RELATIONSHIP BETWEEN TEMPERATURE AND THE MAGNETIC STRENGTH

Abstract

The magnetic field will attract ferrous materials like iron or nickel. It also attracts or repels other magnets depending, on the polarity of the other magnets Permanent magnets are made from materials that will remain magnetized and are hence able to maintain the magnetic field around them continuously. The study aims at investigating the effect of temperature on the strength of magnets; emphasizing both the scientific and practical significancetheworkprovidesknowledge to undertand the properties of magnets of its strength when confronted with different temperatures. Once the results are achieved then further studies on permanent loss of magnetic performance on a magnet when heated aboveCurie temperature will follow. The methodology is based on Observations on the effect of temperature on the strength of magnets were made. The deflections made on the compass needle on magnet heated at different temperatures from 25^{o} C to 98 ^{o} C were recorded. The general conclusions were the effects of the temperature to the rate of the pull of a magnet are inversely proportional. That is the temperature of a magnet increases, it becomes weaker and as the temperature of a magnet decreases, it becomes stronger.

Keywords: magnetic domains, cold strength magnet, Curie point, magnetic poles

1. INTRODUCTION

"The very magnets known in the early days were naturally occurring lodestones, a type of iron ore called magnetite (Fe_3O_4). People of ancient Greece and China discovered that a lodestone always align itself in a longitudinal direction if it was allowed to rotate freely"(Meyers,1997)."The property of lodestones enabled creation of compasses two thousand years ago, which was usedto determine the magnetic field"(Wasserman, 1991)."It wasdiscovered that a magnet had two magnetic poles North a and South poles"(Morinand Schmitt, 1990, Morrish, 1965). "It was then, concluded that Earth itself is a giant magnet"(Yadav, 2016,Li et al.,2022,Maksimova et al.,2022).

“This led to the discovery of an electric current flowing through a wire can cause a compass needle to deflect, showing that magnetism and electricity were related”(Osipov et al.,2022,Tuet al.2021, Xiaet al.,2021).”Loomis 2023 wrote about the effects of the changes of temperature on permanent magnets on heating and cooling”(Loomis, 2023)

“Laterdiscoveriesfor changing magnetic field produced a current in a coil of wire which ledto invention of the dynamo (a generator) was made leading to major contributions to electric motors. This resulted to the unification the electric and magnetic forces. The concept that light was electromagnetic radiationand laterdiscoveries showed magnets lose their magnetism above a certain temperature that later became known as the Curie point. A magnet is an object that will produce a magnetic field around it also magnet can be defined as any object that produce magnetic field.Some magnets referred to as permanent; hold their magnetism without an external electric current.A magnet of this nature can be created by exposing a piece of metal containing iron to a number of situation, soft magnet on the other hand, are those that lose their magnetic charge properties over time. On the other hand, paramagnetic objects are those that can become magnetic only when in the presence of an external magnetic field. A magnetic field is a space surrounding a magnet, in which magnetic force is exerted, the motion of negatively charged electrons in the magnet determines not only the polarity but also the strength of the magnet. Due to the capability of a magnet, magnetism has been a big part in development of machines and gadgets that are of great use in the modern age. In this study we are able to investigate on the factors that affect the magnetic strength particularly the temperature. Furthermore the magnetic field will attract ferrous materials like iron or nickel. It also attracts or repels other magnets depending, on the polarity of the other magnets Permanent magnets are made from materials that will remain magnetized and are hence able to maintain the magnetic field around them continuously. An example is the small magnets used to hold notes on refrigerator doors. Ferromagnetic materials like iron, cobalt and nickel have a very strong attraction towards magnets. Some ferromagnetic materials will become magnetic when exposed to a magnetic field for a long time. They will be able to retain the magnetic properties even after the field is removed. Other "soft" ferromagnetic materials will lose their magnetism once the magnetic field disappears when electric current flows through a coiled wire, an electromagnet will be produced. However, when the current is removed, the magnetic properties will be lost. By placing ferromagnetic materials in the middle of the coil, the magnetic strength of the coil will be increased many times over also temperature are the degree of hotness or coldness of the body or substances”(Weissitsch,2024).

There are three types of performance loss experienced by magnets when exposed to elevated temperatures; Reversible loss occurs for every degree rise in temperature the magnet experiences above ambient, up to its maximum operating temperature. As the magnet cools, the performance returns to the previous level. When a magnet is heated above its maximum operating temperature but below its Curie temperature, it will experience irreversible losses in performance. This means if the magnet is then cooled, its performance will be weaker than it was before it was heated. A magnet that has experienced irreversible loss could theoretically be demagnetized back to its original strength, but this is not a cost effective process. Irreversible loss is a result of the elevated temperature reversing the magnetization of single individual magnetic domains. This means that irreversible loss happens just once; if the same thermal cycle is repeated no additional loss will occur as each individual domain can only be reversed once after it is magnetized.Permanent loss of magnetic performance is experienced when a magnet is heated above its Curie temperature. At this point the structure of the magnetic domains changes and become self-kippering, resulting in permanent magnetic damage which cannot be repaired by anothermagnetization.The Curie temperature of permanent magnetic materials is often quoted on datasheets, but when taken in isolation this is often the least useful thermal characteristic when designing an application as no design should function close to these extreme high temperatures. Therefore, other parameters such as maximum operating temperature should be considered. Each ferromagnetic material has a Curie temperature, above which it can no longer be magnetized. For example, iron has a Curie temperature of over 1,300°C. A higher temperature weakens a magnet's strength and magnetic field. As heat increases the magnet's kinetic energy and makes its molecules move faster, they become more and more sporadic.

