Research Question: What is the value of the damping coefficient due to eddy currents and the coefficient of static friction between neodymium magnets and an aluminum sheet, and the relationship between the number of magnets and the damping coefficient?

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Subject: Physics

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Introduction

While studying electromagnetic induction and learning how motors and transformers work I was intrigued. The Concise Physics 10th Standard textbook often used terms and phrases such as eddy currents and magnetic hysteresis, that I did not understand and wanted to explore more about. I read that the efficiency of transformers was reduced due to the presence of eddy currents. I wondered why this happened and why they couldn't make transformers that simply did not lose power due to eddy currents. By reading research papers on what they were and how they worked I realised that they were unavoidable and simply a version of the law of conservation of energy, in fact if they didn't exist the world of magnetism and electricity would be very different. Through this research, I stumbled onto an idea for my extended essay. I felt that I could delve further into the theory of eddy currents and investigate the factors it depends on.

What are eddy currents?

According to the law of Electromagnetic Induction when there is a change in the magnetic flux linked with a coil an Electromotive Force (EMF) is induced in the coil. Eddy currents refer to the small, closed loops of current that are induced in any conductor when placed in a changing magnetic field. This current creates its own internal magnetic field and opposes the original field. (Eddy Currents)

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Figure 1.1 "EDDY CURRENTS." NDT Resource Centre, www.nde-ed.org/EducationResources/HighSchool/Electricity/eddycurrents.htm. Accessed 7

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Figure 1.2 "EDDY CURRENTS." NDT Resource Centre, www.nde-ed.org/EducationResources/HighSchool/Electricity/eddycurrents.htm. Accessed 7 November 2017

In the figures shown the aluminum sheet moves from left to right in the magnetic field. The eddy current is in the clockwise direction, using the right hand thumb rule, the magnetic field due to this current is going from front to back. This magnetic field is opposite to the magnetic field due to the horseshoe magnet, which is from back to front (north to south).

I saw similarity between eddy current force and the force of friction. Just as friction opposed relative motion, eddy currents oppose the cause that created it, following Lenz's law. It was possible for eddy currents to behave like friction and oppose relative motion (Eddy Currents).

I decided to slide a magnet down an incline whose surface is a conductor but does not have magnetic properties. When the magnet slides down the conductor, the magnetic field created by the eddy currents generates a force, which drastically reduces the acceleration of the magnet as compared to the acceleration when the incline is not a conductor.

The magnetic force due to eddy currents is dependent on the magnetic field strength and the properties of the conductor (such as thickness and material) as well as the properties of the magnet. (Bolivar and Pallcios 3)

In general, two experiments are carried out. The first is to vary the angle at which I release the magnet and use this to find the value of the damping coefficient between the aluminum sheet and the magnet(s) used as well as the value for the coefficient of static friction. For the second experiment, I will vary the number of magnets that I slide down the incline to get the relationship between the number of magnets (n) and the damping coefficient (b).

This led me to my research question:

What is the value of the damping coefficient due to eddy currents and the coefficient of static friction between neodymium magnets and an aluminum sheet, and the relationship between the number of magnets and the damping coefficient?

Hypothesis

As theta (θ) (the angle between the horizontal and the incline) increases, the time taken for the magnet to slide down the incline will reduce, as the velocity of the magnet will increase. Using these values the coefficient of friction and the damping coefficient can be found. As the numbers of magnets increase the magnetic field strength will increase which will cause the damping coefficient of the magnet- aluminum set up to increase.

Theory

The force due to eddy currents is dependent on the damping coefficient and the velocity of the magnet. The current creates a significant drag on the motion of the magnet. The damping coefficient is a constant for a given pair of a magnet and a surface (aluminum in this case) which when multiplied by the velocity of the magnet will give the value of the force due to the eddy currents.

$F=bv$ (Gilbert)

Where b is the damping coefficient and v is the velocity of the magnet at any instant of time.

When the magnet is sliding down the incline the forces acting on it are:

1) The weight of the magnet (mg)

2) Static friction ($F_{f)}$

3) Force due to the eddy currents (F_e)

4) The normal reaction force (N)

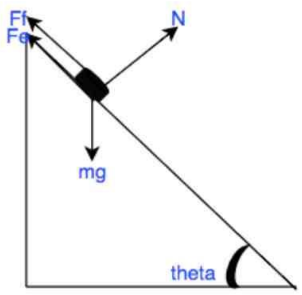

Figure 1.3

On the axis perpendicular to the incline, the net force on the magnet will be

mg cos θ and N

Where m is the mass of the body, g is the gravitational field strength and R is the normal reaction force.

Since there is no acceleration in the vertical direction,

mg cos θ = R (Tsokos 61)

In the axis along the incline, the net force on the magnet will be:

Net force= component of weight – force of static friction – force due to eddy currents

$F = mg \sin\theta - \mu R - bv$

$F = mg \sin\theta - \mu\, mg \cos\theta - bv$

Where μ is the coefficient of static friction.

$F_{net} = m \frac{dv}{dt}$

$m \frac{dv}{dt} = mg \sin \theta - \mu\, mg \cos \theta - bv$. ((Bolivar and Pallcios 4)

The force of friction and that the weight remain constant while the force due to the eddy currents continues to increase as the magnet slides down the incline. However once the force due to the eddy currents is equal to the mg sin θ - μmgcos θ then the net force on the magnet becomes zero and the acceleration becomes zero and hence the magnet continues to move at a constant velocity (terminal velocity).

$0 = mg \sin \theta - \mu mg \cos \theta - bv$ (Vidaurre 11)

$V_T = \frac{mg \sin \theta - \mu\, mg \cos \theta}{b}$ ….Equation 1

Using these equations it is possible to obtain the values of μ as well as b through analysis.

For the second part of the experiment, a relationship between the number of magnets and the damping coefficient needs to be found. The damping coefficient depends on various factors such as the mass, geometry and magnetic field strength of the magnets. An exact formula for the relation between these quantities could not be found. However, I expect that the damping coefficient would increase with a greater magnetic field strength as the eddy currents that are induced will be more, as the change in magnetic flux would be greater (Molina-bolivar and Abella-Pallcios). Although stacking the magnets on top of each other would increase the distance from the conductor would increase which would cause the magnetic field strength to be less than if a magnet of the same dimensions but double magnetic field strength was used. (Dorham) As the number of magnets increase the damping coefficient will increase, but the relationship might not be linear.

Variables

Independent variables

1) The angle of the incline with the horizontal (θ)

Reason: For every trial the magnet is slid down the incline at different angles.

This will cause the acceleration due to the component of weight to increase as when θ will increase, sin θ will increase. The different accelerations will also cause the force due the eddy currents to have a different value as it depends of the velocity of the magnet.

2) The number of magnets

Reason: If at every angle the experiment is carried out with different number of magnets, the magnetic field strength will increase. This will cause the damping coefficient to increase.

Dependent variables

1) Force due to Eddy currents

This depends of the velocity of the magnet, which will vary through the angle of inclination and the damping coefficient (which will vary due to the number of magnets).

2) Damping Coefficient

This is dependent on the number of magnets.

3) The mass of the magnets

As the number of magnets increase, the mass will also increase.

4) The time taken for the magnets to slide down the incline.

As the angle increases the time taken will increase and this is the main variable that will be measured.

Controlled variables

1) The surface on which the experiment is being conducted

If this is varied, the coefficient of friction would vary as it depends on the materials, which are in contact, which would in turn affect the value of the terminal velocity. The damping coefficient is also a constant for a pair of bodies, hence would change if the surface were changed.

2) The type of magnets

Different magnets will have different magnetic field strengths, which will have different damping coefficients, as one of the bodies would have changed.

3) The temperature and pressure conditions as if the temperature increases, the resistance of the sheet will increase which will cause the damping coefficient to change. Therefore all experiments are carried out in a controlled room on the same day.

Apparatus

1) An incline with an angle indicator

2) An aluminum sheet

3) 3-4 Neodymium magnets

4) A timer

5) A permanent marker

6) A spring balance

Designing the apparatus

Figure 1,4- experimental setup (personal picture)

1) The aluminum sheet is cut (65cm x 7cm) to fit the incline apparatus perfectly.

2) Lines are drawn on the sheet at every 3cm to enable me to measure the time taken for every 3/6cms covered.

3) The aluminum sheet is attached to the incline

Method

The procedure was split up into two major components.

