IB EXTENDED ESSAY

SUBJECT: PHYSICS

Investigating The Change In Magnetic Field Repulsion Force Due To Varying Masses In A Jumping Ring Mechanism

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Abstract

Magnetism has always been seen as one of the most exciting and interesting topics of physics by both scientists and common folk alike. Such enthusiasm is the result of the rather extraordinary, invisible forces of magnetic attraction and repulsion caused by magnetic fields. Today, with the help of Faraday's Law of Induction, Lenz Law, Meissner Effect and many more contributions to this area, we are able to understand the nature of magnetic forces and experiment on them. For my project, I questioned "How does mass affect the magnetic repulsion force applied on it by a magnetic field?".I decided that Elihu Thompson's Jumping Ring Mechanism would be the best way to perform my experiment. Therefore, to test different masses, I worked with 20 aluminum rings which I will explain with detail later in Introduction and Method. In order to be able to measure the difference in the magnetic repulsion force, I chose to measure the vertical distance that the aluminum rings jumped, as an indicator of the repulsion force. I recorded my trials to examine, with a camera. Later, in order to better observe the relation between mass and vertical distance covered by the rings, I repeated my experiment but with cooling down the rings before the trials by using liquid nitrogen. Still, I investigated the relation between mass and the vertical distance and this second experiment allowed me to see that the temperature shift made the rings more conductive and made them cover more distance. However, the pattern between mass and distance stayed the same. In both experiments as mass increased the distance increased, from a peak point on as mass increased the distance decreased. My experiments provided me with an understanding of how mass affects magnetic repulsion force and possible ways of usage of this phenomenon.

Word Count: 297

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INTRODUCTION

For my Physics Extended Essay, I chose to focus on magnetic repulsion force and do my research and experiments regarding this. But the question why I chose magnetic repulsion force for my Extended Essay goes way back…

As a little child I was amazed by magnets and by magnetism. My first encounter with magnetism was with the comic books about “Magneto, Master of Magnetism”. Later in elementary school we learned about magnets and our teacher demonstrated us how magnetism works. Objects attracting and repulsing each other without any visible force in-between them; this phenomenon, no matter how supernatural it seems, is a scientific concept which can be measured and experimented on. I was amazed. Then, our teacher told us a story about the discovery of magnetism. In ancient times a shepherd was leading his herd as usually when his iron stick suddenly stuck. To his surprise, he found out that one end of his stick was in fact, lying on a rock that didn’t let go of his stick. According to the story,the region where this event took place was called Magnesia and therefore the names magnet and magnetism was born. The part that surprised me most was that Magnesia is in Anatolia and known as Manisa today. The fact that magnetite, the most magnetic natural mineral found on Earth **(12)** is found abundantly in Manisa, backs up the story and as a child it made me proud.

Remembering the good memories, I wanted to work on magnetic forces and decided on the magnetic repulsion force caused by magnetic fields. I thought I could blend it with superconductivity and therefore do experiments on how the world-famous Mag-Lev(Magnetic-Levitation) trains work. This idea came true when The Physics Faculty of Ankara University allowed me to work in one of their labs and provided me with some of their equipment and materials that I personally could not afford. But before I proceed to my experiment I want to share some general information on the key topics of my experiment.

Faraday’s Law of Induction and Lenz Law

It is discovered by Michael Faraday in 1830, and defines the Electromotive Force(emf) resulting from the change of magnetic field.**(3)** According to Lenz Law, change of magnetic field around a coil induces current on the coil. These laws led to the development of inductors, electric motors, generators and transformers.**(8)**

Figure1–Faraday’s Law of Induction.