The objectives of this work are to determine whether the temperature of the magnet affects its strength. Also we want to see if we change the temperature of a magnet it works better or worst.Specifically test will be done on magnets at different temperatures to see if their strength is affected. The purpose of this project is to determine how extreme temperature affects magnets. For the given permanent magnet we would like to calculate the different distances of sensitivity of the needle of the compass when magnet is subjected or approachthe compass by using a meter rule.

It isto be determined whether magnets exhibit greater strength at colder temperatures compared to higher temperatures. Increasing the temperature of a magnet reduces its strength. If a magnet is exposed to different temperatures it would work better in cold temperatures than at hot or room temperatures. A magnet in cold temperatures would carry or attract more, so when a magnet is on cold temperatures has more attraction than when they are on hot temperatures.

The studies are significant as it further elaborate on how a magnetic strength changes accordance to a certain temperature and why that kind of reaction happens. It enables us to develop and improve the machines and devices that are already using magnets as one of its main components. Itenables us to look further on the possible advantages and flaws on the concept of magnetism. Itallows us to abroad the use of this material. It paves the way for us to increase its efficiency.

2. LITERATURE REVIEW

"The amplitude of the external magnetic field and the ambient temperature are important factors to determine the magnetic properties of permanent magnets after magnetization. In this paper, the magnetic properties of NbFeB (N50) permanent magnets in 60-300K are measured by a physical property measurement system (PPMS) in the quasi-static magnetic field, and the minimum magnetic field required for saturation magnetization of NbFeB permanent magnet decreases gradually with the increase of temperature. In addition, the effect of eddy current on the magnetic field and temperature of permanent magnet during pulse magnetization are also studied by the comparison of pulse magnetization experiments”(Chen,2018)

“Temperature cycling tests in various temperature ranges were carried out to investigate the magnetic degradation of the Zn-coated NdFeB magnet. The losses of the surface magnetic field and magnetic flux were well fitted by using an index model. Compared with the lower limit temperature, the upper limit temperature had more obvious effect on the magnetic degradation. Once the upper limit temperature exceeded ≥160 °C, the magnetic degradation mainly occurred during the first cycle, which was different from the gradual decline with an increase in cycle number at a temperature of ≤140 °C. Moreover, the temperature cycling with a maximum upper limit temperature of 180 °C led to a loss of the eminence intensity, while the coercively remained stable. Microstructure and element distribution analysis revealed that the oxidation of the Zn coating layer during the temperature cycling causes its cracking and an insertion of the oxygen element into the NdFeB substrate. The Nd-, Pr-rich phase at grain boundaries provided diffusion channels for oxygen elements, leading to a surface oxidation of NdFeB grains” (Wu et al.,2022,Li,2018,Kim,2021).

“Microstructures of Sm $(Co_{bal}Fe_{0.12}Cu_{0.07}Zr_{0.02})_7$ high temperature magnets with different final slow cooling aging temperatures were investigated to uncover the underlying mechanism of magnetic property losses after operating at 500 °C. When the final slow cooling aging temperature is 400 °C, lower than the operating temperature, both eminence and coercively reduce after operating, and cannot be recovered to the initial state. Such losses stem from the secondary diffusion induced microchemistry change in the high temperature environment, which will seriously shorten its service life. While when the final slow cooling aging temperature is 500 °C or higher than the operating temperature, the eminence slightly reduces but the coercively remains nearly unchanged after operating, and can be recovered to the initial level. Consequently, our comparative investigations suggest that final aging at temperatures equivalent or higher than the operating temperature can not only provide stable and reliable magnetic properties for application, but also extend the service life of the present Sm-Co-based magnets”(Xiaet al.,2021).

Thefindings were conducted to determine how extreme temperature affects magnets. For the given permanent they have obtained, they would like to calculate not only the Curie point but also the slope of decrease of magnetism that occurs as they approach a curie point.The assumption is that colder the magnet the stronger the magnet force, graphically they are results will resemble an exponential curve, with magnetic force decreasing at temperature increases. They are independent variable is temperature and dependent variable is magnetism; this will be calculated using the amount of bb pellets that the magnet is able to collect at each measured temperature. Also used are the Bowl, 1,000 BB's, scale, magnet, oven, freezer, freezer thermometer.Thefollowing procedurewas carried out.