For the first part, which involved finding the value of the damping coefficient and the coefficient of static friction, the following steps were followed:

1) The magnet is held on top of the incline and released from rest to fall freely under the influence of gravity.

2) As soon as the magnet is released a timer is started.

3) A video is taken of the entire process while keeping the camera in slow motion mode to get a more accurate value for the time taken.

4) This process is repeated 5 more times to get more accurate results

5) The angle is altered by 5 degrees and steps 1-4 are repeated for each angle.

6) The magnets are weighed using a spring balance.

For the second part, which involves varying the number of magnets to find a relationship between the number of magnets and the damping coefficient. The following procedure was followed:

1) One magnet is added to already existing magnet(s). Due to the attractive nature of magnets they stay together firmly.

2) The same procedure is followed as for the first part of the method.

3) Steps one and two are repeated for 3,4,5,6 magnets in total.

The videos are then analysed and the time taken for the magnet to cover every 3 cm is noted. This can now be used to find the velocity of the magnet at different intervals while also giving the value of the terminal velocity.

Precautions

1) While setting up the incline apparatus ensure that no metallic surfaces such as screws are used, as they will alter the path of the magnet by attracting it.

2) The readings are taken from a spring balance, as readings from the mass balance would not be as accurate, as the magnetic properties of the magnet would affect the readings.

Raw Data

Tables 1.1- 1.6 shows that data for the time taken for one magnet to slide down the incline at angles of 20°, 25°, 30°, 35°, 40° and 45°. The magnet(s) was slid down 6 times for each angle and the values shown here are the average times for each angle. The readings for each of the 6 trials for each angle can be found in the appendix on page 26.

Table 1.1 – Average time taken for one magnet

Time taken (s)(±0.01) for each 5 ±0.1 cm at **20°**	Time taken (s)(±0.01) for each 5±0.1 cm at **25°**	Time taken (s)(±0.01) for each 5 ±0.1 cm at **30°**	Time taken (s)(±0.01) for each 5 ±0.1 cm at **35°**	Time taken (s)(±0.01) for each 5 ±0.1 cm at **40°**	Time taken (s)(±0.01) for each 5 ±0.1 cm at **45°**
1.23	1.15	0.97	0.88	0.51	0.5
1.11	1.08	0.93	0.79	0.5	0.45
1.07	0.93	0.88	0.74	0.49	0.44
1.04	0.88	0.76	0.68	0.47	0.43
1.04	0.84	0.68	0.62	0.47	0.43
1.04	0.83	0.68	0.62	0.47	0.43
1.04	0.83	0.68	0.62	0.47	0.43
1.04	0.83	0.68	0.62	0.47	0.43

Table 1.2 – Average time taken for 2 magnets

Time taken (s)(±0.01) for each 5 ±0.1 cm at **20°**	Time taken (s)(±0.01) for each 5±0.1 cm at **25°**	Time taken (s)(±0.01) for each 5 ±0.1 cm at **30°**	Time taken (s)(±0.01) for each 5 ±0.1 cm at **35°**	Time taken (s)(±0.01) for each 5 ±0.1 cm at **40°**	Time taken (s)(±0.01) for each 5 ±0.1 cm at **45°**
1.15	1.21	0.83	0.67	0.51	0.54

1.12	1.13	0.72	0.62	0.48	0.43
1.08	0.93	0.67	0.51	0.43	0.37
1.02	0.88	0.59	0.48	0.38	0.36
0.94	0.79	0.59	0.45	0.38	0.35
0.94	0.79	0.59	0.45	0.38	0.35
0.94	0.79	0.59	0.45	0.38	0.35
0.94	0.79	0.59	0.45	0.38	0.35

Table 1.3- Average time taken for 3 magnets

Time taken (s)(±0.01) for each 5 ±0.1 cm at **20°**	Time taken (s)(±0.01) for each 5±0.1 cm at **25°**	Time taken (s)(±0.01) for each 5 ±0.1 cm at **30°**	Time taken (s)(±0.01) for each 5 ±0.1 cm at **35°**	Time taken (s)(±0.01) for each 5 ±0.1 cm at **40°**	Time taken (s)(±0.01) for each 5 ±0.1 cm at **45°**
1.23	1.13	0.89	0.72	0.67	0.64
1.22	0.91	0.75	0.67	0.61	0.62
1.21	0.82	0.63	0.61	0.55	0.48
1.09	0.73	0.56	0.57	0.45	0.39
1.04	0.72	0.56	0.48	0.42	0.34
0.98	0.69	0.56	0.45	0.38	0.34
0.98	0.69	0.56	0.45	0.37	0.34
0.98	0.69	0.56	0.45	0.37	0.34

Table 1.4- Average time taken for 4 magnets

Time taken (s)(±0.01) for each 5 ±0.1 cm at **20°**	Time taken (s)(±0.01) for each 5±0.1 cm at **25°**	Time taken (s)(±0.01) for each 5 ±0.1 cm at **30°**	Time taken (s)(±0.01) for each 5 ±0.1 cm at **35°**	Time taken (s)(±0.01) for each 5 ±0.1 cm at **40°**	Time taken (s)(±0.01) for each 5 ±0.1 cm at **45°**
1.04	1.07	0.79	0.61	0.63	0.61
0.99	0.93	0.76	0.55	0.53	0.52
0.92	0.81	0.72	0.49	0.48	0.44
0.89	0.76	0.63	0.44	0.44	0.31
0.89	0.68	0.61	0.40	0.33	0.31
0.89	0.68	0.55	0.40	0.33	0.31
0.89	0.68	0.55	0.40	0.33	0.31
0.89	0.68	0.55	0.40	0.33	0.31

Table 1.5- Average time taken for 5 magnets

Time taken (s)(±0.01) for each 5 ±0.1 cm at **20°**	Time taken (s)(±0.01) for each 5±0.1 cm at **25°**	Time taken (s)(±0.01) for each 5 ±0.1 cm at **30°**	Time taken (s)(±0.01) for each 5 ±0.1 cm at **35°**	Time taken (s)(±0.01) for each 5 ±0.1 cm at **40°**	Time taken (s)(±0.01) for each 5 ±0.1 cm at **45°**
1.05	0.88	0.72	0.6	0.54	0.49
1.01	0.81	0.69	0.6	0.51	0.41
0.98	0.72	0.65	0.59	0.46	0.35
0.91	0.64	0.59	0.56	0.38	0.30
0.81	0.64	0.53	0.45	0.32	0.30
0.81	0.64	0.53	0.38	0.32	0.30

0.81	0.64	0.52	0.38	0.32	0.30
0.81	0.64	0.52	0.38	0.32	0.30

Table 1.6- Average time taken for 6 magnets

Time taken (s)(±0.01) for each 5 ±0.1 cm at **20°**	Time taken (s)(±0.01) for each 5±0.1 cm at **25°**	Time taken (s)(±0.01) for each 5 ±0.1 cm at **30°**	Time taken (s)(±0.01) for each 5 ±0.1 cm at **35°**	Time taken (s)(±0.01) for each 5 ±0.1 cm at **40°**	Time taken (s)(±0.01) for each 5 ±0.1 cm at **45°**
1.01	0.83	0.73	0.61	0.48	0.43
0.97	0.77	0.71	0.59	0.43	0.41
0.93	0.71	0.63	0.53	0.39	0.38
0.85	0.65	0.51	0.45	0.34	0.34
0.79	0.65	0.48	0.36	0.31	0.30
0.75	0.63	0.48	0.36	0.31	0.30
0.75	0.63	0.48	0.36	0.31	0.30
0.75	0.63	0.48	0.36	0.31	0.30

Analysis

One magnet sliding down the incline

Table 2.1

Speed (cm/s ±0.001) for each 5 ±0.1 cm at **20°**	Speed (cm/s ±0.001) for each 5 ±0.1 cm at **25°**	Speed (cm/s ±0.001) for each 5 ±0.1 cm at **30°**	Speed (cm/s ±0.001) for each 5 ±0.1 cm at **35°**	Speed (cm/s ±0.001) for each 5 ±0.1 cm at **40°**	Speed (cm/s ±0.001) for each 5 ±0.1 cm at **45°**
0.028	0.043	0.052	0.057	0.098	0.100

0.032	0.046	0.054	0.063	0.1	0.111
0.034	0.054	0.057	0.068	0.102	0.114
0.035	0.057	0.066	0.074	0.106	0.120
0.035	0.060	0.074	0.090	0.106	0.120
0.035	0.060	0.074	0.090	0.106	0.120
0.035	0.060	0.074	0.090	0.106	0.120
0.035	0.060	0.074	0.090	0.106	0.120

By using the formula Speed = $\frac{Distance}{time}$, the speed of the magnet for each reading is found. It is seen that in each case, the magnet eventually reaches terminal velocity. However it is observed that on an average in each case as the angle increases the time taken for each individual 6cm to be covered decreased. This ties in with the original hypothesis.

