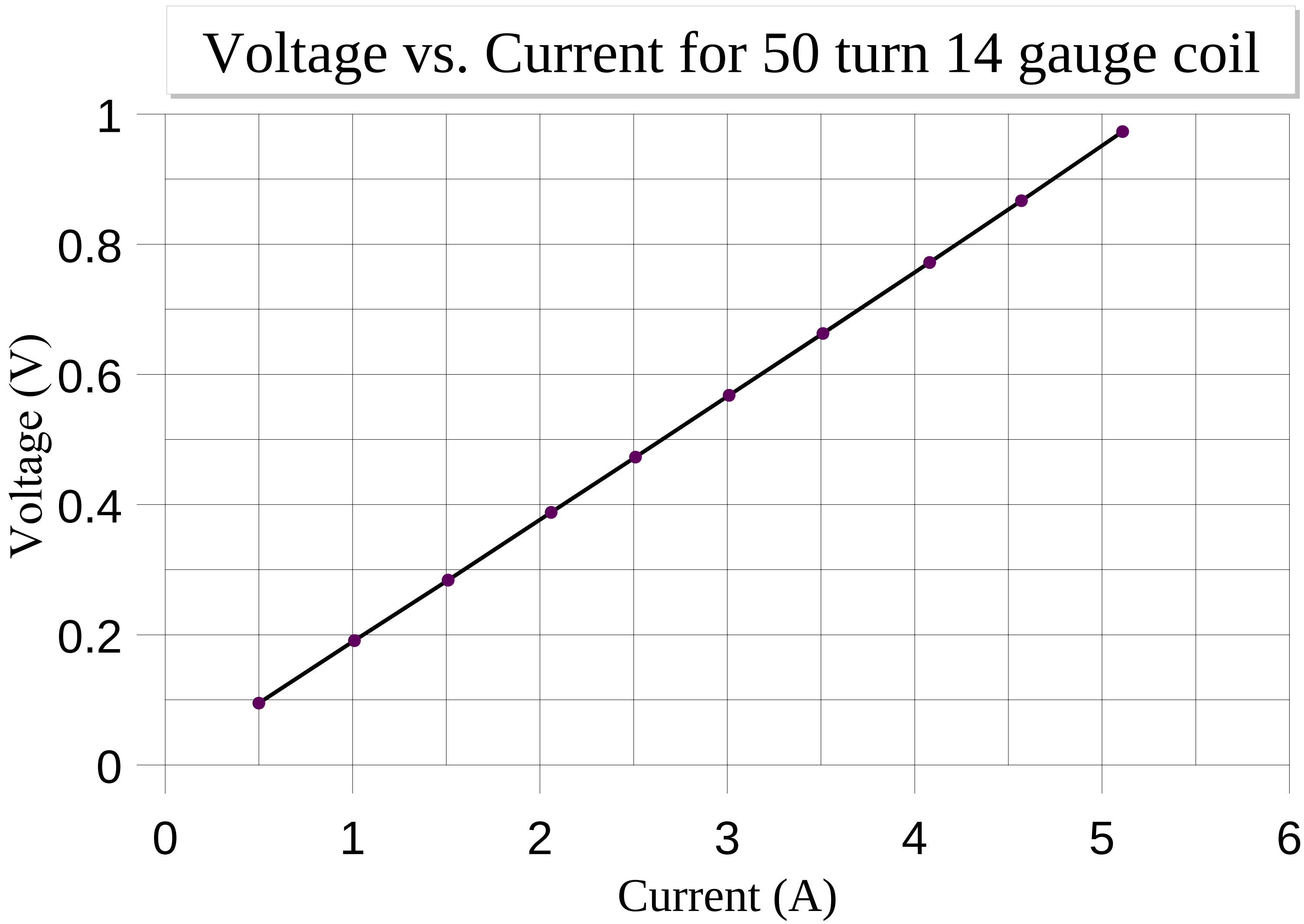
Coil Properties

- Coil Size: 7mm by 17 mm
- Number of Turns: 50
- Wire Gauge: 14

Width Determination

- Average inside width 0.0528 m
- Average outside width 0.0796 m
- Average coil width 0.0662 m