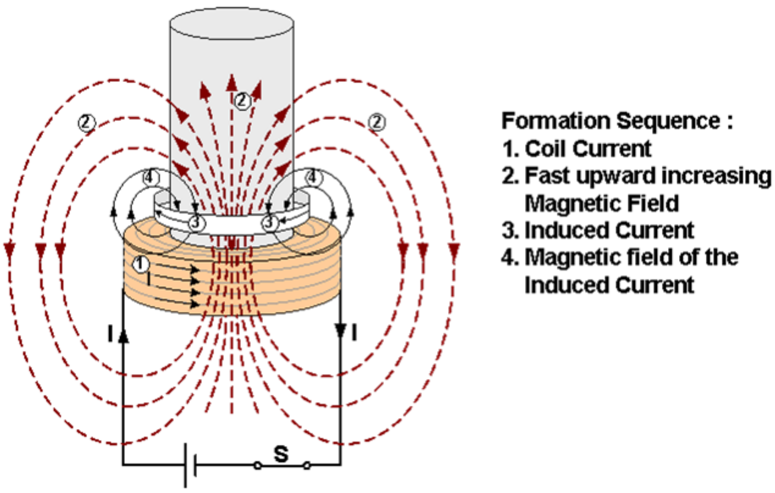


Figure2–Faraday’s Law of Induction

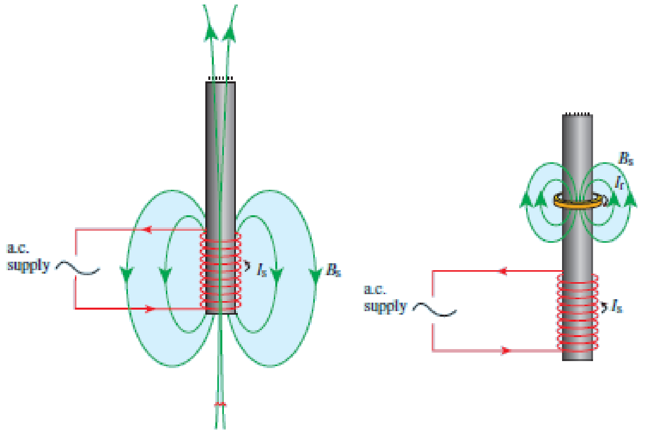


Figure3–Lenz's Law

Meissner Effect and Superconductivity

Conductors are converged into superconductors by cooling them down.**(11)** Superconductors can float in the air by repelling the magnetic field acting on it. This phenomenon is called Meissner effect.**(1)**

Jumping Rings

Discovered by Elihu Thompson(1853-1937),

A solenoid is connected to a power supply and a metal ring is put onto it. When the power is connected for a short time, a strong but temporary current passes through the solenoid, inducing a magnetic field to the upside direction. The induced magnetic field passes through the metal ring perpendicularly and induces an electric current inside the ring.**(5)** The current in the ring induces a magnetic field in the opposite direction of the first magnetic field. Two fields repel each other and make the metal ring jump upside.**(4)**

