REVIEW PAPER ON DETERMINATION OF CURIE TEMPERATURE

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الملحص:

في هذا العمل, تم إقتراح عدة تجارب بسيطة لقياس درجة حرارة كوري باستخدام إمكانيات متوفرة مع التركيز على أستخدام الهاتف الذكي. إن الغرض الرئيسي من التجربة الأولى هو إستخدام الهاتف الذكيلتعرف على إعتماد مركبة المجال المغناطيسي على المسافة لعدة مغناطيسيات. حيث كانت النتيجة المتحصل عليها في هذا الجزء تأكد على العلاقة بين المجال المغناطيسسي والمسافة على الصورة x^{-3}

وهي على توافق كلي مع التحليل النظري. في الجزء الثاني تم قياس درجة حرارة كوري لسلك حلزوني من مادة فيرومغناطيسية حيث كانت درجة حرارة $1195K$

في التجربة الثالثة تم استخدام الهاتف الذكي لقياس درجة حرارة كوري لمغناطيس دائم , حيث كانت درجة الحرارة 378 K.

في التجربة الرابعة تمت قياس درجة حرارة (Stainless steel bolls) حيث كانت درجة كوري للكورة الصغيرة هي 898 K بينما بالنسبة للكورة الأخرى هي 973K كوري

ABSTRACT

In this work, we suggested several simple experiments to determine the Curie temperature using available apparatus, with concentration on use of Smartphone. The main purpose of the first practice is to use Smartphone to determine the dependence of the component x of the magnetic field produced by different magnets. The result obtained in this part confirm the dependence of the magnetic field with the distance takes the form x^{-3} , in total agreement with theoretical analysis. In the second practice we determined the Curie temperature of a ferromagnetic material in the form of the spiral-heating wire. With the voltage and current values for spiral wire equal to V=50.V, and I=3.2A, respectively, its surface temperature was found to be 1195 K. In the third practice where Curie temperature was determined using Smartphone magnetometer, the drawing of square magnetization(M^2) of the permanent magnet at various temperatures showing that the square magnetization decreases linearly with temperature, and will approach zero when the temperature increases to the Curie temperature. In our case the measurement results and calculation show that the Curie temperature ($T_{C.Approx}$) 378K. In the fourth practice where Curie temperature for ferromagnetic spheres were determined, we noticed that while the temperature of the spheres is above its Curie temperature , the spheres remains in contact with the thermocouple. When slowly falling temperature reaches T_C, the sphere recovers its ferromagnetic property and jumps to the magnet. The corresponding Curie temperatures , 898K for small sphere, and 973K for larger sphere.

KEYWORDS： Curie temperature, Curie point, ferromagnetic-,paramagnetic, magnetic moments

1.INTRODUCTION

The phenomenon of Curie point is well-known to physics students, its physical basis is explained in most general physics textbooks[1-2]. There are some elegant undergraduate experiments that investigate the ferromagnetic-paramagnetic phase transition. However most of the simple classroom demonstrations of this phenomenon are designed essentially for demonstrating the existence of the Curie point. The common method for ascertaining Curie temperature is by using a pendulum Curie point[3], or using a small magnet attached to a horizontal ferromagnetic wire. The Curie temperature(T_c)is named in honor of the French physicist Pierre Curie, who supposedly discovered it, in 1892, also called the Curie point, is the temperature at which magnetic material undergoes a phase transition from ferromagnetic to paramagnetic properties. The Curie temperature is about 770^0C(1043K) for soft iron and about 358^0C(631K) for nickel. In ferromagnetic materials, atomic magnets(magnetic moments) are spontaneously oriented in the same direction in each microscopic domain, resulting in a strong magnetic field . raising the temperature of ferromagnetic materials to the Curie point will interfere with various spontaneous arrangements, and only the weak type of magnetization remains, called paramagnetic[4-5].

In order to build our confidence in our work , hoping to lead us to more accurate results in studding this phenomena, we will start with three simple experiments. The first one will deal with using Smartphone to measure the magnetic field of permanent magnet as a function of a distance and discover this relation[6], while In the second experiment a long ferromagnetic wire, in the form of a spiral, is attracted to a strong permanent magnet placed near its midpoint[7]. The temperature of the wire is increased by passing a current through it, until the temperature reaches the Curie point , in which the wire becomes paramagnetic and is no longer strongly attracted to the magnet. In the third experiment a Curie temperature and Smartphone magnetometer was studied. While in the fourth experiment temperature for ferromagnetic spheres was investigated.