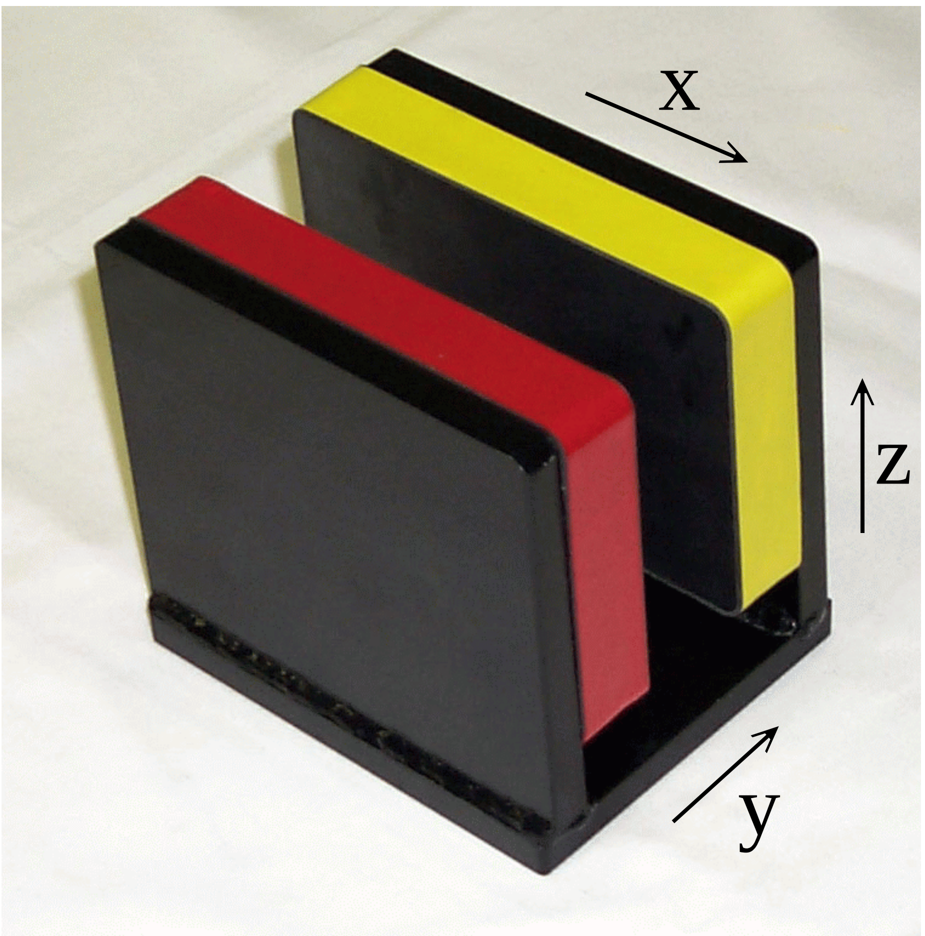
Coil Resistance