This is because as the θ increases, sinθ will increase and cosθ will decrease. The net force on the body which is mg sinθ - mg cosθ - bv, will increase. However it does not increase proportionately as with the larger force it also implies that the velocity will be greater which will cause the net force to reduce, as the damping force will increase. Overall, The increase in θ favours the increase in the velocity more than the decrease, as the force due to eddy currents is to oppose the cause that created it. This force very closely resembles the force of air resistance.

The aim of this experiment is to find the value of the damping coefficient and the coefficient of static friction. From equation 1, to get a linear graph, the equation is divided by cos θ throughout to give:

$$\frac{V_t}{\cos\theta} = \frac{mg}{b}(\,tan\theta - \mu)$$

This now resembles a linear equation y= mx+ c where the slope of the graph will be $\frac{mg}{b}$ and the y intercept will be $\frac{mg\mu}{b}$, If a graph of $\frac{V_t}{\cos\theta}$ versus tan θ is plotted. (Molina-bolivar and Abella-Pallcios 7)

Table 2.2

θ (°)	Vt (cm/s) (±0.001)	tan θ	cos θ	V_t/ cosθ (cm/s)
20	0.035	0.364	0.939	0.037
25	0.060	0.466	0.906	0.066
30	0.074	0.577	0.866	0.086
35	0.090	0.700	0.819	0.110
40	0.106	0.839	0.766	0.138
45	0.12	1.000	0.707	0.170

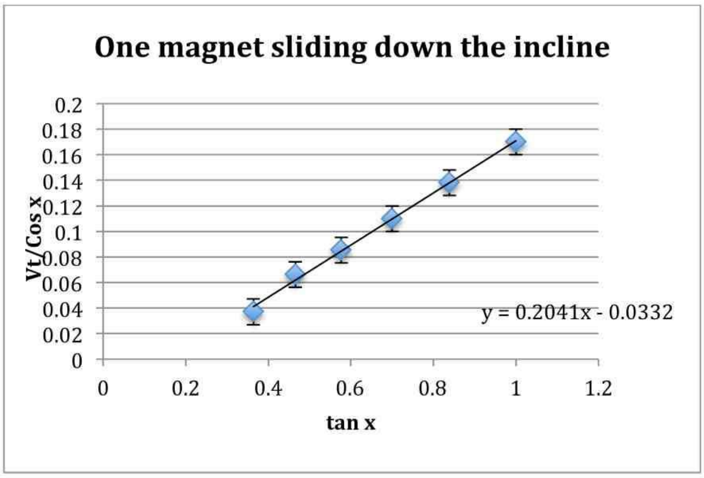

Figure 2.1

The above graph of $\frac{V_t}{\cos\theta}$ versus tan θ is a linear graph as expected. The line of best fit has the equation y= 0.2041x-0.0332. The line of best fit passes through almost all data points. The deviation seen from some data points could be due to various types of systematic and random errors, which will be discussed later. The graph has a positive slope as expected. As θ increases, the value of terminal velocity will also increase as discussed earlier. When the graph is divided by cosθ the same relation continues to hold true. This is because y which in this case is $\frac{V_t}{cos\theta}$, as θ got larger, cosθ got smaller, however since the entire LHS has been divided by cosθ, overall, as θ increases y increases and even V_t increases with a larger θ. Hence dividing by θ had no effect on the overall trend of the graph but helped easily identify the coefficient of static friction and the damping coefficient. (Damping Due to Eddy Currents 3)

0.2041 is $\frac{mg}{b}$. Through measurements, the mass of one magnet is measured to be 7.13g. For purpose of calculations, the value of the gravitational field strength is 9.8 ms^{-2}.

Hence b= $\frac{7.13 \times 0.001 \times 9.8}{0.2041} = 0.342$

0.0332 is $\frac{mg\mu}{b}$, in the previous line the value of b has been found and m and g are known, hence μ = $\frac{0.0332 \times 0.342}{7.13 \times 9.8 \times 0.001} = 0.162$

For two magnets sliding down the incline

The same data was collected for two magnets as for one magnet. The data for the time taken for each angle as well as the speed for every 6 cm can be found in the appendix.

The data for the terminal velocity for each angle is in table 3.1

Table 3.1

θ (°)	Vt (cm/s) (±0.001)	tan θ	cos θ	V_t/ cosθ (cm/s)
20	0.053	0.364	0.939	0.056
25	0.063	0.466	0.906	0.069
30	0.085	0.577	0.866	0.098
35	0.110	0.700	0.819	0.134
40	0.132	0.839	0.766	0.172
45	0.142	1.000	0.707	0.201

The value for the terminal velocity for each angle is greater for two magnets than for one. By referring back to the formula of terminal velocity $V_T = \frac{mg \sin\theta - \mu\, mg \cos\theta}{b}$ we can decipher why this happens.

For each extra magnet, the mass of the system increases, which means that the terminal velocity should also increase. However adding an extra magnet increases the magnetic field strength created by the magnet, which increases the damping coefficient. If adding an extra magnet increased the magnetic field strength, then the terminal velocity would be lesser due to this factor. However, since the velocity increased, which means that adding an extra magnet caused the magnetic field strength to increase and hence the damping coefficient, but the increase in b was less than the increase in mass. Since we know that the mass doubled, we can conclude that the damping coefficient did not double. (Dohram Paul 2017)

For this data we can once again plot a graph of $\frac{V_t}{\cos\theta}$ versus tanθ. The graph obtained is as follow:

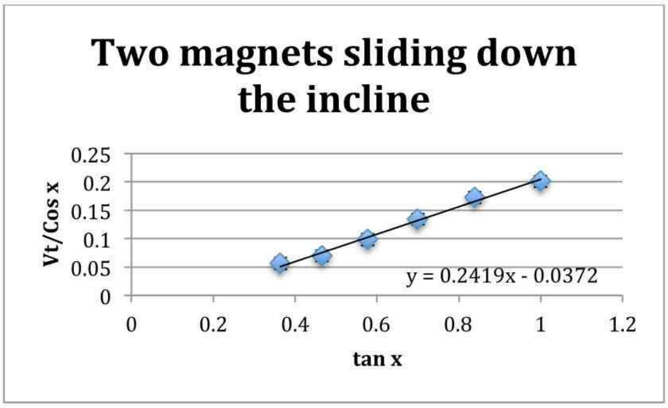

Figure 2.2

Here, as expected the graph is a linear line with a positive slope. By analyzing the values of the slope and the y intercept we can get the value of the coefficient of static friction and the damping coefficient. The equation of the line is y=0.2419x-0.0372

0.02419 (the slope) is = $\frac{mg}{b}$ which is $\frac{2\times7.13\times0.001\times9.8}{b}$

On calculating, b comes to 0.577

Here as expected through the values of the terminal velocity and the hypothesis, the value of the damping is greater in this case. However to get the trend of the damping coefficient readings from all six magnets needs to be evaluated.

To get the value of the coefficient of static friction, the y intercept is found to be 0.0172 and is equal to $\frac{mg\mu}{b}$, which gives

μ = 0.153

This value for the coefficient of static friction as obtained from this trial is almost equal to that of one magnet. This once again ties in with the theory, since the coefficient of friction depends on the two surfaces and not the mass of one of the surfaces, adding more magnets should have no effect on this coefficient, as the two are unrelated. (Tsokos K.A.). The slight difference in values can be attributed to errors in the experiment.

3, 4, 5 and 6 magnets sliding down the incline

The entire data for this trial can also be found in the appendix.

Table 4.1 Values for terminal velocity, tanθ and Vt/cosθ for three magnets

θ (°)	Vt (cm/s) (±0.001)	tan θ	cos θ	V_t/ cosθ (cm/s)
20	0.051	0.364	0.939	0.054
25	0.072	0.466	0.906	0.079
30	0.089	0.577	0.866	0.102
35	0.111	0.700	0.819	0.136
40	0.14	0.839	0.766	0.183
45	0.149	1.000	0.707	0.21

A graph is plotted for V_t/cosθ versus tanθ.