Cold Process

1. Place BB's in bowl.
2. Situate scale near bowl.
3. Weigh magnet and record.
4. Place magnet and freezer thermometer in freezer set to lowest temperature possible.
5. Wait approximately 30 minutes for the magnet to reach the temperature of the freezer.
6. Record temperature read by freezer thermometer.
7. Place a magnet in the bowl filled with BB's
8. Remove magnet and attached BB's and place on a scale.
9. Record temperature of a magnet and gram attracted.
10. Subtract the weight of magnet from the weight of the magnet and the BB's combined.
11. Remove BB's and place back in the bowl.
12. Set the freezer to 5-celsius degrees high than previous temperature.
13. Repeat steps 4-12 until freezer and magnet have reached zero degree Celsius.

Hot Process

1. Place BB's in the bowl.
2. Situate scale near the bowl.
3. Weigh magnet and record.
4. Place magnet in oven set to highest temperature possible.
5. Wait approximately 30 minutes for the magnet to reach the temperature of the oven.
6. Place a magnet in the bowl filled with BB's.
7. Remove magnet and attached BB's and place on a scale.

8. Record temperature of a magnet and gram attracted.
9. Subtract the weight of magnet from the weight of the magnet and the BB's combined.
10. Remove BB's and place back in the bowl.
11. Allow magnet to reset for 10 minutes undisturbed.
12. Repeat steps 6-11 until the magnet reaches the room temperature

The data recorded on the table. !.

Fig.1.: Magnet strength with colder temperature

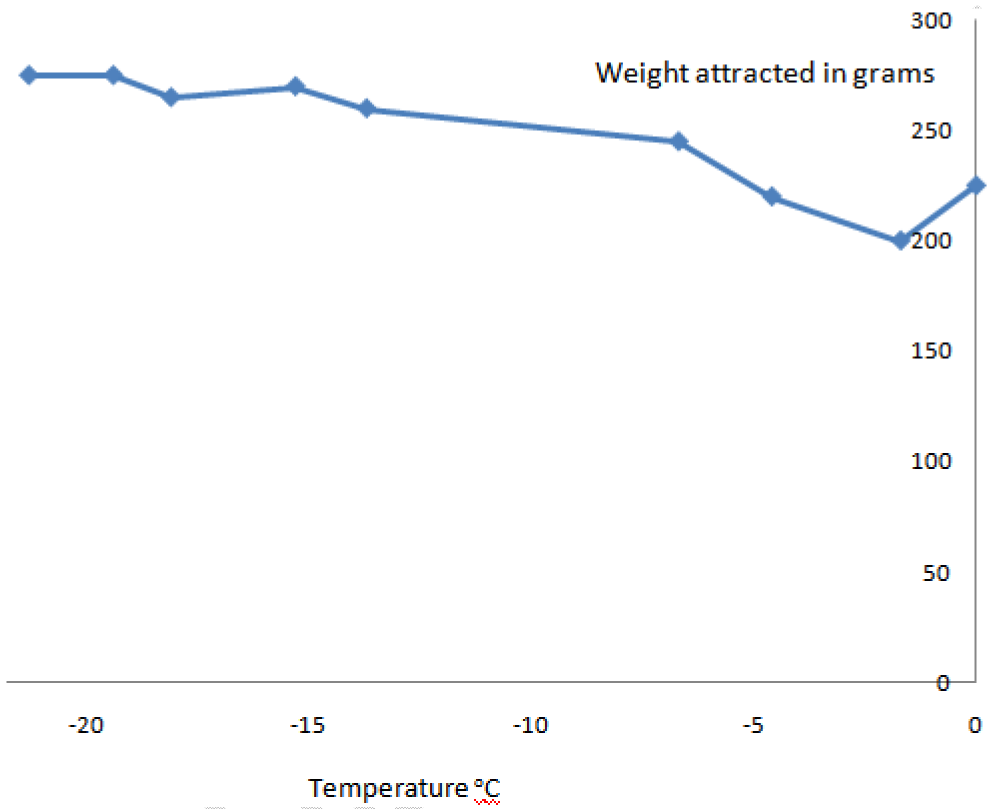
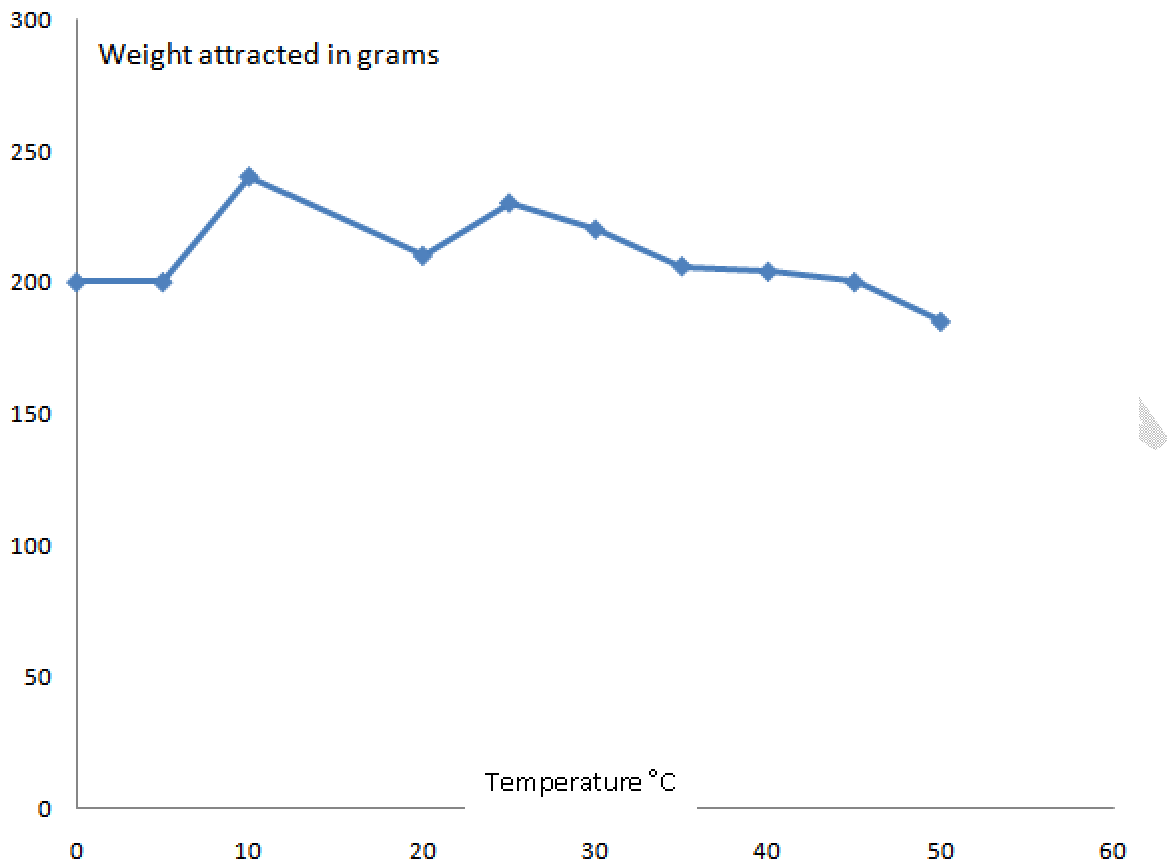