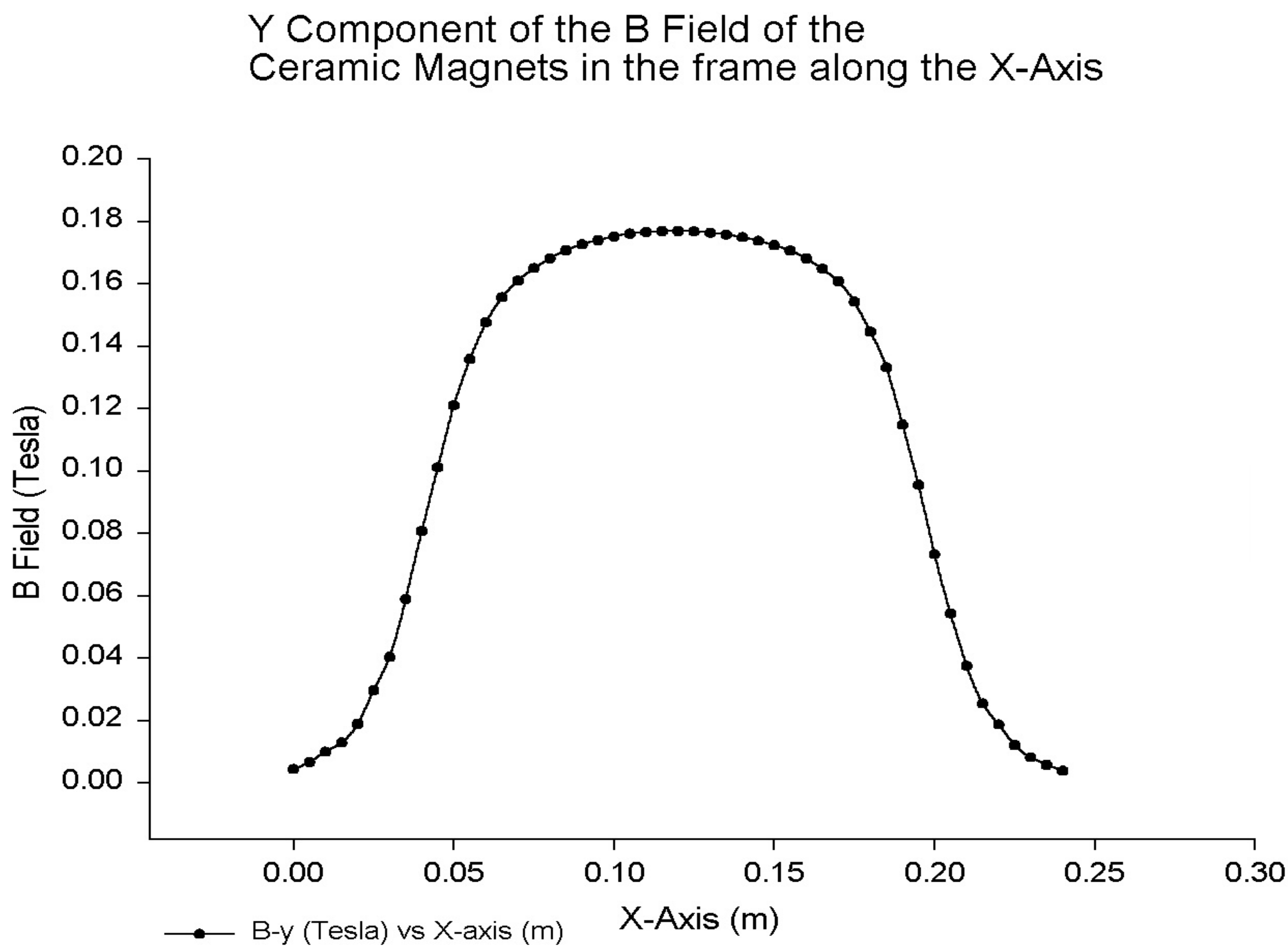
R = slope = 0.1902 Ohms   Intercept = -0.0026 V