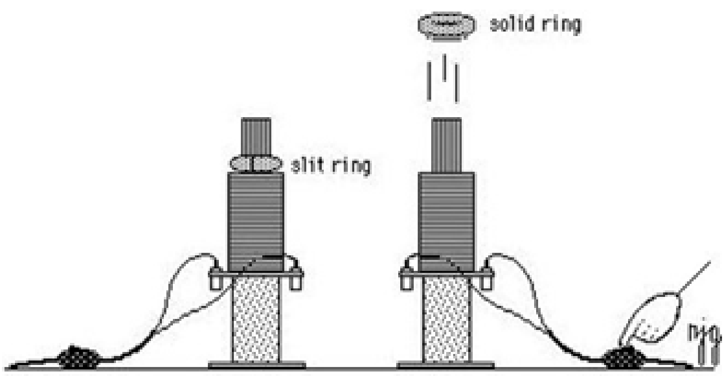


Figure4–Jumping Ring System

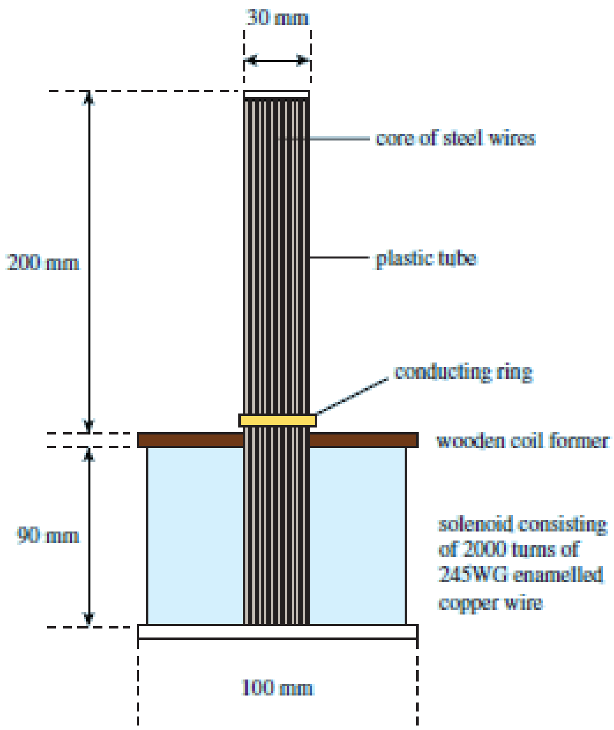


Figure5–Jumping Ring System

With the guidance of all these information I decided that the best way to observe the magnetic repulsion force was to use a Jumping Ring Mechanism. The Jumping Ring Mechanism, created by Elihu Thompson, basically consists of a metal rod with solenoid wire and the experimenter puts a metal ring of desired mass, diameter and type.I will tell how the system works in the Method section with more detail. So, The Jumping Ring Mechanism seemed like the perfect way to see how the magnetic repulsion force changes according to various variables. I decided to change the mass, thus observing how mass affects the magnetic repulsion force. As masses, I used 20 identical aluminum rings and put first one ring to the mechanism, then two, then three… up until 20 rings. In order to easily measure and later calculate on the results I will obtain, I chose to measure how much vertical distance can the aluminum rings jump, as an indicator of magnetic repulsion force. As the peak distance that each ring jumps is momentary, in order to better examine my results I videotaped each trial. At the end of the experiment, in order to check the relation between mass and vertical distance covered by the rings, I repeated my experiment with cooling down my aluminum rings with liquid nitrogen before putting them into the mechanism. Just to be clear; I did not take temperature as an independent variable, I repeated my experiment with cooled down rings but still having temperature as unvarying in order to doublecheck the relation between the mass of the aluminum ring and the vertical distance covered by them. The key information regarding my experiment is as follows:

Research Question

How does the vertical distance that the aluminum ring jumps changes according to the mass of the aluminum ring in a Jumping Ring Mechanism?

Aim

To investigate how does the vertical distance that the aluminum ring jumps changes according to the mass of the aluminum ring in a Jumping Ring Mechanism

Hypothesis

In a Jumping Ring Mechanism, as the mass of the aluminum ring increases, the vertical distance that the ring jumps increases.

Null Hypothesis

In a Jumping Ring mechanism, the mass of the aluminum ring doesn't affect the vertical distance that the ring jumps.

Independent Variable

The mass of the aluminum ring that is put into the Jumping Ring Mechanism

Dependent Variable

The vertical distance covered by the aluminum ring when jumping upwards from the system.

Controlled Variables

The shape of the metal that is put into the mechanism

The type of metal that the rings are made from

The inner diameter of the rings

The outer diameter of the rings

The temperature of the rings

The number of turns of the solenoid coil wire

The material of the solenoid coil wire

The gravitational attraction affecting the jumping ring

The type of metal rod used in the Jumping Ring System

The length and thickness of the metal rod used in the system

The electric current that the Jumping Ring Mechanism is given

The temperature that the experiment is conducted at

I controlled these variables by using the same aluminum rings, by using the same solenoid coil wire, by performing the trials at the same place, by using the same metal rod, by connecting the mechanism to the same socket and by controlling the temperature with a thermometer in this order according to the controlled variables list.

Changing the shape, type, inner and outer diameters and temperature of the rings, turn number and material of the solenoid, gravitational attraction, metal rod, the electric current and the temperature would change the experiment's outcome. For example increasing electric current would increase the magnetic field generated by the mechanism or decreasing the turn number of solenoid would decrease the magnetic field that the mechanism can generate.

Materials

20Aluminum rings of inner diameter 28mm, outer diameter 35mm and masses varying between 1.04g and 1.13g

an iron rod of length 20cm and diameter 25mm

a wooden prism of size 25x25x5cm

a 2050turn solenoid made of 24SWG (Standard Wire Gauge) copper

an electronic precision weighing machine(±0.01g)

a 3m long tape measure(±0.5cm)

a camera

A roll of sellotape

a thermometer(±0.5ºC)

