Investigation of a Magnet falling through a copper tube

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Abstract. Electromagnetic induction one of the most important concept around which most of the devices are developed around. My investigation explores the same concepts wherein a magnet falling through a copper tube depicts the same concept using a theoretical and experimental model. To be precise the research question is to investigate how the thickness of the copper tube affect the time taken for the magnet to fall through it. The investigation was done by dropping a magnet inside the copper tubes of different thickness and the time taken by the magnet to pass through the pipe of one meter length was noted. Moreover a theoretical model is devised using some concepts and equations. Using the theory the actual value of the gradient i.e. \( \frac{1}{w} \) was found to be 120.58 m/s², in the investigation, the value of the gradient was found to be 116.89 m/s², which is only deferring by 3.16 % form the actual value. Therefore the investigation is accurate and reliable. Also the relationship between the thickness of the copper tube and the time taken by the magnet to pass through it is found to be linear, whereas the thickness increases the time taken by the magnet also increases.

1. Introduction

Magnet has always amazed us through their attraction-grabbing properties and lead to many great inventions and discoveries. Once while exploring more about magnets I came across a very interesting observation that magnet inside a copper pipe take much more time than it actually does to come down the same length in air. On further researching, moving magnet inside the copper pipe connects many important concepts in physics which have heavily affected the society. Knowing that today’s world works on energy, power, current, electricity and electricity is now one of a necessity in human lives. Almost every devices and machines around us needs current to run, we often say that “The world has become Digital” and to have this digital world running we need electric current to power it. If we talk about the sources of energy then we have various number of energies but to convert those into electrical energy we need generators. Generators work on the concept of electromagnetic induction, and magnet inside a copper pipe could be a very interesting model for the students to understand the concept of electromagnetic induction and electromagnetic breaking. Furthermore the model could be used in building an emergency exit from tall buildings where a man can wear the magnet suit and then can come down slowly and safely through the copper tunnel. Hence it is worthy and significant to investigate a magnet falling through a copper pipe. In this research paper I will be investigating the time taken by the magnet to pass through it and how the thickness of the tube affects the time.

Direct Current (DC) generators work on the principle of Faraday’s law [1] of electromagnetic induction. First law of faraday’s electromagnetic induction states that, whenever there is changing magnetic flux
around a conductor there is emf induced in it. “Magnetic flux is the measurement of total magnetic field passing thorough a given area. Magnetic flux is also given by the following equation; \( \Phi = B A \cos \theta \), where “\( \Phi \)” is the magnetic flux, “\( B \)” in the magnetic field strength, “\( A \)” is area and “\( \theta \)” is the angle between the normal of the surface and the magnetic field vector.”[1] As per Faraday’s statement i.e. “change in magnetic flux induces current”. So as Magnetic flux is equal to \( B A \cos \theta \), which means that change in any of these factors near a conductor would induce current. Second law of Faraday states that the induced emf is equal to the rate of change of magnetic flux, which means greater the change in flux linkages the induced emf will be more.

![Figure 1. Faraday’s Law](image)

This principle can be applied to a falling magnet through a copper tube, when a magnet is dropped inside a copper tube it moves far slower inside the copper tube than it actually does outside under free fall. Understanding what actually happens, we will starting from the first action where the magnet is taken to a certain height where there is some gravitational potential energy (mgh) being stored in the magnet. Now when you drop the magnet in then the gravitational potential energy starts to convert into kinetic energy which helps the magnet come down. The reason for the magnet slowing down is somewhere connected to the principal we discussed above. Now when the magnet is moving inside the copper tube, which means that flux is changing (because of the moving magnet) near the conductor (i.e. the copper tube) and as per Lenz’s law this induces emf in the conductor which opposes the cause i.e. the moving magnet. Lenz’s law2 states that, when an emf in generated by a change of magnetic flux as per the Faraday’s induction Law, the polarity of the induced emf is such that it then produces a current that is magnetic field opposes the change which is producing it. As said above that due to the falling magnet there is a change of flux which induces current, now this induced current produces an another magnetic field by turning the copper pipe into a temporary magnet. The orientation of the new magnetic field is opposite with respect to the magnet. Now these two opposing fields result in repulsion of the magnet which make the magnet travel slower. The phenomena is similar to a magnet inside a solenoid. Here the copper pipe could be referred to the solenoid as there are winding over the pipe.