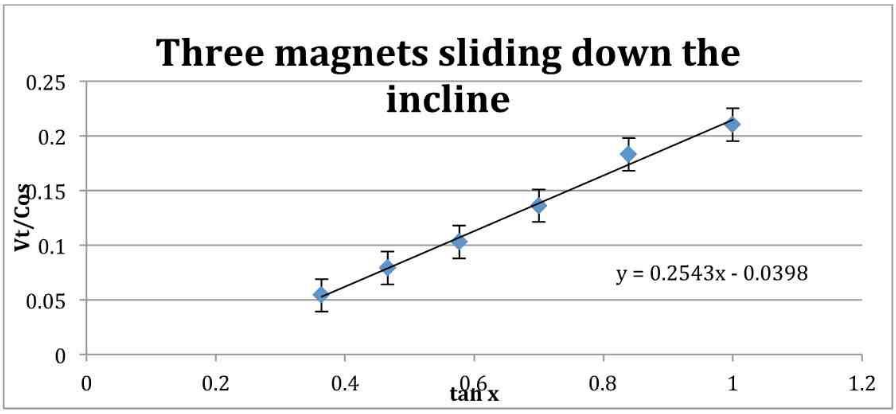

Figure 2.3

Using the same method as before, the values for b and μ are calculated.

b= 0.824and μ= 0.157

Similarly, graphs are plotted for 4,5 and 6 magnets, the data from which these graphs were plotted can be found in the appendix.

Table 4.2 Values for terminal velocity, tanθ and Vt/cosθ for 4 magnets

θ (°)	Vt (cm/s) (±0.001)	tan θ	cos θ	V_t/ cosθ (cm/s)
20	0.056	0.364	0.939	0.06
25	0.074	0.466	0.906	0.08
30	0.091	0.577	0.866	0.11
35	0.125	0.7	0.819	0.15
40	0.152	0.839	0.766	0.19
45	0.161	1	0.707	0.23

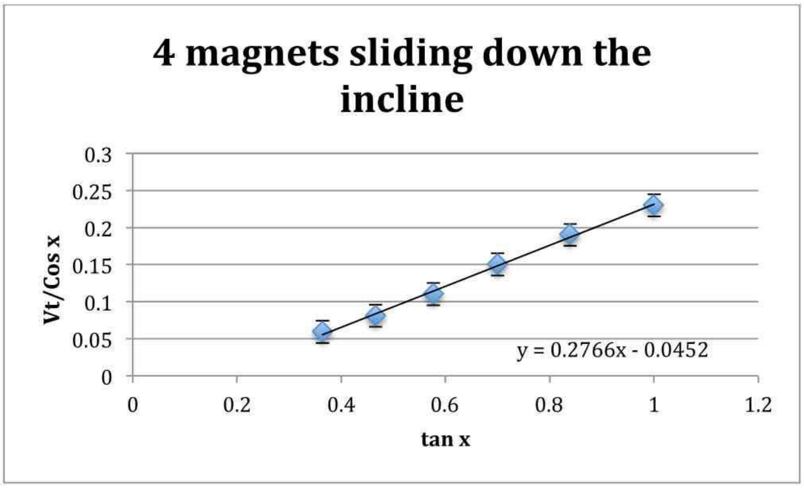

Figure 2.4

Table 4.3 Values for terminal velocity, tanθ and Vt/cosθ for 5 magnets

θ (°)	Vt (cm/s) (±0.001)	tan θ	cos θ	V_t/ cosθ (cm/ s)
20	0.062	0.364	0.939	0.066
25	0.078	0.466	0.906	0.086
30	0.096	0.577	0.866	0.11
35	0.131	0.7	0.819	0.159
40	0.156	0.839	0.766	0.203
45	0.169	1	0.707	0.24

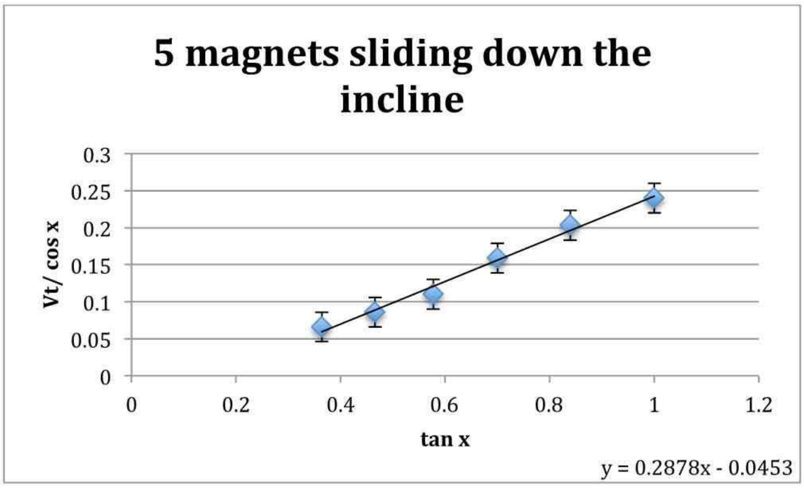

Figure 2.5

Table 4.4 Values for terminal velocity, tanθ and Vt/cosθ for 6 magnets

θ	Vt (cm/s) (±0.001)	tan θ	cos θ	V_t/ cosθ θ (cm/s)
20	0.067	0.364	0.939	0.071
25	0.079	0.466	0.906	0.087
30	0.103	0.577	0.866	0.119
35	0.138	0.7	0.819	0.168
40	0.162	0.839	0.766	0.211
45	0.167	1	0.707	0.253

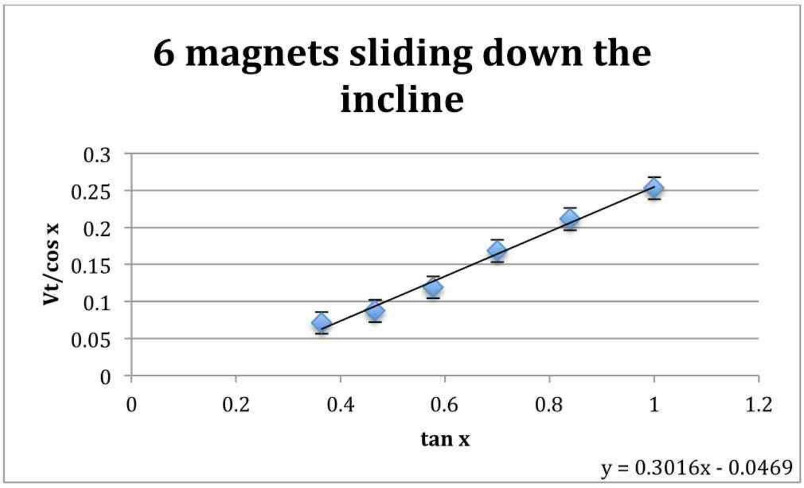

Figure 2.6

Table 5- Values for the coefficient of static friction and the damping coefficient.

Number of magnets	μ	b
1	0.162	0.342
2	0.153	0.577
3	0.157	0.824
4	0.163	1.010
5	0.157	1.21
6	0.155	1.39

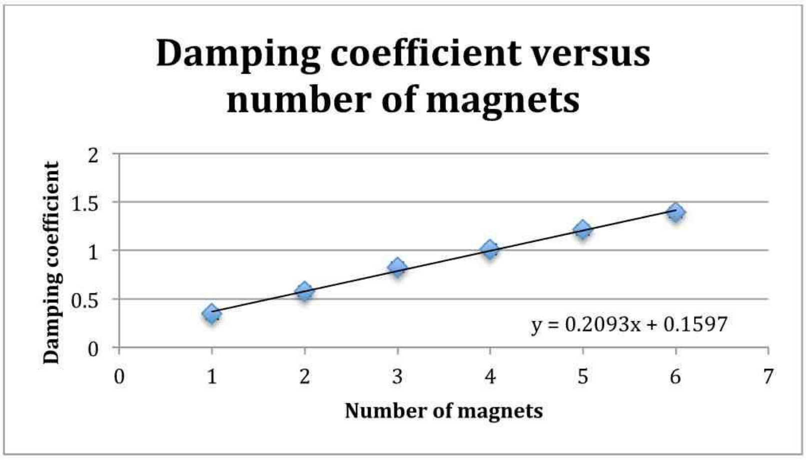

Figure 2.7

The relationship between the damping coefficient and the number of magnets is linear. The equation of the line is y= 0.2093x + 0.1597. This shows that with every magnet that is added, the damping coefficient increases by 0.2093.