The main aim of this study is to design an experiment using simple available equipments including thermocouple, Smartphone, ferromagnetic spheres of different sizes, and permanent magnet to measure Curie temperature.

2. BASIC THEORY

2.1 Measurement of the magnetic field of a small magnet with a Smartphone

The x component of the magnetic field produced by a small magnet of length d and magnetic moment m at a point located at a distance x along the axis of the magnet see figure (1)is given by the equation[8].

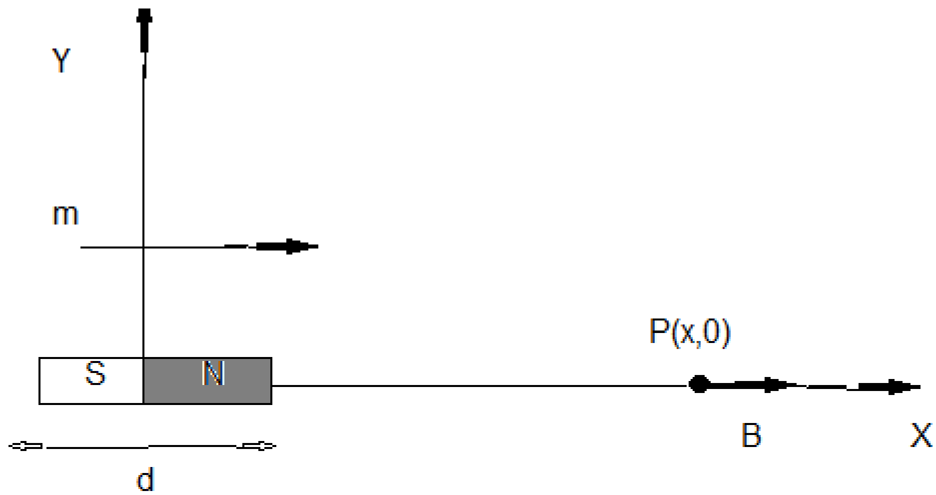


Figure 1. Small magnet of length d and magnetic moment m placed on the x-axis centered at the origin, and the x component of the magnetic field at a point P .

$$B = \frac{\mu m x}{2\pi(x^2 - d^2/4)^2} \quad \text{.........(1)}$$

where μ is the magnetic permeability of the free space(μ =4 π 10^{-7}N.A^{-2}). In the SI, the units of the magnetic moment of a magnet, m, are A.m^2. If we evaluate this magnetic field at a distance x, much larger than size of the magnet, d, we can simplify the previous result , taking into account of x>>d

$$B = \frac{\mu m}{2\pi x^3} \quad \text{.........(2)}$$

With these mathematical tools , we can measure the x component of the magnetic field of a small magnet as a function of the distance to the center of the magnet using Smartphone[9-11].

2.2 Curie Temperature for a Long Ferromagnetic Wire

Electrical energy W is delivered to the spiral wire at a constant rate P=VI, where V and I are, respectively, the potential difference across the wire and the current flowing through it. We may therefore write:

$$W = VIt \qquad \text{.........(3)}$$

where t is the amount of time the current has flowed. A portion of this energy increases the internal energy of the spiral wire, and another portion is radiated into the surrounding environment.

If a spiral of mass m and specific heat c is heated from an initial temperature T_0 to a higher temperature T, then the change in the internal energy of the spiral is given by:

$$\Delta E_t = mc(T - T_0) \qquad \text{.........(4)}$$

Furthermore, the energy radiated out of the spiral is given by[12]:

$$E_p = e\sigma S(T^4 - T_0^4)t \qquad \text{.........(5)}$$

where S and e are, respectively, the surface area and emissivity[9] of the spiral wire , and σ $=5.675\mathrm{x}10^{-8}\mathrm{W/m^2K^4}$ is the Stefan-Boltzman constant.