Fig.2: Magnet strength with Hotter Temperature table of results

Its graph



But for our project we want to determine the how the temperature affect the strength of magnets by subjecting the bar magnet in different temperature such as 25°C,30°C,50° C,70°C.90°C and 98°C also by using a meter rule can measures the angle of deflection of a compass when a bar magnet is sliding on a ruler to approach the compass as shown in the procedures session. Collection of the data on the effect of temperature on the strength of magnets were made.

3. MATERIALS AND METHODS

3.1 The procedures that carried out the experiment is given under very normal room temperature, humidity and environmental conditions. The facilities used in these studies are generally those available under simple laboratory capacity. However, these studies will facilitate and attract further explorations on higher temperatures and complex experiments in future.

The following procedures and methods was carried out through

1. Set one magnet out on a table so that it reaches room temperature, as given below

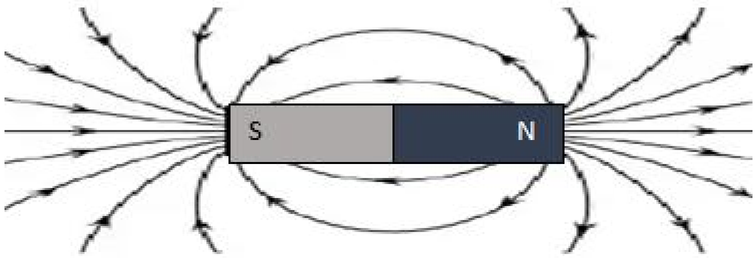


Fig.3. A Magnet

2. Place another magnet in a pot of boiling water for 45 seconds as shown below

3. Place the compass on a flat table so that the needle facing right

4. Turn the compass so the needle lines up with the ‘0.’ Tape the compass to the table.

5. Tape the ruler to the table so that its direction is perpendicular to that of the needle. The ‘0’ on the ruler should touch the ‘0’ on the compass.

6. Take a magnet (using tongs for the heated and cooled magnets) and slide it along the ruler towards the compass. You want the needle to move towards the magnet, so if it is moving away, flip it over.Other instrument (materials) used in this experiment which are tongs, thermometer and ruler

7. Take note of the distance between the magnet and the compass when the needle of the compass begins to move. Compare the distances you recorded for all of your magnets.

8. Repeat procedure 3, 6 and 7 for different temperatures such as 25^{o}C, 30^{o}C, 50^{o}C,70^{o}C, 90^{o}C, and 98^{o}C, the following results were obtained.

4. RESULTS AND DISCUSSIONS

The results of the deflections of the compass made by several distances at various temperatures are shown in Figures 4,5,6,7,8 individually and Fig.10 collectively corresponding to table.1.