3-4 liters of liquid nitrogen

two conductive wires of 50cm length covered with nonconductive plastic

Photo:Jumping Ring Mechanism

METHOD

In order to perform my experiment I first needed to set up my equipment. As The Physics Faculty Of Ankara University provided me with the lab and equipments, the Jumping Ring mechanism was already set, the iron rod was attached to the wooden prism and the solenoid wire was coiled around the iron rod. I placed the Jumping Ring Mechanism against a wall and placed the tape measurer above the mechanism with 0 cm label of the tape in line with the end of the metal rod. I taped the tape to the wall using sellonoid tape as measuring scale.After that I put the two conductive wires with nonconductive covering into the electric socket nearby with 220 Volts line voltage and 50 Hz frequency in order to give electric current to the system easily and momentarily.I set up my camera one and a half meter away from the system in order to be able to record the whole action. Then I checked the thermometer and started my experiment with weighing one aluminum ring with the electronic weighing device. After noting down the value, I put the ring into the mechanism and made the two open ends of the solenoid wire touch the two ends of the wires that are put into the socket. This way, electric current passed to the mechanism without harming me because of the protective covering of the wires.The electric current flowing through the coil induced a magnetic field going perpendicular with respect to the stationary ring on the upside. Induced current on the ring generated a magnetic field in the opposite direction, resulting in a magnetic repulsion and therefore the ring “jumped”. I retrieved the ring and repeated this procedure four more times. After that, with the help of the solenoid tape I attached the ring to another ring and measured the mass of the two rings. I chose to attach the rings with solenoid tape to have minimal interference on the experiment. Then I put the two rings into the mechanism and gave the electric current and repeated the procedure four more times. I proceeded to repeat the steps for up until 20 rings. This way I repeated my trials 5 times for all 20 different masses of rings.

Number Of Rings	Mass (g, ±0,01)
1 Ring	1,11
2 Rings	2,23
3 Rings	3,3
4 Rings	4,35
5 Rings	5,43
6 Rings	6,45
7 Rings	7,71
8 Rings	8,71
9 Rings	9,81
10 Rings	10,92
11 Rings	12,02
12 Rings	13,13
13 Rings	14,24
14 Rings	15,34
15 Rings	16,49
16 Rings	17,54
17 Rings	18,63
18 Rings	19,74
19 Rings	20,83
20 Rings	21,92

After this experiment, to better see the pattern of how the magnetic repulsion force changes according to varying masses, I repeated the same experiment with cooled down rings. The temperature of the rings is not changed during the experiment and still, the effect of varying masses on magnetic repulsion force was observed. In this experiment I did everything the same as I explained for the first experiment and the only difference was that I put the ring or rings into liquid nitrogen and waited two minutes for the rings to cool down because of the liquid nitrogen and increase in conductivity as the concept of superconductivity suggests.Also , I repeated the trials for each 20 mass of aluminum rings three times rather than five like the previous experiment as I was nearing the end of the time that the University allowed me to work in their lab. Due to working under such low temperatures, safety measures are prioritized while conducting the experiment.

All the repetitions of the experiment were recorded using a video camera, every single repetition was examined carefully and vertical distances of the jumping rings were noted. Raw data obtained from both experiments were transferred to tables that match mass and vertical distance data of each separate experiment. Margins of error are taken as 0.5 cm for vertical distance and 0.01g for mass. Average values of all the repetitions for a single mass is taken. For the average result, mass versus vertical distance tables are formed and finally, graphs that demonstrate mass vs vertical distance data that include margins of error are formed.

RESULTS

	Mass (g, ±0,01)	Vertical Distance of The Rings (cm, ±0,5)				
		Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
Ring 1	1,11	30,0	32,0	31,5	32,0	31,0
Ring 2	2,23	34,0	36,5	35,5	32,0	35,0
Ring 3	3,30	40,0	38,0	37,5	42,0	33,0
Ring 4	4,35	43,0	39,0	43,5	39,0	40,5
Ring 5	5,43	42,0	48,0	46,5	45,5	40,0
Ring 6	6,45	50,0	50,0	48,5	48,5	49,0
Ring 7	7,71	51,5	51,0	53,0	51,0	52,0
Ring 8	8,71	52,0	55,0	54,0	52,0	51,5
Ring 9	9,81	53,5	54,5	52,0	53,5	53,5
Ring 10	10,92	54,0	55,5	52,0	55,0	54,0
Ring 11	12,02	48,5	52,5	55,0	53,5	54,0
Ring 12	13,13	52,5	53,0	50,5	51,5	54,0
Ring 13	14,24	51,0	52,5	53,0	51,5	50,5
Ring 14	15,34	45,0	53,5	50,0	50,0	52,0
Ring 15	16,49	49,0	49,5	50,5	48,5	48,0
Ring 16	17,54	50,5	46,0	49,0	52,5	45,0
Ring 17	18,63	49,5	46,5	45,5	47,5	47,5
Ring 18	19,74	47,5	46,5	47,5	46,5	47,0
Ring 19	20,83	47,0	45,5	46,5	45,5	44,0
Ring 20	21,92	43,5	42,5	42,5	45,0	43,5

TableA:Mass and vertical distance table for the first experiment, including all repetitions