The magnet

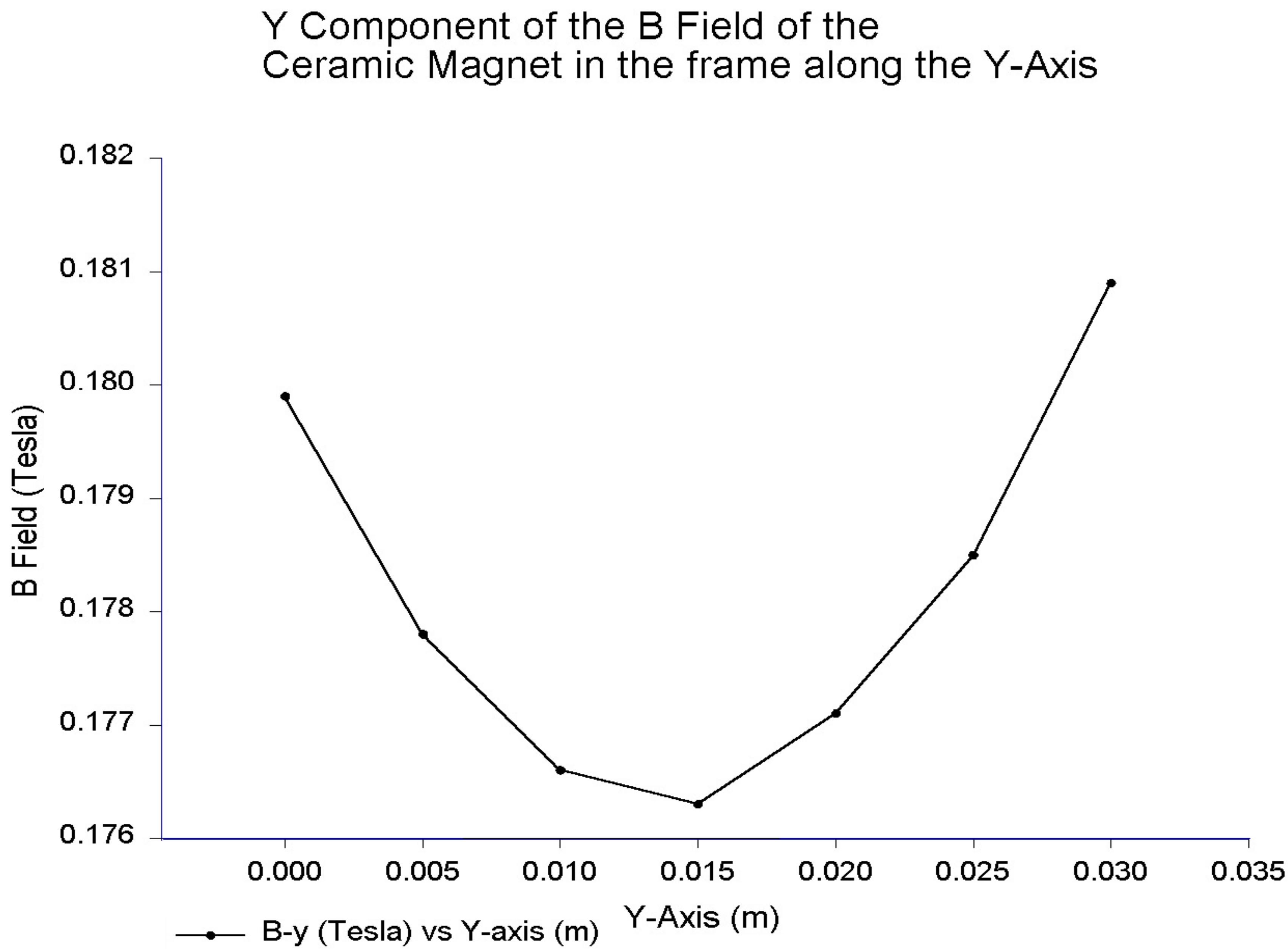
A U-shaped steel frame with a 4 inch x 6 inch x 1 inch ceramic magnet on each side.