Observations are made that the value of the coefficient of static friction remains relatively unchanged throughout the process as expected, while the value of the damping coefficient increased as the number of magnets increased.

Uncertainty Analysis

To calculate the in b and μ, we must look at how it was calculated. Let us take the example of 3 magnets sliding down the incline. $b=\frac{mg}{slope}$. To get the uncertainty in the slope, we find the maximum and minimum slope.

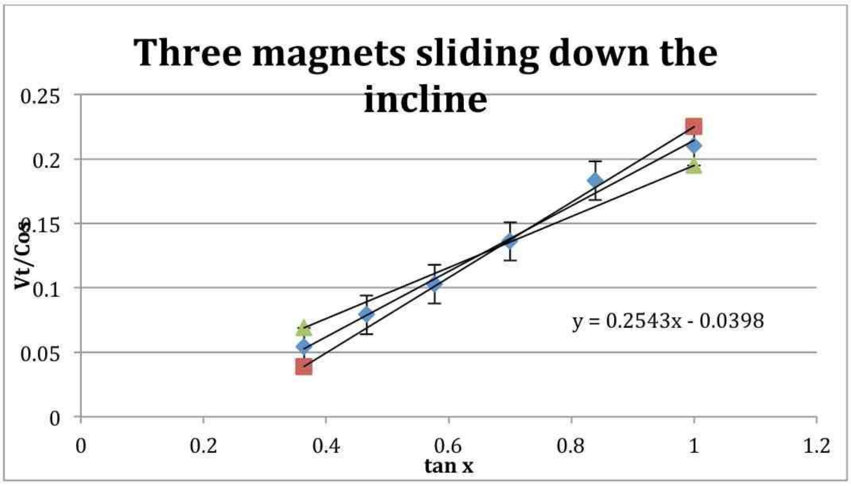

Figure 2.8

The maximum slope is 0.296 and the minimum slope is 0.198. The uncertainty in the slope is given by

$\frac{\text{maximum } slope - minimum\ slope}{2} = \frac{0.296-0.198}{2} = \frac{0.098}{2} = 0.049$ (Richmond Michael 2012)

Hence the uncertainty in the slope is given by 0.254 ± 0.049.

Slope = $\frac{mg}{b}$; b=$\frac{mg}{slope}$

The uncertainty in m is 21.39 ± 0.01, when multiplied by a constant, the uncertainty in mg = 0.01 x 9.8 = 0.098. The fractional uncertainty in mg becomes $\frac{0.098}{213.9} = 0.0005$ (Combining uncertainties - percentage and absolute. Brief summary.)

The fractional uncertainty in the slope is $\frac{0.049}{0.254} = 0.193$

The fractional uncertainty in b is 0.193+0.0005= 0.194

b is 0.824, hence the absolute uncertainty in b becomes 0.824 x 0.194 = 0.159

Hence the uncertainty in b is 0.824 ± 0.159.

μ = $\frac{0.0398}{slope}$, hence the uncertainty in it is 0.049x 0.0398 = 0.002

Hence, μ= 0.157 ±0.002.

Similarly calculations can be carried out for all readings.

Evaluation

On the whole, the experiment was a success but there were errors that could have been avoided and that might have caused the readings to deviate slightly. By repeating each data set six times, the possible random errors (discussed later) reduced and the precision of the data collected increased. Since the value of b cannot be found online as it depends on the thickness and material of the aluminum sheet and the material, size, shape and make of the magnet that I specifically used in my experiment, the accuracy of the results obtained cannot be verified through the internet. While performing the experiment a lot of difficulties were also faced. Some of these can be overcome to get more accurate and precise readings the next time this experiment is performed. There difficulties were:

1) The magnet would often get attracted to metallic parts that were a part of the apparatus even though all efforts were made to keep the magnet out of the range of the metallic parts
Solution- a better apparatus could be used which does not have any particles with magnetic properties such as one made of wood.

2) The use of videos and a stopwatch did not provide as accurate readings as desired as camera had fewer framers per second than expected.
Solution- Use of software's such as Tracker can be used to get more accurate readings as well as a larger data with instantaneous speeds rather than average speed.

<u>The possible sources of Systematic errors are:</u>

1) The magnet was not left at rest and was given an initial velocity by mistake while leaving it.
Solution- Ensure that the magnet is left to move on its own without any external force

2) The angle indicator of the apparatus could have had slightly wrong scaling as the angle indicator was redrawn on cardboard as the original indictor was attracting the magnet.

Solution- A better apparatus could have been used where the angle indicator was not hand drawn.

The possible sources of Random errors are:

1) Due to changing temperature and pressure conditions the current generated could vary as the resistance of the aluminum sheet would vary.

Solution- Multiple readings should be taken to ensure less deviations and more precise

2) The timer could have been started little earlier or later than the actual time.

Solution- A more accurate system can be devised for switching on the timer. Once again the use of software's like tracker will help.

Conclusion

Through the experiments conducted and the analysis of the data collected, the aim of this extended essay has been accomplished. I found the value of the coefficient of static friction between the aluminum sheet used and the neodymium magnet(s). The value of the damping coefficient was also found and a relation between the number of magnets and the damping coefficient was found. As the number of magnets increased, the damping coefficient also increased and is modeled by a positive linear line $y= 0.2093x + 0.1597$. There was a positive linear relationship found between the terminal velocity and the angle of inclination, which helped determine the values needed. Through the study of the theory of eddy currents and the determination of its force we can see that eddy currents can be used as a great brake force and can be used in many magnetic and electric devices like rollercoasters. The brakes used are better than friction brakes as they are not affected by factors such as rain. However it cannot be used to completely stop the rollercoaster as the braking force decreases with speed, so another force would be required to stop it. (OpenStax College)

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Appendix

Distance is in cm, time is in seconds and speed is in cm/s. For each number of magnet(s), for each of the 6 magnets, 6 time trials were taken. These are all the readings taken.

Angle of 20 degrees one magnet								
Distance	Time (average)	Speed	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6
6	1.78	0.028	1.8	1.76	1.79	1.77	1.78	1.8
6	1.56	0.032	1.58	1.54	1.55	1.53	1.56	1.58
6	1.48	0.034	1.5	1.45	1.48	1.47	1.49	1.46
6	1.43	0.035	1.43	1.42	1.41	1.44	1.45	1.4
6	1.43	0.035	1.43	1.42	1.41	1.44	1.45	1.4
6	1.43	0.035	1.43	1.42	1.41	1.44	1.45	1.4
6	1.43	0.035	1.43	1.42	1.41	1.44	1.45	1.4
6	1.43	0.035	1.43	1.42	1.41	1.44	1.45	1.4

Angle of 25 degrees one magnet								
Distance	Time (average)	Speed	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6
6	1.15	0.043	1.17	1.18	1.08	1.14	1.13	1.21
6	1.08	0.046	1.1	1.12	1.03	1.04	1.09	1.1
6	0.93	0.054	0.96	0.99	0.91	0.93	0.94	0.85
6	0.88	0.057	0.89	0.91	0.86	0.86	0.91	0.85
6	0.84	0.06	0.84	0.85	0.85	0.83	0.83	0.83
6	0.83	0.06	0.81	0.85	0.83	0.83	0.83	0.83
6	0.83	0.06	0.81	0.85	0.83	0.83	0.83	0.83
6	0.83	0.06	0.81	0.85	0.83	0.83	0.83	0.83

Angle of 30 degrees one magnet								
Distance	Time (average)	Speed	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6
6	0.97	0.052	0.97	0.98	0.96	0.95	0.97	0.98
6	0.93	0.054	0.91	0.92	0.91	0.95	0.94	0.93
6	0.88	0.057	0.87	0.89	0.88	0.86	0.86	0.91
6	0.76	0.066	0.77	0.79	0.76	0.74	0.73	0.75
6	0.68	0.074	0.68	0.69	0.7	0.74	0.63	0.64
6	0.68	0.074	0.68	0.69	0.7	0.74	0.63	0.64
6	0.68	0.074	0.68	0.69	0.7	0.74	0.63	0.64
6	0.68	0.074	0.68	0.69	0.7	0.74	0.63	0.64