	Mass (g, ±0,01)	Vertical Dsitance of The Rings (cm, ±0,5)		
		Trial 1	Trial 2	Trial 3
Ring 1	1,11	58,0	75,5	66,5
Ring 2	2,23	82,0	101,0	90,5
Ring 3	3,30	114,5	146,0	94,5
Ring 4	4,35	106,0	158,5	131,0
Ring 5	5,43	163,0	156,0	128,5
Ring 6	6,45	164,0	172,0	167,0
Ring 7	7,71	145,0	167,5	165,0
Ring 8	8,71	143,0	172,0	147,0
Ring 9	9,81	135,0	146,0	151,0
Ring 10	10,92	132,0	134,5	128,0
Ring 11	12,02	117,5	125,0	119,5
Ring 12	13,13	104,5	120,0	102,5
Ring 13	14,24	112,5	112,0	85,5
Ring 14	15,34	98,5	97,0	98,0
Ring 15	16,49	90,5	98,5	88,0
Ring 16	17,54	68,0	92,5	87,0
Ring 17	18,63	72,5	78,0	76,0
Ring 18	19,74	76,0	58,5	67,5
Ring 19	20,83	59,5	64,5	63,0
Ring 20	21,92	62,0	50,5	61,5

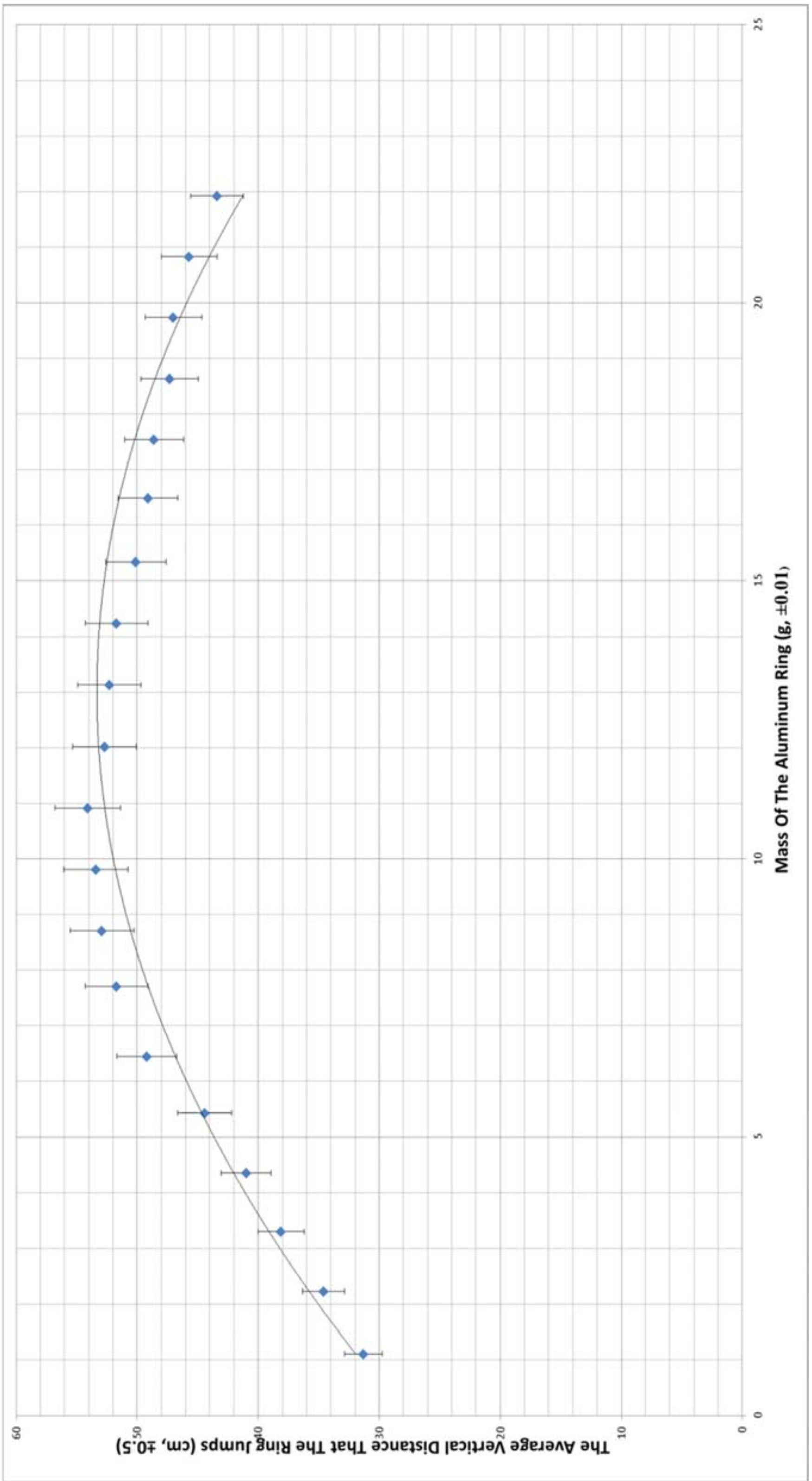
TableB:Mass and vertical distance table for the second experiment, including all repetitions