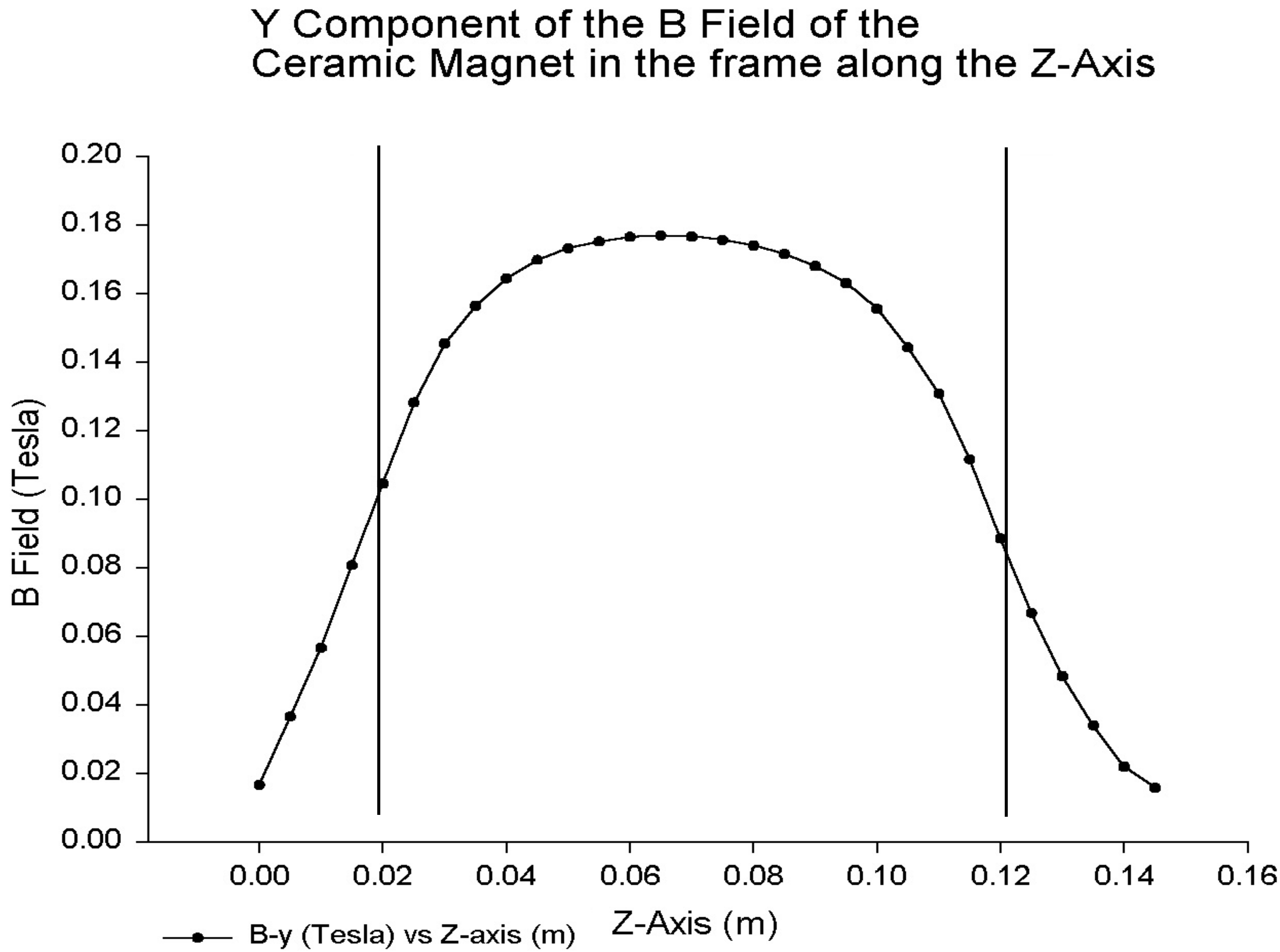


A magnetic field of about 1750 gauss in an air gap of 1.5 inches.



Y Component of the B Field of the
Ceramic Magnets in the frame along the X-Axis
B Field (Tesla)
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0.00
0.05
0.10
0.15
0.20
0.25
0.30
X-Axis (m)
B-y (Tesla) vs X-axis (m)


Y Component of the B Field of the
Ceramic Magnet in the frame along the Y-Axis
B Field (Tesla)
0.182
0.181
0.180
0.179
0.178
0.177
0.176
0.000
0.005
0.010
0.015
0.020
0.025
0.030
0.035
Y-Axis (m)
B-y (Tesla) vs Y-axis (m)


Y Component of the B Field of the
Ceramic Magnet in the frame along the Z-Axis
B Field (Tesla)
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
Z-Axis (m)
B-y (Tesla) vs Z-axis (m)

Determination of the Average B Field over the Coil Width

An average of the measurements of the magnetic field over the coil width indicated by * gives the result