Angle of 35 degrees one magnet								
Distance	Time (average)	Speed	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6
6	0.88	0.057	0.89	0.9	0.87	0.87	0.88	0.88
6	0.79	0.063	0.8	0.81	0.79	0.8	0.77	0.78
6	0.74	0.068	0.71	0.75	0.73	0.75	0.76	0.76
6	0.68	0.074	0.67	0.69	0.7	0.66	0.68	0.67
6	0.56	0.09	0.58	0.55	0.55	0.57	0.54	0.56
6	0.56	0.09	0.58	0.55	0.55	0.57	0.54	0.56
6	0.56	0.09	0.58	0.55	0.55	0.57	0.54	0.56
6	0.56	0.09	0.58	0.55	0.55	0.57	0.54	0.56

Angle of 40 degrees one magnet								
Distance	Time (average)	Speed	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6
6	0.51	0.098	0.54	0.55	0.48	0.49	0.52	0.5
6	0.5	0.1	0.51	0.53	0.47	0.48	0.49	0.5
6	0.49	0.102	0.48	0.49	0.48	0.48	0.49	0.5
6	0.47	0.106	0.48	0.43	0.46	0.48	0.49	0.5
6	0.47	0.106	0.48	0.43	0.46	0.48	0.49	0.5
6	0.47	0.106	0.48	0.43	0.46	0.48	0.49	0.5
6	0.47	0.106	0.48	0.43	0.46	0.48	0.49	0.5
6	0.47	0.106	0.48	0.43	0.46	0.48	0.49	0.5

Angle of 45 degrees one magnet								
Distance	Time (average)	Speed	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6
6	0.5	0.1	0.55	0.53	0.47	0.48	0.49	0.5
6	0.45	0.111	0.46	0.47	0.43	0.45	0.43	0.47
6	0.44	0.114	0.43	0.45	0.432	0.43	0.43	0.47
6	0.42	0.12	0.43	0.41	0.43	0.42	0.42	0.43
6	0.42	0.12	0.43	0.41	0.43	0.42	0.42	0.43
6	0.42	0.12	0.43	0.41	0.43	0.42	0.42	0.43
6	0.42	0.12	0.43	0.41	0.43	0.42	0.42	0.43
6	0.42	0.12	0.43	0.41	0.43	0.42	0.42	0.43

Angle of 20 degrees 2 magnet								
Distance	Time (average)	Speed	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6
5	1.15	0.043	1.18	1.13	1.14	1.16	1.17	1.14
5	1.12	0.045	1.14	1.09	1.08	1.1	1.16	1.13
5	1.08	0.046	1.11	1.05	1.09	1.12	1.05	1.06
5	1.02	0.049	1.04	1.01	1.06	1	0.99	1.04
5	0.94	0.053	0.91	0.96	0.98	0.92	0.97	0.92
5	0.94	0.053	0.91	0.96	0.98	0.92	0.97	0.92
5	0.94	0.053	0.91	0.96	0.98	0.92	0.97	0.92

5	0.94	0.053	0.91	0.96	0.98	0.92	0.97	0.92

Angle of 25 degrees 2 magnet							
Distance	Time (average)	Speed	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6
5	1.21	0.041	1.17	1.18	1.08	1.14	1.13	1.21
5	1.13	0.044	1.1	1.12	1.03	1.04	1.09	1.1
5	0.93	0.054	0.96	0.99	0.91	0.93	0.94	0.85
5	0.88	0.057	0.89	0.91	0.86	0.86	0.91	0.85
5	0.79	0.063	0.84	0.85	0.85	0.83	0.83	0.83
5	0.79	0.063	0.81	0.85	0.83	0.83	0.83	0.83
5	0.79	0.063	0.81	0.85	0.83	0.83	0.83	0.83
5	0.79	0.063	0.84	0.85	0.83	0.83	0.83	0.83

Angle of 30 degrees 2 magnet			Time(s)					
Distance	Time (average)	Speed	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6
5	0.83	0.06	0.86	0.81	0.84	0.81	0.87	0.81
5	0.72	0.069	0.75	0.71	0.69	0.71	0.69	0.761
5	0.67	0.075	0.7	0.64	0.61	0.64	0.67	0.71
5	0.59	0.085	0.56	0.49	0.64	0.64	0.57	0.61
5	0.59	0.085	0.56	0.49	0.64	0.64	0.57	0.61
5	0.59	0.085	0.56	0.49	0.64	0.64	0.57	0.61
5	0.59	0.085	0.56	0.49	0.64	0.64	0.57	0.61
5	0.59	0.085	0.56	0.49	0.64	0.64	0.57	0.61

Angle of 35 degrees one magnet								
Distance	Time (average)	Speed	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6
5	0.67	0.075	0.69	0.65	0.68	0.64	0.63	0.71
5	0.62	0.081	0.65	0.6	0.63	0.59	0.58	0.66
5	0.51	0.098	0.53	0.48	0.52	0.5	0.49	0.55
5	0.48	0.104	0.53	0.48	0.52	0.5	0.42	0.44
5	0.45	0.111	0.53	0.48	0.47	0.47	0.39	0.3
5	0.45	0.111	0.53	0.48	0.47	0.47	0.39	0.3
5	0.45	0.111	0.53	0.48	0.47	0.47	0.39	0.3
5	0.45	0.111	0.53	0.48	0.47	0.47	0.39	0.3

Angle of 40 degrees 2 magnet								
Distance	Time (average)	Speed	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6
5	0.51	0.098	0.61	0.49	0.51	0.5	0.48	0.48
5	0.48	0.104	0.53	0.47	0.49	0.48	0.46	0.47

5	0.43	0.116	0.48	0.42	0.42	0.43	0.41	0.41
5	0.38	0.132	0.37	0.42	0.36	0.37	0.41	0.37
5	0.38	0.132	0.37	0.42	0.36	0.34	0.41	0.37
5	0.38	0.132	0.37	0.42	0.36	0.34	0.41	0.37
5	0.38	0.132	0.37	0.42	0.36	0.34	0.41	0.37
5	0.38	0.132	0.37	0.42	0.36	0.34	0.41	0.37

Angle of 45 degrees 2 magnet								
Distance	Time (average)	Speed	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6
5	0.54	0.093	0.64	0.53	0.54	0.54	0.53	0.48
5	0.43	0.116	0.47	0.49	0.41	0.42	0.43	0.38
5	0.37	0.135	0.38	0.39	0.39	0.35	0.36	0.34
5	0.36	0.139	0.38	0.39	0.37	0.35	0.36	0.33
5	0.35	0.143	0.35	0.36	0.37	0.35	0.36	0.33
5	0.35	0.143	0.35	0.36	0.37	0.35	0.36	0.33
5	0.35	0.143	0.35	0.36	0.37	0.35	0.36	0.33
5	0.35	0.143	0.35	0.36	0.37	0.35	0.36	0.33

Angle of 20 degrees 3 magnet								
Distance	Time (average)	Speed	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6
5	1.23	0.041	1.19	1.21	1.24	1.27	1.22	1.26
5	1.22	0.041	1.25	1.18	1.2	1.21	1.24	1.26
5	1.21	0.041	1.18	1.21	1.23	1.24	1.21	1.19
5	1.09	0.046	1.12	1.08	1.06	1.09	1.1	1.07
5	1.04	0.048	1.06	1.03	1	1.02	1.07	1.05
5	0.98	0.051	0.96	0.98	1	1.02	0.95	0.99
5	0.98	0.051	0.96	0.98	1	1.02	0.95	0.99
5	0.98	0.051	0.96	0.98	1	1.02	0.95	0.99

Angle of 25 degrees 3 magnet								
Distance	Time (average)	Speed	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6
5	1.13	0.044	1.14	1.09	1.12	1.17	1.16	1.08
5	0.91	0.055	0.94	0.87	0.89	0.95	0.93	0.88
5	0.82	0.061	0.84	0.8	0.83	0.86	0.78	0.79
5	0.73	0.068	0.76	0.71	0.75	0.76	0.69	0.72
5	0.72	0.069	0.74	0.72	0.73	0.72	0.71	0.7
5	0.69	0.072	0.71	0.67	0.69	0.66	0.72	0.7
5	0.69	0.072	0.71	0.67	0.69	0.66	0.72	0.7
5	0.69	0.072	0.71	0.67	0.69	0.66	0.72	0.7