Now the question arises of why does the magnet not stop at a particular point? This is because the downward force (due to the kinetic energy) is more that the repulsive for (due to Lenz law).

![Figure 2. Faraday’s Law of Induction](image) ![Figure 3. Magnet inside the copper tube and its pole reaction](image)

2. Theory
As per the earlier discussion that it is convenient to imagine the pipe as a uniform subdivided rings parallel arranged, so now let the width of the unit ring be “l”. When the magnetic flux changes around the ring due to the falling action of the magnet, there is electromotive force induces inside the ring which produces its own magnetic field. According to Lenz’s law these fields will oppose and the repulsion caused will make the magnetic move slower. Now there are various factors which will affect the magnitude of the repulsion (upward force) taking place which affects the time taken by the magnet to pass through the pipe. So the repulsion taking place directly depends on the current induced inside the pipe which decides the magnitude of another magnetic field created to oppose the falling magnet. In the copper pipe as the magnet moves it attains constant velocity, the reason for this is, electromagnetic force being an increasing function of the velocity which will decelerate the falling magnet. The acceleration becomes zero at a point and the magnet then tends to move in a constant velocity which is also called the terminal velocity. So as the velocity “v” is constant the kinetic energy of the falling magnet inside a copper pipe remains constant and the gravitational potential energy then transforms into Ohmic heating of copper pipe, where the gravitational potential energy dissipates through eddy currents induced in the copper pipe or the unit ring. Also the rate of loss of gravitational potential energy will be equal to the rate of dissipation by the Ohmic resistance.

Figures above show the magnet flux and its arrangement while falling inside the copper tube.

Now Considering;
“Y” being the coordinate along the pipe length, I(Y) current induced in the ring at some point Y, R the resistance of the ring we get;

$$mgv = \sum Y I(Y)^2 R$$

(equation 1)

Considering no losses, where all the variation in electric current in the given ring at point Y is resulting into the change in flux due to magnetic motion. Here we can ignore the self-induction effect. Now let’s calculate the distribution of current I(Y) in each ring. To calculate this we first need to study the rate of change of magnetic flux through a ring when the magnet passes through the pipe. Before moving forward let’s note that, magnetic field of the magnet inside the pipe is somewhat similar to the one in the vacuum, this is because the magnetic permeability of copper is very close to the magnetic permeability of vacuum.

Assuming that magnetization $M = MY$ is uniform for the magnet, where the magnetic charge density is zero inside the magnet. Moreover at the ends of the magnet (top and bottom) the magnetic surface density will be uniform $\sigma m = M$ and $-\sigma m = -M$.

The flux created by the magnet can be assumed as fields of two disks of the same radius “r” with a distance “d”. Now making another assumption/approximation, we will replace the charged disks by point monopoles of the same total charge i.e. $q_m = \prod r^2 \sigma m$.

Flux through a ring created by passing two monopoles;
\[
\Phi(Y) = \frac{\mu_0 q_m}{2} \left[ \frac{Y + d}{\sqrt{(Y + d)^2 + a^2}} - \frac{Y}{\sqrt{Y^2 + a^2}} \right]
\] (equation 2)

Where,
\( \mu_0 \) Refers to the permissibility of vacuum
\( Y \) Refers to the distance from the closest monopole

Due to the fall of magnet through the ring, there is an electromotive force as per Faraday’s law;

\[
E(Y) = -\frac{d\Phi(Y)}{dt}
\] (equation 3)

Equation of electric current;

\[
I(Y) = \frac{\mu_0 q_m a^2 v}{2R} \left[ \frac{1}{(Y^2 + a^2)^{\frac{3}{2}}} - \frac{1}{\left(\frac{Y + d}{a}\right)^3 + \frac{a^2}{Y}} \right]
\] (equation 4)