$B_{ave} = 0.165$ T

position	B	
cm	T	
26.80	0.0934	
26.30	0.1190	
25.90	0.1327	*
25.35	0.1506	*
24.85	0.1613	*
24.35	0.1674	*
23.90	0.1713	*
23.32	0.1738	*
22.80	0.1750	*
22.40	0.1752	*
21.80	0.1752	*
21.20	0.1744	*
20.70	0.1733	*
20.10	0.1708	*
19.80	0.1691	*
19.10	0.1632	*
18.80	0.1591	*
18.20	0.1474	*
17.70	0.1328	
17.20	0.1123	
16.85	0.0995	
Bave	0.1650	

Force and Velocity Data for Run 10

F_{off} = -0.043 N

F_{r1}= 0.780 N

F_1= 0.823 N

v_1= 0.545 m/s

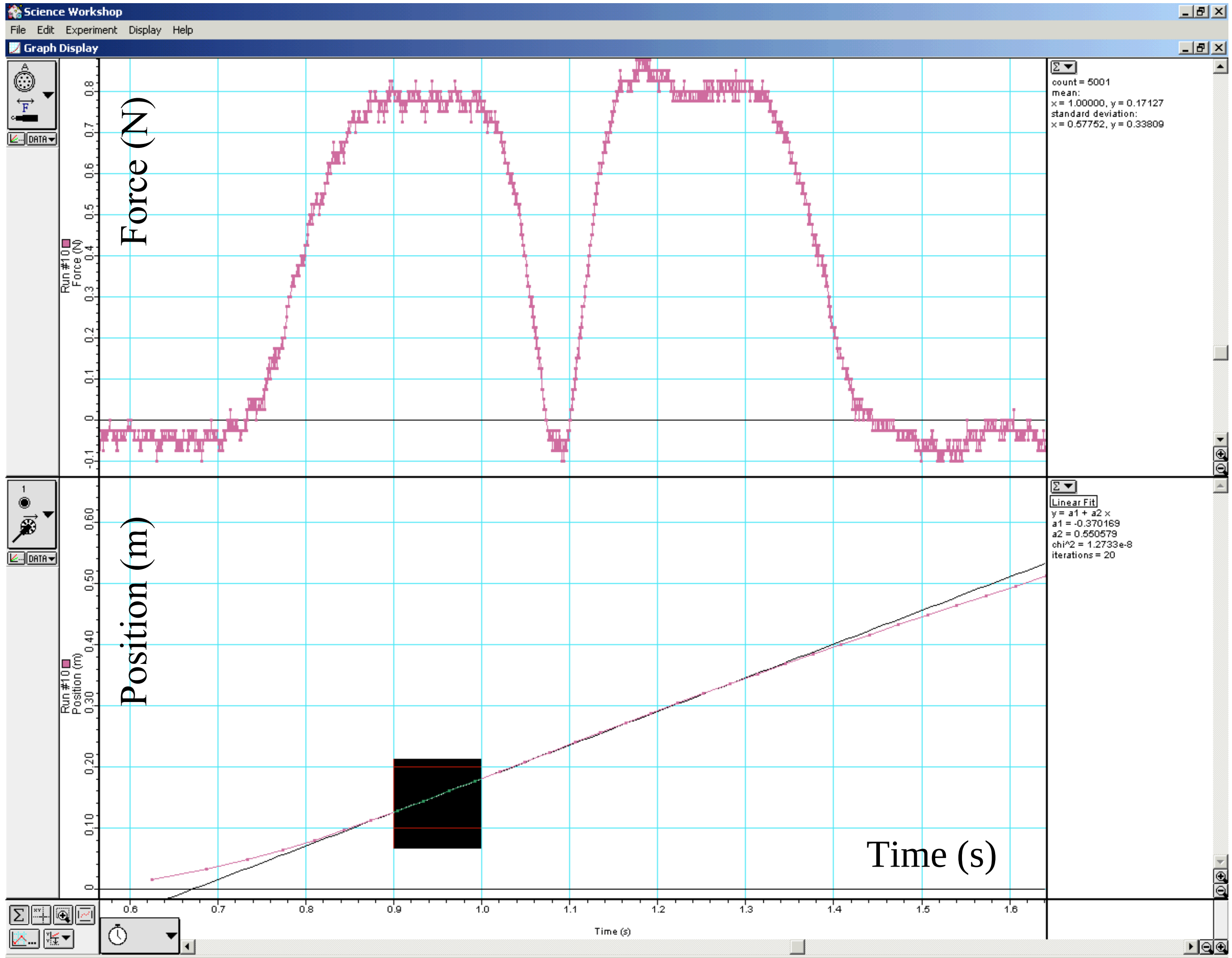
F_{p1}= 0.844 N

F_{r2}= 0.800 N

F_2= 0.843 N

v_1= 0.530 m/s

F_{p1}= 0.844 N



Determination of Coil Average Width on Each Half

	Wout	Win	Wave2-7
ave 2-7	0.07924	0.05238	0.06581
sd 2-7	0.00037	0.00034	

	Wout	Win	Wave 8-13
ave 8-13	0.08007	0.05324	0.06666
sd 8-13	0.00074	0.00036	

Dist	Wout	Win
1	0.07820	0.05332
2	0.07883	0.05290
3	0.07886	0.05211
4	0.07948	0.05198
5	0.07958	0.05230
6	0.07963	0.05265
7	0.07907	0.05232
8	0.07904	0.05265
9	0.07949	0.05300
10	0.08013	0.05330
11	0.08092	0.05346
12	0.08000	0.05338
13	0.08086	0.05367
14	0.07961	0.05204

Results for 10 Runs

Lenz's Law, Measurement of Reaction Force on a Coil as Magnet Sweeps Past											
July 2, 2002		N	B	W_{1ave}	W_{2ave}	N B W_1	R	$(NBW_1)2/R$		N B W_2	$(NBW_2)2/R$
AAPT Talk		50	0.165	0.0658	0.0667	0.54285	0.1902	1.54935		0.55028	1.59202
Boise, ID											
August 4, 2002											
Run#	Force of	F_1	V_1	F_{1meas}	F_{1pred}	F_{1meas}/V_1	F_2	V_2	F_{2meas}	F_{2pred}	F_{2meas}/V_2
1	-0.042	0.769	0.542	0.811	0.8397	1.4963	0.806	0.525	0.848	0.8358	1.6152