Angle of 30 degrees 3 magnet						

Distance	Time (average)	Speed	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6
5	0.89	0.056	0.92	0.86	0.88	0.91	0.87	0.92
5	0.75	0.067	0.78	0.73	0.79	0.76	0.74	0.72
5	0.63	0.079	0.66	0.62	0.61	0.65	0.62	0.64
5	0.56	0.089	0.52	0.55	0.61	0.54	0.57	0.59
5	0.56	0.089	0.52	0.55	0.61	0.54	0.57	0.59
5	0.56	0.089	0.52	0.56	0.61	0.53	0.57	0.59
5	0.56	0.089	0.52	0.55	0.61	0.54	0.57	0.58
5	0.56	0.089	0.52	0.55	0.61	0.54	0.57	0.59

Angle of 35 degrees 3 magnet								
Distance	Time (average)	Speed	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6
5	0.72	0.069	0.68	0.74	0.76	0.69	0.7	0.72
5	0.67	0.075	0.66	0.7	0.62	0.68	0.66	0.71
5	0.61	0.082	0.61	0.62	0.64	0.59	0.57	0.63
5	0.57	0.088	0.59	0.54	0.56	0.53	0.58	0.6
5	0.48	0.104	0.5	0.49	0.45	0.48	0.51	0.47
5	0.45	0.111	0.46	0.43	0.45	0.46	0.44	0.485
5	0.45	0.111	0.46	0.43	0.45	0.46	0.44	0.485
5	0.45	0.111	0.46	0.43	0.45	0.46	0.44	0.485

Angle of 40 degrees 3 magnet								
Distance	Time (average)	Speed	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6
5	0.67	0.075	0.69	0.65	0.68	0.64	0.67	0.7
5	0.61	0.082	0.63	0.62	0.59	0.6	0.64	0.57
5	0.55	0.091	0.57	0.56	0.58	0.53	0.54	0.52
5	0.45	0.111	0.44	0.42	0.45	0.46	0.48	0.47
5	0.42	0.119	0.4	0.43	0.46	0.45	0.39	0.39
5	0.38	0.132	0.36	0.4	0.41	0.39	0.37	0.37
5	0.37	0.135	0.37	0.39	0.39	0.34	0.36	0.35
5	0.37	0.135	0.37	0.39	0.39	0.34	0.36	0.35

Angle of 45 degrees 3 magnet								
Distance	Time (average)	Speed	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6
5	0.64	0.078	0.63	0.66	0.64	0.65	0.62	0.66
5	0.62	0.081	0.63	0.6	0.59	0.64	0.62	0.64
5	0.48	0.104	0.52	0.47	0.46	0.51	0.49	0.5
5	0.39	0.128	0.41	0.4	0.37	0.38	0.41	0.39
5	0.34	0.147	0.35	0.31	0.33	0.36	0.32	0.34
5	0.34	0.147	0.35	0.31	0.33	0.36	0.32	0.34

5	0.34	0.147	0.35	0.31	0.33	0.36	0.32	0.34
5	0.34	0.147	0.35	0.31	0.33	0.36	0.32	0.34

Angle of 20 degrees 4 magnet								
Distance	Time (average)	Speed	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6
5	1.04	0.048	1.02	1.05	1.03	1.06	1.04	1.05
5	0.99	0.051	1	0.98	0.97	1.01	0.96	1.01
5	0.92	0.054	0.94	0.91	0.95	0.93	0.9	0.91
5	0.89	0.056	0.91	0.88	0.92	0.87	0.9	0.88
5	0.89	0.056	0.91	0.88	0.92	0.87	0.9	0.88
5	0.89	0.056	0.91	0.88	0.92	0.87	0.9	0.88
5	0.89	0.056	0.91	0.88	0.92	0.87	0.9	0.88
5	0.89	0.056	0.91	0.88	0.92	0.87	0.9	0.88

Angle of 25 degrees 4 magnet								
Distance	Time (average)	Speed	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6
5	1.07	0.047	1.09	1.05	1.04	1.06	1.08	1.09
5	0.93	0.054	0.96	0.92	0.9	0.95	0.92	0.94
5	0.81	0.062	0.78	0.8	0.82	0.77	0.84	0.83
5	0.76	0.066	0.75	0.77	0.78	0.72	0.75	0.76
5	0.68	0.074	0.71	0.7	0.69	0.66	0.67	0.655
5	0.68	0.074	0.71	0.7	0.69	0.66	0.67	0.655
5	0.68	0.074	0.71	0.7	0.69	0.66	0.67	0.655
5	0.68	0.074	0.71	0.7	0.69	0.66	0.67	0.655

Angle of 30 degrees 4 magnet								
Distance	Time (average)	Speed	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6
5	0.79	0.063	0.81	0.76	0.8	0.78	0.81	0.77
5	0.76	0.066	0.77	0.75	0.78	0.74	0.76	0.74
5	0.72	0.069	0.73	0.71	0.74	0.7	0.7	0.71
5	0.63	0.079	0.6	0.62	0.64	0.61	0.65	0.63
5	0.61	0.082	0.58	0.6	0.63	0.58	0.64	0.6
5	0.55	0.091	0.58	0.54	0.52	0.54	0.56	0.57
5	0.55	0.091	0.58	0.54	0.52	0.54	0.56	0.57
5	0.55	0.091	0.58	0.54	0.52	0.54	0.56	0.57

Angle of 35 degrees 4 magnet								
Distance	Time (average)	Speed	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6
5	0.61	0.082	0.6	0.58	0.61	0.6	0.63	0.61
5	0.55	0.091	0.55	0.57	0.5	0.55	0.56	0.57
5	0.49	0.102	0.5	0.49	0.47	0.52	0.48	0.5
5	0.44	0.114	0.46	0.43	0.45	0.43	0.41	0.47

5	0.4	0.125	0.41	0.39	0.39	0.4	0.365	0.42
5	0.4	0.125	0.41	0.39	0.39	0.4	0.365	0.42
5	0.4	0.125	0.41	0.39	0.39	0.4	0.365	0.42
5	0.4	0.125	0.41	0.39	0.39	0.4	0.365	0.42

Angle of 40 degrees 4 magnet								
Distance	Time (average)	Speed	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6
5	0.63	0.079	0.63	0.59	0.62	0.63	0.62	0.66
5	0.53	0.094	0.55	0.52	0.56	0.49	0.54	0.52
5	0.48	0.104	0.49	0.47	0.47	0.5	0.49	0.47
5	0.44	0.114	0.46	0.42	0.43	0.45	0.46	0.41
5	0.33	0.152	0.34	0.36	0.31	0.33	0.34	0.32
5	0.33	0.152	0.34	0.36	0.31	0.33	0.34	0.32
5	0.33	0.152	0.34	0.36	0.31	0.33	0.34	0.32
5	0.33	0.152	0.34	0.36	0.31	0.33	0.34	0.32

Angle of 45 degrees 4 magnet								
Distance	Time (average)	Speed	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6
5	0.61	0.082	0.62	0.58	0.58	0.63	0.59	0.64
5	0.52	0.096	0.54	0.53	0.5	0.55	0.49	0.52
5	0.44	0.114	0.46	0.45	0.43	0.45	0.42	0.44
5	0.31	0.161	0.31	0.32	0.29	0.325	0.28	0.31
5	0.31	0.161	0.31	0.32	0.29	0.325	0.28	0.31
5	0.31	0.161	0.31	0.32	0.29	0.325	0.28	0.31
5	0.31	0.161	0.31	0.32	0.29	0.325	0.28	0.31
5	0.31	0.161	0.31	0.32	0.29	0.325	0.28	0.31

Angle of 20 degrees 5 magnet								
Distance	Time (average)	Speed	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6
5	1.05	0.048	1.03	1.04	1.08	1.07	1.03	1.06
5	1.01	0.05	0.99	1.02	1.04	1.05	0.99	0.98
5	0.98	0.051	0.97	0.98	1.01	1.02	0.94	0.97
5	0.91	0.055	0.92	0.94	0.9	0.88	0.89	0.91
5	0.81	0.062	0.85	0.81	0.79	0.76	0.8	0.83
5	0.81	0.062	0.85	0.81	0.79	0.76	0.8	0.83
5	0.81	0.062	0.85	0.81	0.79	0.76	0.8	0.83
5	0.81	0.062	0.85	0.81	0.79	0.76	0.8	0.83

Angle of 25 degrees 5 magnet								
Distance	Time (average)	Speed	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6
5	0.88	0.057	0.9	0.88	0.87	0.86	0.87	0.89