To find he rate of the ohmic dissipation, we can now calculate the sum value of the “(equation 1)”. For finding the power dissipated we can put continuum limit:

The limits are set to be infinity assuming that most of the energy dissipation takes place near the magnet with no losses.

\[
P = \frac{\mu_0^2 q_m^2 a^4 v^2}{4R} \int_{-\infty}^{\infty} \frac{dY}{I} \left[ \frac{1}{(Y^2 + a^2)^{\frac{3}{2}}} - \frac{1}{\left(\frac{Y + d}{a}\right)^3 + \frac{a^2}{Y}} \right]^2 \] (equation 5)

Knowing that resistance equals;

\[
R = \frac{\rho L}{A}
\]

Where \( \rho \) is the electrical resistivity of the conductor, \( A \) is the area of the conductor and \( L \) is the length.

So the resistance of the ring;

\[
R = \frac{2\pi a \rho}{wl}
\]

Where “w” is the thickness of the ring. And “\( \rho \)” is the electrical resistivity.

Writing the equation 5 again with replacing \( R \) we get;

\[
P = \frac{\mu_0^2 q_m^2 v^2 w}{8\pi a^2} f\left(\frac{d}{a}\right)
\] (equation 6)

Here \( f(x) \) is a scaling function, which is defined as;

\[
f(x) = \int_{-\infty}^{\infty} dz \left[ \frac{1}{(z^2 + 1)^{\frac{3}{2}}} - \frac{1}{\left(\frac{z + x}{1}\right)^3 + \frac{1}{z}} \right]^2
\] (equation 7)

Now by substituting equation 6 into the equation 1, we get the terminal velocity of the magnet falling through the pipe;

\[
v = \frac{8\pi m g a^2}{\mu_0^2 q_m^2 w f\left(\frac{d}{a}\right)}
\] (equation 8)
Where “v” is the terminal velocity
To simply the equation further, we will plot the function f(x);

$$f(x) = \frac{45\pi x^2}{128} \quad \text{(equation 9)}$$

For the small values of x, the dotted curve is an assumption being made. So the function f(x) could be now defined as;

$$f(x) = \frac{45\pi x^2}{128} \quad \text{(equation 9)}$$

Further we can reduce the equation for terminal velocity “v” as;

$$v = \frac{1024 mg\rho a^4}{45 \mu_0^2 p^2 w} \quad \text{(equation 10)}$$

Where p=qmd which is the dipole moment of the falling magnet, “a” is the inner radius, “g” is the gravitational constant, “m” is the mass of the magnet.

From the equation above we can identify the relationship between terminal velocity and thickness (w) is inverse. As rest of the things in the equation are the constants so we can write the relation as;

$$v \alpha \frac{1}{w}$$

Since the magnet is made to fall thru constant distance in the pipe we can say that the relation of time and thickness as;

$$t \alpha w$$

Is the relationship that will be explored thru my investigation experimentally.

3. The Experiment
So as per the formula that time taken by the magnet to fall thought the copper tube could be affected by the thickness of the copper tube. This experiment will help me investigating the relationship between the thickness of the tube and the time taken by the magnet to fall through it.

Changing the thickness of the copper pipe
For this investigation, I have to wind the copper wire over the copper tube to change the thickness of the copper tube. As there are only commercial thickness of the copper tubes available in the market that too in bulk, so I have to vary the thickness of the tube by winding thin layers of thin copper wire over the pipe. The inner diameter of the copper pipe was 0.5 inch (1.27x 10^-2m) and the thickness of the copper pipe was 20 SWG (0.914 mm).
Moreover the diameter of the copper wire used for winding around the copper pipe was of 20 SWG \((9.14\times10^{-4}\text{m})\). A total of 1090 turn were winded across the pipe evenly in single layer to increase the thickness of the pipe by \(9.14\times10^{-4}\text{m}\). All the winding was done in a transformer industry with the help of a winding machine, which means the winding was of high quality and less uncertainty.