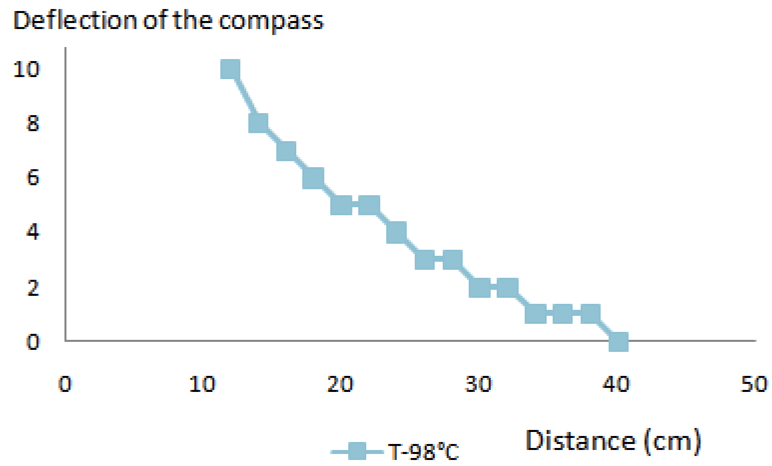


Fig 4. Results for the bar magnet at Temperature 90^{o}C.

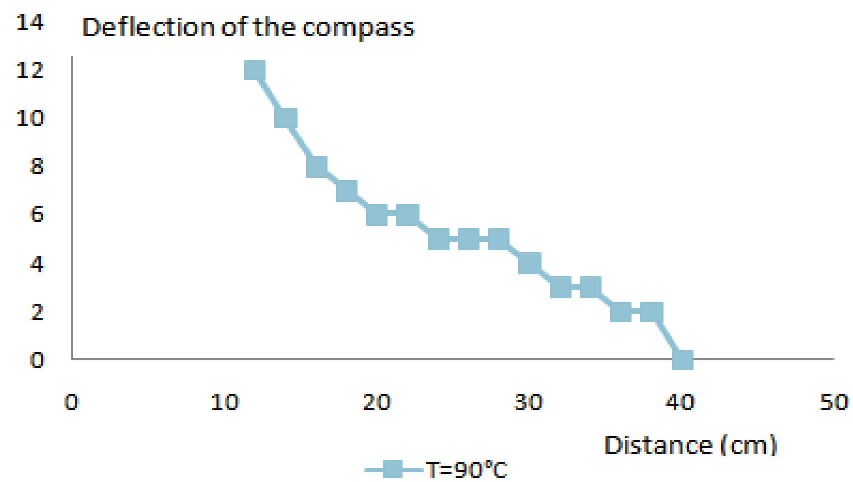


Fig5. Results for the bar magnet at Temperature 90^{o}C.

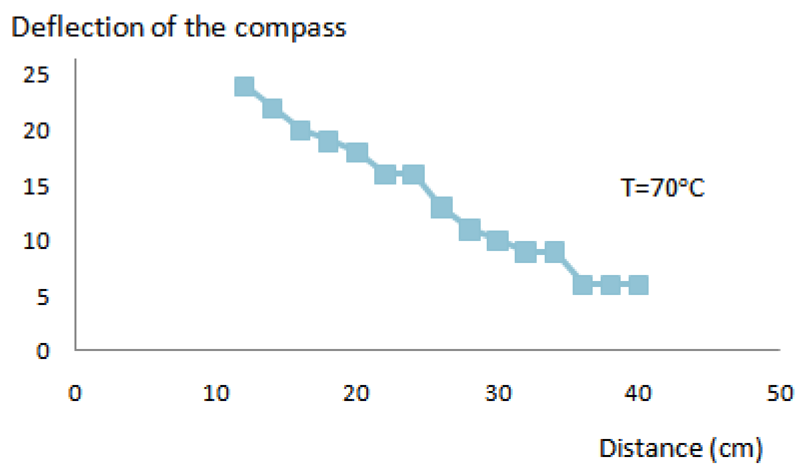


Fig6. Results for the bar magnet at Temperature 70^{o}C.

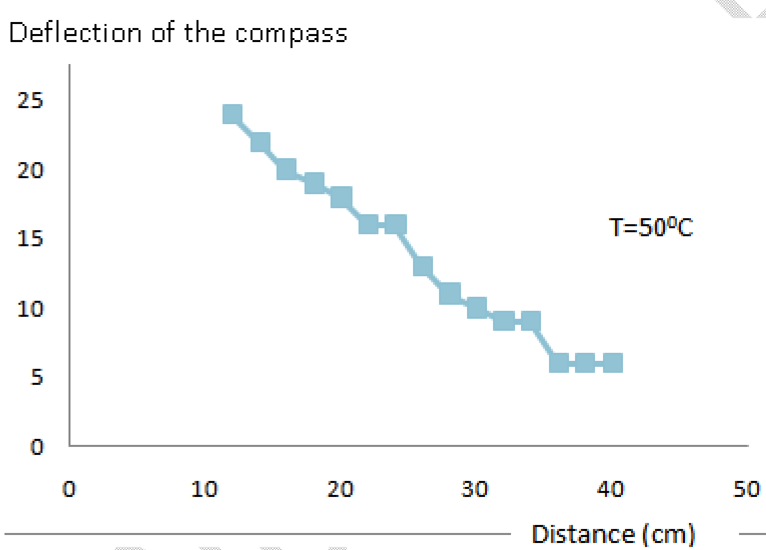


Fig.7 Graph of results for the bar magnet at temperature of 50^{o}C.