	Mass Of The Ring (g, ±0,01)	Average Vertical Distance Covered By The Jumping Rings (cm, ±0,5)
Ring 1	1,11	31,3
Ring 2	2,23	34,6
Ring 3	3,30	38,1
Ring 4	4,35	41,0
Ring 5	5,43	44,4
Ring 6	6,45	49,2
Ring 7	7,71	51,7
Ring 8	8,71	52,9
Ring 9	9,81	53,4
Ring 10	10,92	54,1
Ring 11	12,02	52,7
Ring 12	13,13	52,3
Ring 13	14,24	51,7
Ring 14	15,34	50,1
Ring 15	16,49	49,1
Ring 16	17,54	48,6
Ring 17	18,63	47,3
Ring 18	19,74	47,0
Ring 19	20,83	45,7
Ring 20	21,92	43,4

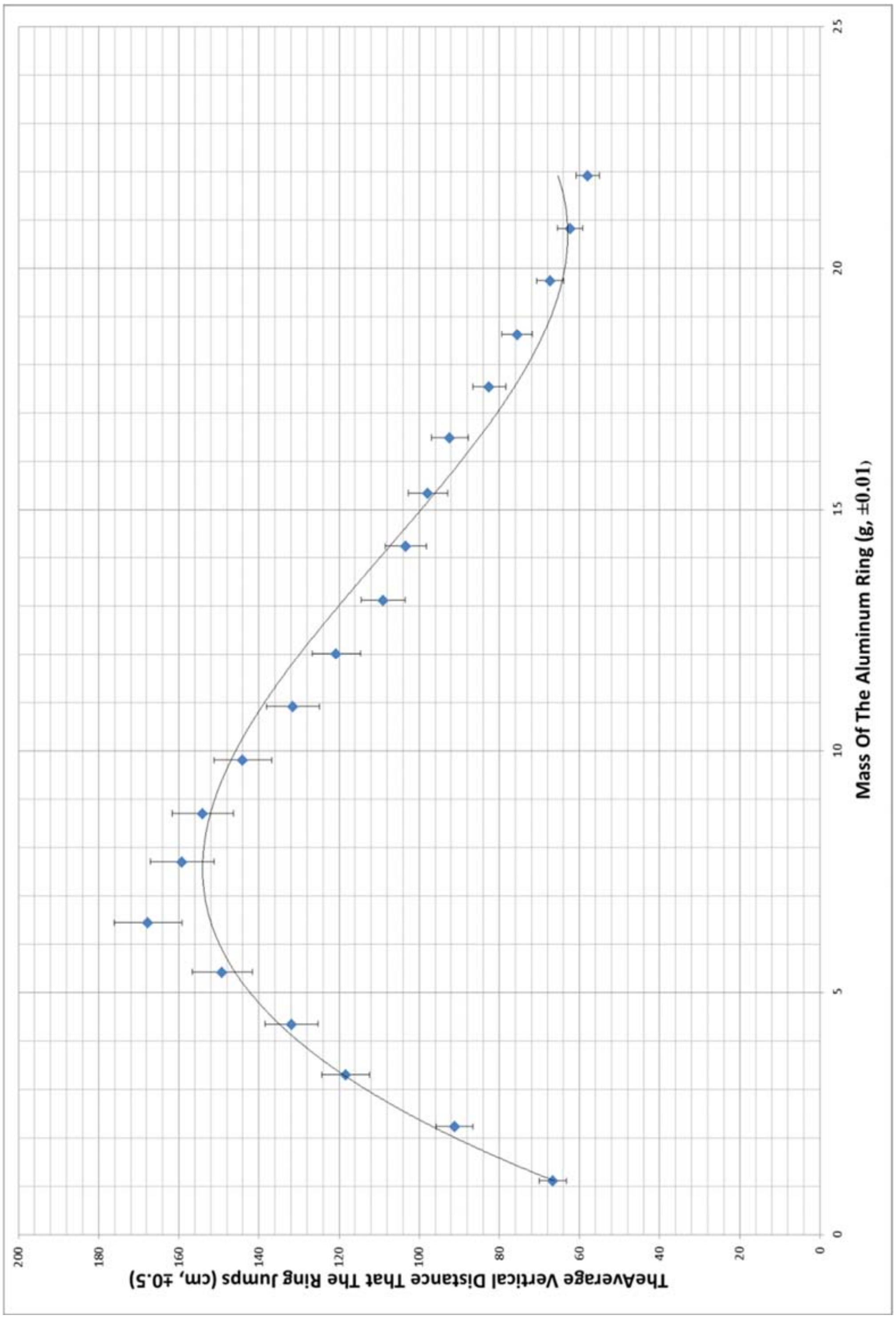
TableA:Mass and average vertical distance table for the first experiment