**The variables**

**Table 1. Independent variable:** I will be varying the thickness of the copper tube by winding different number of layers over the copper pipe. Also for being sure about the trend and for getting a better conclusion I will also vary the thickness of the magnet (Which was varies by varying the number of identical magnets) falling through the pipe. Following thicknesses were considered:

| Thickness w / (m x 10^{-3}) | 1  | 2  | 3  | 4  | 5  | 6  | 7  |
|------------------------------|----|----|----|----|----|----|----|
| w / (m x 10^{-3})            | 0.914 | 1.828 | 2.742 | 3.656 | 4.570 | 5.484 | 6.398 |

**Dependent variable:** The time taken by the magnet to fall through the copper pipe which will be measure using a stopwatch controlled manually.

**Controlled variables:** The variables which were kept constant for the investigation;
- Inner diameter of the copper pipe - \((1.27 \pm 0.01) \times 10^{-2}\text{ m (0.79\%)}\)
- Length of the pipe \((1.00 \pm 0.01)\text{ m (1\%)}\)
- Copper wire of diameter \((9.14 \pm 0.01) \times 10^{-4}\text{ m (0.0012\%)}\)
- Resistivity of the copper wire \(2.63 \times 10^{-2}\text{ Ohm per meter}\)
- Material of the magnet “Neodymium”
- Diameter of the magnet \((10.00 \pm 0.01) \times 10^{-3}\text{ m (0.005\%)}\)
- Width per magnet \((4.00 \pm 0.01) \times 10^{-3}\text{ m (0.0125\%)}\)
- Mass of the magnet \((2.40 \pm 0.01) \times 10^{-3}\text{ kg (0.42\%)}\)
- Turns per layer 1090 \pm 10 (0.92\%)

**Apparatus:**
- Copper pipe, Copper wire, Neodymium magnets, Stopwatch, Winding machine and Stand with clamps.

**Methodology:**
To begin with the investigation, I first took the readings for the pipes own thickness which is 0.914 mm (thickness 1). For recording the time for one magnet (4 mm thickness) to fall through one meter pipe I use a manual stopwatch. I first fixed the copper pipe vertically perpendicular to the surface using the claps on to the stand. Then I took the magnet to the upper opening of the pipe ensuring that the magnet is at the center of the pipe and do not touches the wall of the pipe. Then I gently dropped the magnet into the pipe ensuring that there is no initial force applied by me to the magnet. At the time of releasing the magnet into the pipe I simultaneously stated the stopwatch. Prior to this ensure that the stopwatch is at zero seconds and there is no zero error. After taking 5 repetitive readings for the magnet I then increased the thickness of the magnet by adding one more magnet and did the same process as done for the previous one. Then same was done for all the thickness of the remaining magnets. Now after this to move on to the second thickness 1.828 mm I winded a layer of copper wire on diameter 0.914 mm over the pipe. While winding ensure that there are no gaps in between the winding and it is preferred to take the winding slow. Next 1090 complete turns were taken which ensured the whole pipe is uniformly covered with the copper wire. After winding the wire over the copper tube then the readings for the second thickness was taken in the same way as done for the previous one. The same process was repeated for all the thickness i.e. 0.914, 1.828, 2.742, 3.656, 4.570, 5.484 and 6.39 and the time taken was recorded for all the magnet thicknesses at different thickness of the pipe. A total of 5 readings were taken per case to increase the accuracy and decrease the uncertainty in the result.
4. Data collection and analysis:

**Table 3. Raw data**
The table shows the time recorded for the magnet to pass through the copper pipe of different thicknesses, also the table shows how the different number (width) of magnets affect the time in different thicknesses. Raw data for one magnet (4mm thickness) when dropped in different thicknesses of copper pipe.