5	0.81	0.062	0.82	0.78	0.84	0.79	0.81	0.83
5	0.72	0.069	0.71	0.72	0.7	0.73	0.75	0.72
5	0.64	0.078	0.67	0.61	0.64	0.62	0.63	0.65
5	0.64	0.078	0.67	0.61	0.64	0.62	0.63	0.65
5	0.64	0.078	0.67	0.61	0.64	0.62	0.63	0.65
5	0.64	0.078	0.67	0.61	0.64	0.62	0.63	0.65
5	0.64	0.078	0.67	0.61	0.64	0.62	0.63	0.65

Angle of 30 degrees 5 magnet								
Distance	Time (average)	Speed	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6
5	0.72	0.069	0.69	0.74	0.7	0.7	0.73	0.74
5	0.69	0.072	0.67	0.7	0.68	0.66	0.7	0.72
5	0.65	0.077	0.66	0.64	0.67	0.65	0.66	0.63
5	0.59	0.085	0.58	0.56	0.59	0.6	0.58	0.6
5	0.53	0.094	0.54	0.52	0.53	0.55	0.53	0.53
5	0.53	0.094	0.54	0.52	0.53	0.55	0.53	0.53
5	0.52	0.096	0.52	0.53	0.5	0.52	0.54	0.53
5	0.52	0.096	0.52	0.53	0.5	0.52	0.54	0.53

Angle of 35 degrees 5 magnet								
Distance	Time (average)	Speed	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6
5	0.6	0.083	0.61	0.61	0.6	0.59	0.58	0.62
5	0.6	0.083	0.61	0.61	0.6	0.59	0.58	0.62
5	0.59	0.085	0.58	0.57	0.6	0.62	0.6	0.59
5	0.56	0.089	0.58	0.56	0.55	0.57	0.58	0.54
5	0.45	0.111	0.44	0.47	0.45	0.46	0.43	0.44
5	0.38	0.132	0.37	0.38	0.36	0.39	0.38	0.4
5	0.38	0.132	0.37	0.38	0.36	0.39	0.38	0.4
5	0.38	0.132	0.37	0.38	0.36	0.39	0.38	0.4

Angle of 40 degrees 5 magnet								
Distance	Time (average)	Speed	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6
5	0.54	0.093	0.55	0.53	0.52	0.53	0.55	0.57
5	0.51	0.098	0.5	0.53	0.51	0.49	0.52	0.51
5	0.46	0.109	0.47	0.44	0.44	0.46	0.45	0.48
5	0.38	0.132	0.4	0.37	0.39	0.39	0.37	0.36
5	0.32	0.156	0.31	0.31	0.32	0.34	0.29	0.33
5	0.32	0.156	0.31	0.31	0.32	0.34	0.29	0.33
5	0.32	0.156	0.31	0.31	0.32	0.34	0.29	0.33
5	0.32	0.156	0.31	0.31	0.32	0.34	0.29	0.33

Angle of 45 degrees 5 magnet								
Distance	Time (average)	Speed	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6
5	0.49	0.102	0.51	0.5	0.46	0.48	0.52	0.48
5	0.41	0.122	0.4	0.43	0.39	0.41	0.42	0.4
5	0.35	0.143	0.33	0.34	0.36	0.36	0.38	0.35
5	0.3	0.167	0.28	0.32	0.31	0.31	0.28	0.29
5	0.3	0.167	0.28	0.32	0.31	0.31	0.28	0.29
5	0.3	0.167	0.28	0.32	0.31	0.31	0.28	0.29
5	0.3	0.167	0.28	0.32	0.31	0.31	0.28	0.29
5	0.3	0.167	0.28	0.32	0.31	0.31	0.28	0.29

Angle of 20 degrees 6 magnet								
Distance	Time (average)	Speed	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6
6	1.01	0.05	1.02	1.03	0.99	0.98	1.04	0.97
6	0.97	0.052	0.98	0.97	0.98	0.95	0.97	0.96
6	0.93	0.054	0.94	0.96	0.91	0.93	0.95	0.9
6	0.85	0.059	0.86	0.84	0.82	0.83	0.86	0.87
6	0.79	0.063	0.8	0.77	0.75	0.82	0.79	0.8
6	0.75	0.067	0.77	0.74	0.77	0.75	0.76	0.73
6	0.75	0.067	0.77	0.74	0.77	0.75	0.76	0.73
6	0.75	0.067	0.77	0.74	0.77	0.75	0.76	0.73

Angle of 25 degrees 6 magnet								
Distance	Time (average)	Speed	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6
5	0.83	0.06	0.84	0.85	0.83	0.84	0.82	0.81
5	0.77	0.065	0.75	0.78	0.77	0.79	0.76	0.75
5	0.71	0.07	0.73	0.69	0.71	0.72	0.7	0.73
5	0.65	0.077	0.66	0.62	0.65	0.67	0.64	0.63
5	0.65	0.077	0.66	0.62	0.65	0.67	0.64	0.63
5	0.63	0.079	0.62	0.62	0.65	0.63	0.61	0.62
5	0.63	0.079	0.62	0.62	0.65	0.63	0.61	0.62
5	0.63	0.079	0.62	0.62	0.65	0.63	0.61	0.62

Angle of 30 degrees 6 magnet								
Distance	Time (average)	Speed	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6
5	0.73	0.068	0.75	0.71	0.73	0.74	0.73	0.74
5	0.71	0.07	0.7	0.69	0.72	0.73	0.71	0.72
5	0.63	0.079	0.61	0.62	0.63	0.64	0.65	0.63
5	0.51	0.098	0.53	0.48	0.51	0.5	0.52	0.51
5	0.48	0.104	0.49	0.46	0.47	0.48	0.49	0.5
5	0.48	0.104	0.49	0.46	0.47	0.48	0.49	0.5

5	0.48	0.104	0.49	0.46	0.47	0.48	0.49	0.5
5	0.48	0.104	0.49	0.46	0.47	0.48	0.49	0.5

Angle of 35 degrees 6 magnet								
Distance	Time (average)	Speed	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6
5	0.61	0.082	0.63	0.6	0.61	0.62	0.58	0.6
5	0.59	0.085	0.6	0.59	0.6	0.6	0.57	0.58
5	0.53	0.094	0.54	0.5	0.52	0.54	0.56	0.53
5	0.45	0.111	0.46	0.43	0.44	0.45	0.42	0.47
5	0.36	0.139	0.37	0.34	0.36	0.35	0.37	0.38
5	0.36	0.139	0.37	0.34	0.36	0.35	0.37	0.38
5	0.36	0.139	0.37	0.34	0.36	0.35	0.37	0.38
5	0.36	0.139	0.37	0.34	0.36	0.35	0.37	0.38

Angle of 40 degrees 6 magnet								
Distance	Time (average)	Speed	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6
5	0.48	0.104	0.49	0.47	0.5	0.46	0.47	0.48
5	0.43	0.116	0.44	0.42	0.45	0.41	0.43	0.44
5	0.39	0.128	0.4	0.38	0.37	0.41	0.42	0.37
5	0.34	0.147	0.36	0.32	0.33	0.35	0.34	0.36
5	0.31	0.161	0.32	0.29	0.31	0.32	0.32	0.29
5	0.31	0.161	0.32	0.29	0.31	0.32	0.32	0.29
5	0.31	0.161	0.32	0.29	0.31	0.32	0.32	0.29
5	0.31	0.161	0.32	0.29	0.31	0.32	0.32	0.29

Angle of 45 degrees 6 magnet								
Distance	Time (average)	Speed	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6
5	0.43	0.116	0.45	0.43	0.41	0.44	0.42	0.45
5	0.41	0.122	0.44	0.4	0.41	0.4	0.39	0.44
5	0.38	0.132	0.39	0.37	0.36	0.38	0.4	0.36
5	0.34	0.147	0.34	0.33	0.37	0.36	0.33	0.32
5	0.3	0.167	0.31	0.3	0.28	0.29	0.29	0.31
5	0.3	0.167	0.31	0.3	0.28	0.29	0.29	0.31
5	0.3	0.167	0.31	0.3	0.28	0.29	0.29	0.31
5	0.3	0.167	0.31	0.3	0.28	0.29	0.29	0.31

I declare “That this work is my own work and is the final version. I have acknowledged each use of the words or ideas of another person, whether written, oral or visual”