2	-0.045	0.644	0.479	0.689	0.7421	1.4384	0.768	0.502	0.813	0.7992	1.6195
3	0.011	0.859	0.571	0.848	0.8847	1.4851	0.939	0.576	0.928	0.9170	1.6111
4	0.007	0.903	0.605	0.896	0.9374	1.4810	1.019	0.630	1.012	1.0030	1.6063
5	-0.015	0.810	0.529	0.825	0.8196	1.5595	0.843	0.512	0.858	0.8151	1.6758
6	-0.044	0.797	0.550	0.841	0.8521	1.5291	0.847	0.546	0.891	0.8692	1.6319
7	-0.047	0.840	0.565	0.887	0.8754	1.5699	0.825	0.515	0.872	0.8199	1.6932
8	-0.044	0.687	0.488	0.731	0.7561	1.4980	0.744	0.487	0.788	0.7753	1.6181
9	-0.039	0.801	0.546	0.840	0.8459	1.5385	0.862	0.559	0.901	0.8899	1.6118
10	-0.043	0.780	0.545	0.823	0.8444	1.5099	0.800	0.530	0.843	0.8438	1.5906

F_{1pred}/V_1	1.5493
F_{1meas}/V_1	1.5106
% error	2.50
stand dev	0.0396

F_{2pred}/V_2	1.5920
F_{2meas}/V_2	1.6274
% error	2.22
stand dev	0.0321

Conclusion

- Computer data acquisition provides a means to observe the force on a coil as a result of current induced in it as predicted by Lenz's law.
- Equipment required is readily available or can easily be constructed.
- Care must be taken to suppress normal modes of oscillation.
- Careful measurements must be made of average magnetic field over the coil width and of the average width of the coil since the forces increases quadratically with these variables.
- Predicted and measured values of the force agree to within errors of about 2.5%, consistent with the standard deviation of the force determined over 10 experimental repetition.
- The force versus time graph provides a visual representation that reinforces the teaching of Lenz's law.