| Thickness w / (m ± 0.001) × 10^{-3} | Time Taken t / (s ±0.05) |
|-------------------------------------|---------------------------|
|                                     | For 1 magnet               |
|                                     | t_1 | t_2 | t_3 | t_4 | t_5 |
| 0.914                               | 1.78 | 2.28 | 1.78 | 1.97 | 2.10 |
| 1.828                               | 2.44 | 2.05 | 2.49 | 2.15 | 2.43 |
| 2.742                               | 2.17 | 2.23 | 2.06 | 2.05 | 2.17 |
| 3.656                               | 2.69 | 2.36 | 2.42 | 1.97 | 2.42 |
| 4.570                               | 2.70 | 2.49 | 2.50 | 2.62 | 2.69 |
| 5.484                               | 2.57 | 2.50 | 2.54 | 2.50 | 2.68 |
| 6.398                               | 2.89 | 2.62 | 2.76 | 2.63 | 2.56 |

**Table 4. Processed data table**

| Thickness w / (m ± 0.001) × 10^{-3} | Time Taken t / s |
|-------------------------------------|------------------|
|                                     | For 1 magnet     |
|                                     | t_{avg} | Δ t_{avg} |
|                                     | For 2 magnets   |
|                                     | t_{avg} | Δ t_{avg} |
|                                     | For 3 magnets   |
|                                     | t_{avg} | Δ t_{avg} |
|                                     | For 4 magnets   |
|                                     | t_{avg} | Δ t_{avg} |
|                                     | For 5 magnets   |
|                                     | t_{avg} | Δ t_{avg} |
| 0.914                               | 1.98 | 0.25 | 4.18 | 0.03 | 4.58 | 0.19 | 4.23 | 0.30 | 3.53 | 0.13 |
| 1.828                               | 2.31 | 0.22 | 4.27 | 0.27 | 4.62 | 0.28 | 4.10 | 0.18 | 3.82 | 0.10 |
| 2.742                               | 2.14 | 0.09 | 4.35 | 0.19 | 4.71 | 0.51 | 4.21 | 0.09 | 3.82 | 0.03 |
| 3.656                               | 2.37 | 0.36 | 4.44 | 0.18 | 4.87 | 0.19 | 4.38 | 0.21 | 3.97 | 0.09 |
| 4.570                               | 2.60 | 0.11 | 4.56 | 0.20 | 5.08 | 0.23 | 4.69 | 0.27 | 4.18 | 0.16 |
| 5.484                               | 2.56 | 0.09 | 4.63 | 0.13 | 4.80 | 1.00 | 4.78 | 0.29 | 3.99 | 0.07 |
| 6.398                               | 2.69 | 0.17 | 4.65 | 0.10 | 5.13 | 0.17 | 4.79 | 0.10 | 4.27 | 0.09 |

**Graph 1 – Average Time vs. Thickness of the pipe**
The graph above shows that how change in the thicknesses of the copper pipe leads to change in the time taken for the magnet to fall through. Now in order to verify our theory and the formula which we derived for the relation between the thickness “w” and the velocity “V” we will try putting all the values in to the equation.

Calculating the theoretical and experimental gradient; According to our theory the gradient of the line (coefficient of x from the equations of line) is equal to;

From the equation 10;

\[
v = \frac{1024 \, mg \alpha^4 \, \frac{1}{w}}{45 \, \mu_0 \, P^2}
\]

\[
\frac{1}{v} = \frac{45 \, \mu_0 \, P^2}{1024 \, mg \alpha^4 \, w}
\]

And so,

\[
\left(\frac{1}{v}\right)_{w} = \text{gradient}
\]

And,

\[
\frac{45 \, \mu_0 \, P^2}{1024 \, mg \alpha^4} = \text{gradient (equation11)}
\]

To move forward first lets draw the graph of \(1/v\) (inverse of velocity) vs. \(w\) (thickness);