	Mass Of The Ring (g, ±0,01)	Average Vertical Distance Covered By The Jumping Rings (cm, ±0,5)
Ring 1	1,11	66,7
Ring 2	2,23	91,2
Ring 3	3,30	118,3
Ring 4	4,35	131,8
Ring 5	5,43	149,2
Ring 6	6,45	167,7
Ring 7	7,71	159,2
Ring 8	8,71	154,0
Ring 9	9,81	144,0
Ring 10	10,92	131,5
Ring 11	12,02	120,7
Ring 12	13,13	109,0
Ring 13	14,24	103,3
Ring 14	15,34	97,9
Ring 15	16,49	92,3
Ring 16	17,54	82,5
Ring 17	18,63	75,5
Ring 18	19,74	67,3
Ring 19	20,83	62,3
Ring 20	21,92	58,0

TableB:Mass and average vertical distance table for the second experiment



GraphA:Mass versus average vertical distance graph for the first experiment



GraphB:Mass versus Average Vertical Distance Graph for the Second Experiment

Photo2:Measurement of Masses of Rings Using Precision Weighing Machine

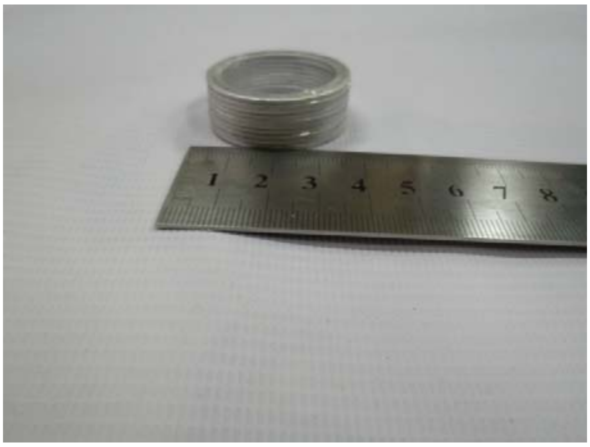


Photo3:Different Aluminum Rings of Same Inner and Outer Diameter

According to the data obtained from experiments and the calculations, it is shown that the experimental results confirm my hypothesis. Considering the mass versus vertical distance characteristics of the Aluminum rings, both cases have an optimum point. Before this point, vertical distance increased with increasing mass whereas after this point, vertical distance decreased with increasing mass.Rate of decrease in the vertical distance covered by the rings after optimum mass is lower than the rate of increase in the vertical distance covered by the rings before optimum mass.

In the experiment conducted in the room temperature mass that caused peak vertical distance is 10.92grams whereas in the experiment conducted with rings cooled in the liquefied nitrogen, the mass that caused peak value in the vertical distance is 6.45grams. This can be explained by the dramatic decrease in the temperature of aluminum rings, thus converging to superconductivity. In the second experiment, rings jumped for a higher vertical distance, 20-30centimeters in the worst case and 115centimeters in the optimum case, due to material converging to superconductivity.

As of error calculation, I haven't found a linear graph or any constant value in the mass vs. vertical distance relation, but rather I observed and evaluated their relation and the pattern involved. Therefore the potential error for mass is 0.01g and the potential error for vertical distance is 0.5cm.

CONCLUSION AND DISCUSSION

Cooling process, whose effects over the electrical resistance of the rings and the magnetic field that they induce can be easily observed by the result that the pattern and relation between mass and the vertical distance didn't change.On the contrary, it confirmed the mass versus vertical distance characteristics of the aluminum rings. In both experiments, the reason why the aluminum rings jumped is because of the magnetic repulsion caused by strong magnetic fields in the opposite directions. In other words, the magnetic force exerted on aluminum rings by the jumping ring mechanism is the reason why rings jumped and thus mass versus vertical distance data is the relation between the change of magnetic force for different masses of aluminum rings.