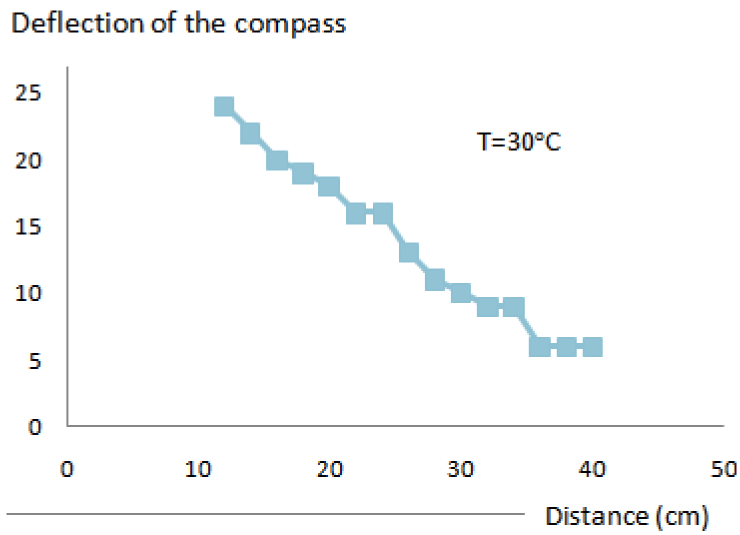


Fig 8. Graph of results for the bar magnet at temperature of 30^{o}C.

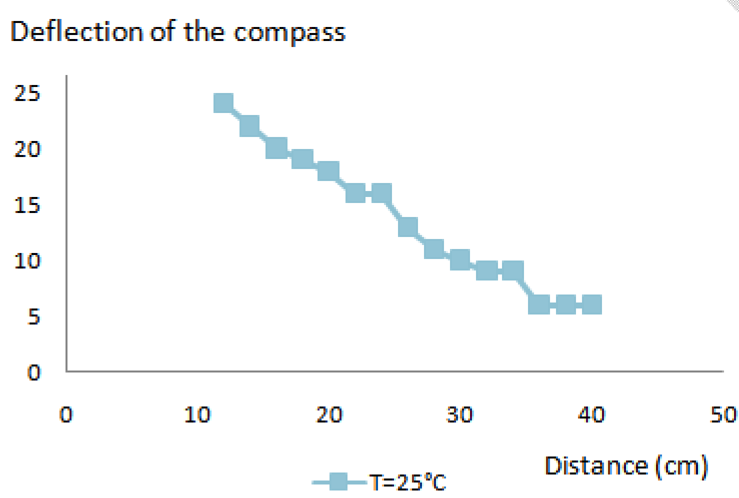


Fig.9: Graph of results for the bar magnet at temperature of 25^{o}C.

In generally the results and graphs are summarized in Fig.10.

From these results at the distance of 40cm the angle of deflection is 6 at a temperature of 25°C, from that as temperature increase at the same distance the angle of deflection decease for example at 70°C the angle of deflection is 3 which show that as temperature increases the strength of the magnet decrease. The graphs are shown in Fig.10.