**Table 5.** \(1/v\) (inverse of velocity) and \(w\) (thickness);

| \(w / (m \pm 0.001) \times 10^{-3}\) | \(1/v \, (s \, m^{-1})\) | \(\Delta \text{tavg} \, /s\) |
|-------------------------------|-----------------|-----------------|
| 0.914                         | 1.982           | 0.250           |
| 1.828                         | 2.312           | 0.220           |
| 2.742                         | 2.136           | 0.090           |
| 3.656                         | 2.372           | 0.360           |
| 4.570                         | 2.600           | 0.105           |
| 5.484                         | 2.558           | 0.090           |
| 6.398                         | 2.692           | 0.165           |

**Graph 2:**

Average Time vs. Thickness
For one magnet (0.004m)
Now the gradient of the graph which is 120.58 should be equal to;

\[
\frac{45 \mu_i^2 p^2}{1024 m g a^4}
\]

Where,
\( a \) is the inner radius = \((6.0 \times 10^{-3}) \) m, \( g \) is a gravitational constant = 9.8 m/s\(^2\), \( m \) is the mass of magnet = \((2.4 \times 10^{-3}) \) kg, \( \mu_i \) is permissibility of vacuum = \((1.257 \times 10^{-6}) \) Henry per meter\(^2\), \( \rho \) is electrical resistivity of the copper = \((2.63 \times 10^{-2}) \) \(\Omega/m\), \( P \) is the Dipole moment of the magnet

Calculating dipole moment of the magnet

To calculate the dipole moment of the magnet we will use the following equation;

\[
P = \frac{2\pi r^3 B}{\mu_0} \quad (equation12) \quad [3]
\]

Where, \( P \) is the Dipole moment, \( r \) is the distance between the poles = \((4.0 \times 10^{-3}) \) m, \( \mu_0 \) is the permissibility of vacuum = \((1.257 \times 10^{-6}) \) Henry per meter, \( B \) is the magnet flux density in Tesla.

Now we see that \( r \) and \( \mu_i \) are constant. To move further now we will have to find out the value of \( B \) (magnet flux density).

Calculating magnet flux density;

For finding the value of \( B \) we will use the equation13;

\[
B = \frac{B_r}{2} \left( \frac{D + z}{\sqrt{R^2 + (D + z)^2}} - \frac{z}{\sqrt{R^2 + z^2}} \right) \quad (equation13) \quad [4]
\]

Where, \( B_r \) is the Remanence field (depends on the grade of the magnet) in Tesla and for the magnet I used \( B_r \) is 1.47 T \([5]\) \( R \) is the Radius of the magnet = \((5.0 \times 10^{-3}) \) m \( D \) is the Thickness of the magnet = \((4.0 \times 10^{-3}) \) m \( z \) is the distance from the pole faced on the symmetrical axis = 0

We see that these all are again some constants and so now by putting the value of these constants in the equation 13 we will get the value of \( B \) as;

\( B = 0.46 \) T (rounded to 2 sf)

Putting the value of \( B \) in the previous equation 12 for calculating the dipole moment \( p \);

\( p = 36.74 \) Nm/T

Figure 9.

Magnet parameters.

Now putting the value of \( p \) in our equation 11 we get the theoretical gradient as;

\( \Rightarrow 116.89 \) m\(^2\) s

5. Conclusion

The aim of the essay was to investigate the relation between the thickness of the copper pipe and the time taken by the magnet to fall through it. From the graph it can be seen that as the thickness of the copper pipe increases the time taken by the magnet also increases. From the gradient of the graph it could be seen that for every 1 m increase in thickness of the copper pipe the time increase by 120.58 seconds, which means for every 1 mm increase in thickness the time increases by 0.1206 s.