In the jumping ring experiment conducted by M.Baylie in 2007 in the Physics department of Bath University, mass versus vertical distance characteristics of aluminum rings are observed.**(2)** In that experiment, solenoid conductor diameter and number of turns were 24SWG and 2000 respectively and the power supply frequency was 50Hz. In that experiment, ring inner and outer diameters were kept constant and only the mass was changed. Room temperature experiment showed that vertical distance increased as mass increased until the optimum mass of 24grams is reached. For higher masses, vertical distance stayed constant. After the cooling process, maximum vertical distance is observed at the optimum mass of 9grams, unlike my respective experiment whose optimum mass result was 6.45grams.

In the resulting mass versus vertical distance characteristics of M.Baylie's experiment, vertical distance increased with increasing mass and a constant peak point is observed after optimum mass. Unlike my respective experiment, results of M.Baylie's experiment didn't record a decrease in vertical distance after optimum mass is exceeded. Also, his experiment recorded different optimum masses. Reason for the difference in optimum masses can be explained by the difference in number of turns and inner and outer diameters of the aluminum rings despite every other constant being the same.

In a similar experiment conducted by Paul J.H.Tjossem and Elizabeth C. Brost in 2011, it is observed that a copper ring of 25grams reached the highest vertical distance and the vertical distance decreased with increasing mass after 25grams. After cooling down to 77^{o}K, maximum vertical distance is measured for 9grams of mass. In both experiments, vertical distance decreased when optimum mass is exceeded.**(9)**

The difference in optimum masses of the experiment conducted by J.H.Tjossem and Elizabeth C. Brost in 2011 with my respective experiment cannot be discussed because of the following reasons:The other experiment is conducted with copper rings of inner radius 50.8mm and outer radius 70mm whereas my experiment is conducted with aluminum rings of inner radius 28mm and outer radius 35mm, there is no data of the other experiment about the material used in solenoid and number of turns of the solenoid.**(10)** Despite all the aforementioned differences, experiment conducted by J.H.Tjossem and Elizabeth C. Brost also recorded a decrease in vertical distance after optimum mass is exceeded and cooling process decreased the optimum mass in comparison to the experiment conducted in the room temperature.Despite the differences in thecontrolled variables;resulting mass versus vertical distance relationship is parallel to the results of my respective experiments.

In 2008, Rondo N. Jeffery discovered in his own experiment that if the length of the iron bar in the jumping ring mechanism is increased, electromotive force increases at the bottom of the bar but decreases on the top of the bar.**(7)**

In Jonathan Hall’s experiment conducted in 1997, it is discovered that raising power supply frequency from 0 to 60Hz resulted a rapid increase in the magnetic force on the rings.**(6)** Raising the power supply frequency above 60Hz also resulted in an increase in the magnetic force, but a lot less compared to the increase in 0-60Hz.

Also, the relationship between magnetic force and mass can be calculated using other methods than using mass versus vertical distance relationship. Effects of the amplitude of the current or other variables such as ring temperature and number of turns on the vertical distance can also be studied.

Although my experiments have proven my hypothesis to some extend and helped us understand and evaluate the relation between mass and magnetic field repulsion force via measuring the vertical distances that the rings of different masses have jumped, my experiments of course are not without any errors and limitations. When I was planning my experiments I wanted to use 20different aluminum rings of the same diameter and sizes but differed only in mass. However I could not find any rings that fit this description. Therefore I experimented with 20identical rings and attached them to each other in order to create different masses. I chose solenoid tape to attach the rings and that may have had an effect on the rings and so the results.If these experiments are to be repeated, using with 20 different masses can prevent any errors resulting from the adhesive tape. Furthermore the second experiment was harder to perform because of the liquid nitrogen. As I mentioned earlier, my liquid nitrogen supply evaporated quickly and I can't be sure that the last few rings have been cooled down as much as the other rings since there were less nitrogen left. So the upcoming experimenters should distribute the amount of nitrogen per ring more carefully than I did. We shouldn't ignore the factor that since the results are momentary, I had to use a camera to better examine the results and the quality of the video and digital imagery may have prevented me from measuring the exact values. Therefore professional cameras with slow motion features can be much more useful in an experiment like this.

Despite the fact that daily life usages of the magnetic fields are expensive and rather limited, it offers much to be discovered and used for greater projects such as Mag-Lev-Trains. The possibility of using the magnetic field repulsion force to send satellites and shuttles into space without using any fuel can be performed in the future. But in order to advance to such extend, magnetic fields and the force associated with them should be better analyzed and understood and for that they should be more experimented on.

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