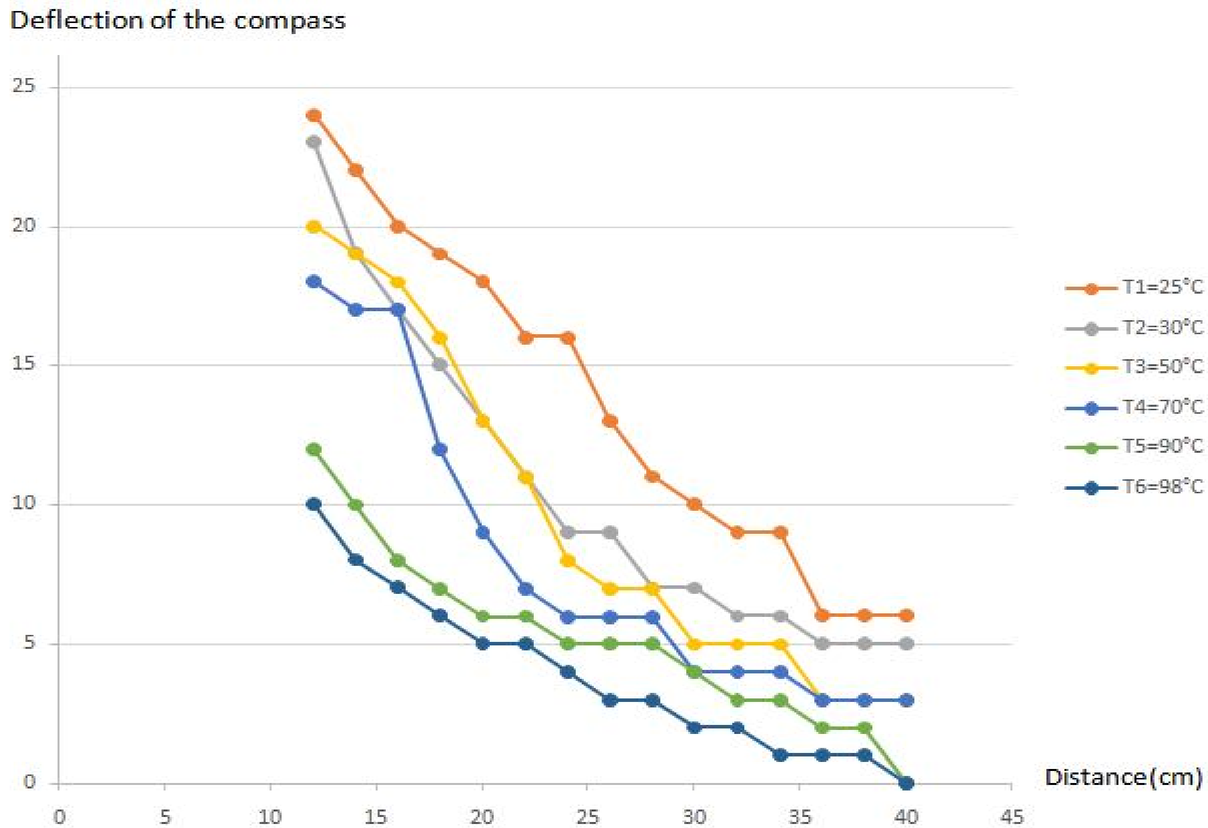


Fig 10. Results for the bar magnet at various temperatures (degree Celsius)

In order to discuss the temperature effects, the elemental atomic structure need to be d addressed which the magnet. Magnetism is affected by temperature either strengthening or weakening its magnetic properties of attraction. “A heated magnet has a reduction in magnetic field as the particles inside the magnet move at a faster speed and even sporadic rate. This environment misaligns the magnetic domains, resulting in the decrease of its magnetism. The opposite occur when a magnet is subjected to low temperatures, its magnetic property is enhanced and the strength increases.

On top of that the strength of the magnet and its demagnetization varies with temperature. Equally as strength of the magnet, also demagnetization resistance normally decreases with increase in temperature. The only exception is ferrite magnets, which easily demagnetize at low temperature and difficult to demagnetize at higher temperatures.

Various magnet materials respond differently with temperatures. Alnico magnets have the best strength stability followed by SmCo, NdFeB, and then ceramic. NdFeB magnets having the highest resistance to demagnetization (coercivity), but the largest change with temperature. Alnico magnets have the lowest resistance to demagnetization, but the smallest change with temperature. Alnico has the highest service temperature followed by SmCo, ceramic and then NdFeB"(Chenet al., 2018).

"Not everyone realizes that the shape of a magnet affects its maximum usable temperature. This is especially important for NdFeB magnets because they have the greatest change in demagnetization resistance with temperature. As the length of the magnetized axis increases, its resistance to demagnetization also increases"(Yu et al., 2020).

In everyday language, we usually refer to magnets, and materials that are attracted to magnets, as *magnetic*. Technically, these materials are called ferromagnetic. Not all metals are ferromagnetic. Try to pick up a copper penny or a piece of aluminum foil with your magnet. Does it work? The most common ferromagnetic metals are iron, nickel, and cobalt. They are special because at the microscopic level, they contain many tiny magnetic domains. Each magnetic domain is like a tiny magnet with a *north* and *South Pole*. Normally, the tiny magnetic forces created in those domains point randomly in all directions, so they cancel each other out, and as a result the material will not exert a magnetic push or pull on other ferromagnetic materials. However, when the material is placed in a strong magnetic field, the material gets magnetized, and all of these tiny magnetic fields line up, creating an overall larger magnetic field, as illustrated in Figure 11. To learn even more about magnets, find out about the Science behind(Popov et al., 2020).

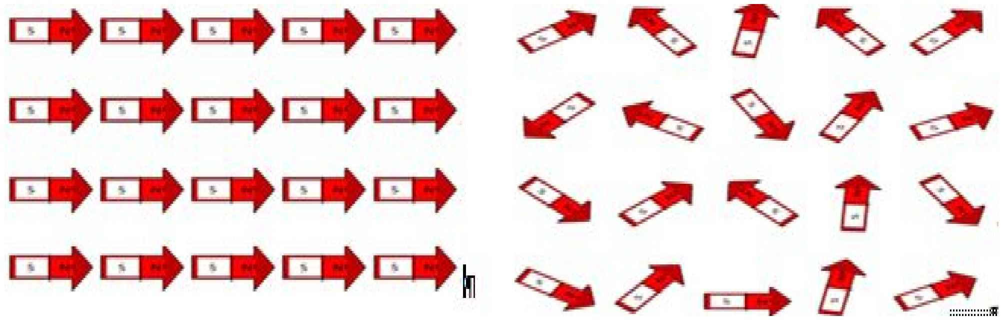


Figure.11. In ferromagnetic material, tiny magnetic domains act like tiny magnets. They can be oriented randomly in different directions, canceling each other out (right) or they can line up and all point in the same direction (left).