The constant above in the equation of the line signifies the y-intercept, which shows the time taken by the magnet when the thickness of the copper pipe is 0 (no pipe just air) is 1.938 s. According to the
The equations of motion \((s = ut + \frac{1}{2}at^2)\) the time taken for a magnet to fall through distance of 1 m in air should be; \(t = 0.412\) s. The difference between the theoretical and the experimental value could be considered as a systematic error in my experiment which is equal to 1.526 s. Furthermore the theoretical value I calculated and the experimental value I received for the gradient are pretty close, where the theoretical value is; 116.89 m-2 s and the experimental value obtained from the graph is; 120.58 m-2 s. Consequently the experimental derivation from the actual value is;

\[
\frac{120.58 - 116.89}{116.89} = 0.0316
\]

\[
= 3.16\%
\]

So the deviation is only 3.16% from the theoretical value, which is almost inconsequential. This shows the accuracy of my investigation and also how reliable my results are. I can now conclude that thickness of the copper pipe and the time taken by the magnet to fall through it has a linear relationship. The thicker the pipe the more the time magnets takes to pass through it. Furthermore the deviation of 3.16% of the experimental value from the theoretical value can be due to the errors instigated while performing the experiment including random and systematic errors both. To further validate the data, I have also performed the experiment with more number of magnets and the gradient of the results is almost in a range of 90-120 (refer graph 1) which is close to the predicted theoretical value.

6. Evaluation and scope of improvement:
Knowing that there is no such experiment that does not have errors and uncertainties. Below is the list of the errors which might have affected my readings and maybe be responsible for the uncertainties. List also mentions the scope of improvement to obtain a better result.

1. Uncertainty in measuring the time taken by the magnet to pass the copper tube. As the work was done manually through a stopwatch there are chances of the readings being imperfect, as human reflex time plays a major consult here. I may have turned on or off the stopwatch late or early which might have majorly affected my readings. This error could be counted as a major limitation in my methodology as a random error and to avoid this error I have taken multiple trials the error could be significantly reduced if sensors are used to record the time.

2. Difference between the material of the pipe and the material of the winding of the copper wire. Though both pipe and winded wire was both of the same metal but the electrical resistivity of both of them could differ a bit as there manufacturing is done accordingly to give them certain strength. This error could be counted as a systematic error because this applies to all thicknesses, and to avoid this error we can directly use copper pipe of different thicknesses but this wasn’t easily available in the market.

3. Error while dropping the magnet into the copper pipe, there might be some initial force being applied on the magnet which could have accelerated the magnet for some distance and so the magnetic might have taken longer time to achieve terminal velocity which also reduces the distance travelled by the magnet in its terminal velocity. To avoid this error form my mythology I could have used a mechanical dropper instead.

4. Length of the pipe could be a limitation leading to disparity in the outcome, as the length of the pipe in my experiment was only 1 meters which is pretty much less. As the magnet takes some time to achieve its terminal velocity hence considering the length of the copper pipe to 1 meters in the calculation would be inappropriate. To get away with this error we cloud have used a pipe of a longer distance and also considering the time from some specific pion in the pipe and not the very top.

5. While winding the wire manually over the machine I might have missed some turns or might have increased the number of turns per layer by mistake, this could have affected the thickness of the copper pipe by disturbing the uniformities of it. To avoid this error again I could have directly use pipes of different thicknesses or instead of using copper wire to increase the thickness is could have used copper foil.

6. Air spacing between the winded coil, this is an error which can’t be eliminated bur could have been reduced by using a wire if smaller diameter (thickness).

7. Use of insulation while winding. In order to increase the thickness of the pipe I had to wind one layer of copper wire over other and to do that in between I had to use and thin insulation paper. Moreover the copper
wire I used was also enamel insulated. This factor might have minutely affected the calculated thickness as the insulated material thickness gets added. Again to eliminate this error we could have used copper foil or directly use copper pipe of different thicknesses.

8. While performing the experiment carefully I heard a little noise, on investing I found that the noise was of the magnet being rubbed against the copper pipe wall which created noise. Due to this error the time taken be the magnet could have been affected due to the friction created between the pipe and the magnet, to eliminate the error I eliminated the trials in which I heard this noise and repeated that reading again.

9. Number of readings taken were less in my experiment and I only took 5 readings per trial, this again could have led to more uncertainty in time taken by the magnet to fall through the pipe. The error could be reduced by taking more number of reading.

As a further study, varying more number and grades of magnets and also varying the lengths of the pipe will help to reconfirm the theoretical model and equation predicted in my research paper.

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