“When they line up, they combine and create a large magnetic force field, which allows the magnet to exert a magnetic force on other ferromagnetic materials(Fig.11).Scientists define the temperature of a material as a measure of random movement of atoms or molecules (the tiny particles the material is made of) within the material. Even when you see a solid block of metal, the atoms within this solid block are constantly vibrating back and forth. They move a little less when the block is cold and a little more when the block is warm. Because heating up the block increases the random motion within the metal, would it also affect the alignment of magnetic domains? If so, an increase in the temperature of a magnet would tend to decrease its strength. In fact, each ferromagnetic material has a *Curie temperature* (named after Pierre Curie), above which it can no longer be magnetized”(Mackieet al., 2018, Zhanget al.,2015).

“For some metals, like iron, the Curie temperature is over 1,300°C! Your oven at home might get as hot as 260°C, so obviously 1,300°C is out of the question for a science projects”(Romero et al.,2013,Feng et al. 2011,Ceshi and Zhenduan ,2024,Dai et al.,2022).

“But what happens to the strength of a magnet over a more approachable range of temperatures, like from the temperature of your freezer (about −20°C) to the temperature of boiling water (+100°C)? In this study it is found that, the magnetic field strength depends on temperature. The magnetic field strength decreases with an increase in temperature. With an increase in temperature, there is a misalignment in the domains. This decreases the magnetic field strength,Hansheng Chenet et al. 2018 suggests Attractive-domain-wall-pinning controlled Sm-Co magnets overcome the coercivity-remanence trade-off"(Chenet al.,2018, Zhouet al.,2023,Wang et al.,2023,Lyu, et al.,2022).

5. CONCLUSION AND RECOMMEDATION

Heating the magnet will cause the magnet to have weaker magnetic field, cooling the magnet will cause a magnet to have stronger magnetic field. Cool magnets can be far away from the compass than hot magnets when they make the compass needle move. The results of the testing show that the magnet at low temperature deflects the needle of the compass at high distance compared to the magnet at high temperature.

Magnetic materials should maintain a balance between temperature and magnetic domains (the atoms' inclination to spin in a certain direction). When exposed to extreme temperatures, however, these destabilized, magnetic properties are then affected, while cold strength magnet, heat can result in the loss of magnetic properties. In other words, too much heat can completely ruin a magnet. Excessive heat causes atoms to move more rapidly, disturbing the magnetic domains, as the atoms are speed up the percentage of magnetic domains spinning in the same direction decreases. This lack of cohesion weakens the magnetic force and eventually demagnetizes it entirely(Ceshi and Zhenduan,2024, Zhouet al.,2023,Wang et al.,2023,Lyu, et al.,2022), in contrast, when a magnet exposed to the low temperature, the atoms slow down so that the magnetic domains are aligned and, in turn, strengthened.

Temperature heavily impacts magnets. Permanent magnets like iron or neodymium lose all magnetism above the Curie point. Colder temperature improves their field strength.

In making magnets, you need find a group of magnetic atoms. These are the half-filled electron shells in the middle of the major blocks of the periodic table.Prepare a compound for the magnetic fields of the atoms with the same direction alignment. This is ferromagnetism, name given to magnetic iron.

It is possible for the atoms align to their magnetic fields in alternating directions. This is the anti-ferromagnetism where the material hasno magnetic field at all. At times the atomic magnets tend to align or anti-align is just too weak to overcome their temperature. All the individual atoms in the material can bemagnetic while the whole isn't.

However, In paramagnets a strong external magnetic field, the atoms do tend to align with each other in the direction parallel to the field., and liquid oxygen is among them.. It's attracted by a magnet, but doesn't stay magnetized afterwards.A material can only be ferromagnetic at low temperature. Above a certain critical temperature, the ordered atomic magnetic fields melt into disorder, in the same way ice crystals melt into water when heated past 0 Celsius.

So to destroy a magnet, you just need to heat it up above its magnetic melting point, called the Curie temperature. The atoms are moving in different direction at a very high speed around when heated at very high temperatures; their magnetic fields will no longer all point in the same direction. Magnet isthen destroyed(Yasui, et al.2024,Zhang, et al.2021,Zhang et al.2022, Romaguera et al. 2022).

. It is the future interest to look at the arrangements for High temperature electrical resistivity measurements of magnetic materials (Fecher, et al., 2022,Marelli, et al., 2024. Porée, et al., 2024 Sharma, and Maitra, 2023, RomagueraA., Medarde M.,2024)..

Low-magnetic-field magnetoelectricity at room temperature. Magnetic properties of highly ordered single crystals with layers(Zhao, et al.,2012,,Romaguera et al.,2023,Cheong and Xu,2022, Fecher, et al.,2022, Camps et al.,2023).and tuning magnetic spirals beyond room temperature with chemical disorder (Zhang et al.,2022, Morin et al.,2016, Hu et al.,2024,.Brooks et al.,2024)can then be studied..

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

Disclaimer (Artificial intelligence)

Authorhereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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