The energy balance equation for the spiral wire is:

$$W = \Delta E_t + E_p \qquad \text{.........(6)}$$

or

$$VIt = \Delta E_t + E_p \qquad \text{.........(7)}$$

After the spiral reaches a constant temperature, the ΔE_t term in Eq.(7) is equal to zero. Substituting Eq.(3) and (5), w obtain:

$$VIt = e\sigma S(T^4 - T_0^4)t \qquad \text{.........(8)}$$

if $T=T_c$ then:

$$T_c = \sqrt[4]{\frac{VI + e\sigma S T_0^4}{e\sigma S}} \quad \text{.....(9)}$$

2.3 Curie Temperature and Smartphone Magnetometer

For magnetism observation below that of Curie temperature ($T \ll T_c$), mean field theory (MFT) predicts that the magnetic field of the ferromagnetic material decreases with increasing temperature. The spontaneous magnetism behavior (magnetization, M) at the critical point (β) is given by the following equation[10]:

$$M \approx (T - T_c)^{\beta} \quad \text{.....(10)}$$

with β =1/2, using linear fitting, Eq.(10) should be

$$M^2 = aT - aT_C = aT + b \text{ with } T_C = -b/a \quad \text{.....(11)}$$

3. METHODOLOGY

3.1 Measurement of the magnetic field of a small magnet with a Smartphone

To carry out this experimental work we need to install an application that measures the magnetic field on our Smartphone. It is important to install an application that is able to measure the three spatial components of the magnetic field. On the internet, there are different apps that allow one to make these measurements. We recommend the Magnetometer app, which run on Smartphone with an iOS operating system[13].

Since the objective of this experiment is to determine the dependency of the magnetic field with the distance, we will consider only a component of the magnetic field, for example, the x component. The first aspect is to determine the direction of the XYZ Cartesian axes see figure 2, this will be done by bringing a small magnet to our phone in different directions and observe the component that varies.

Another relevant aspect to take into account is the position of the detector in the interior of the Smartphone. Once again, and on an experimental basis, we move the magnet slowly on the phone screen and note the position in which the total magnetic field is higher. At that point exactly, within the Smartphone, the magnetic sensor will be located.

As we know that the Earth itself is a magnet, with a magnetic field of the order of 50 μT , and will influence our measurements. To avoid having a background of this magnetic field, the only thing we have to do is to direct our Smartphone in a particular position when making measurements. Experimentally, we will turn the Smartphone slowly until we detect a position in which the value of the component of the magnetic field x is practically null, and we will call it B_{x0} . Later, we will have to add or subtract from our measures in function of it being negative or positive , respectively.

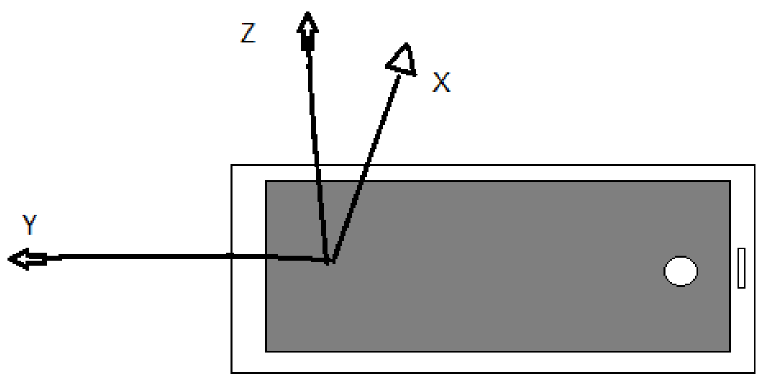


Figure 2. Orientation of the spatial axes on a Smartphone

Once we have taken into account all these preliminary adjustments, we can start performing our experiment, which is very simple . We place our Smartphone at a suitable orientation on a graph paper which is more convenient, and chose the corresponding x-axis of the phone that must pass through the sensor. Then we place the magnet at different distances and write down the value of the x component of the magnetic field provided by the application.

3.2 Curie Temperature for a Long Ferromagnetic Wire

The experimental setup used in finding the Curie point is shown in fig.(3). It consists of a ferromagnetic spiral-heating wire, taken from a heater brand Evsan (of diameter 0.42mm, and 1500mm length), stretched vertically between insulating clamps mounted on the support stand. A permanent magnet is placed near the middle of the support stand in such way that attracts the spiral wire. The spiral is connected to the output of a Variac.

Figure 3. Experimental setup.

The current through the wire is measured with the ammeter(A), and the potential difference across it with the voltmeter(V).

3.3 Curie Temperature and Smartphone magnetometer

The apparatus used in this experiment are:

- Small permanent magnet(usually used to demonstrate superconductivity

- Type K thermocouple(-270^{0}C-1260^{0}C with 0.3-cm diameter stainless steel probe)

-Smartphone(iPhone6) with magnetometer application from Magnetometer app[13]

- Some ice cubes , boiling water, and plastic cup as a water bath

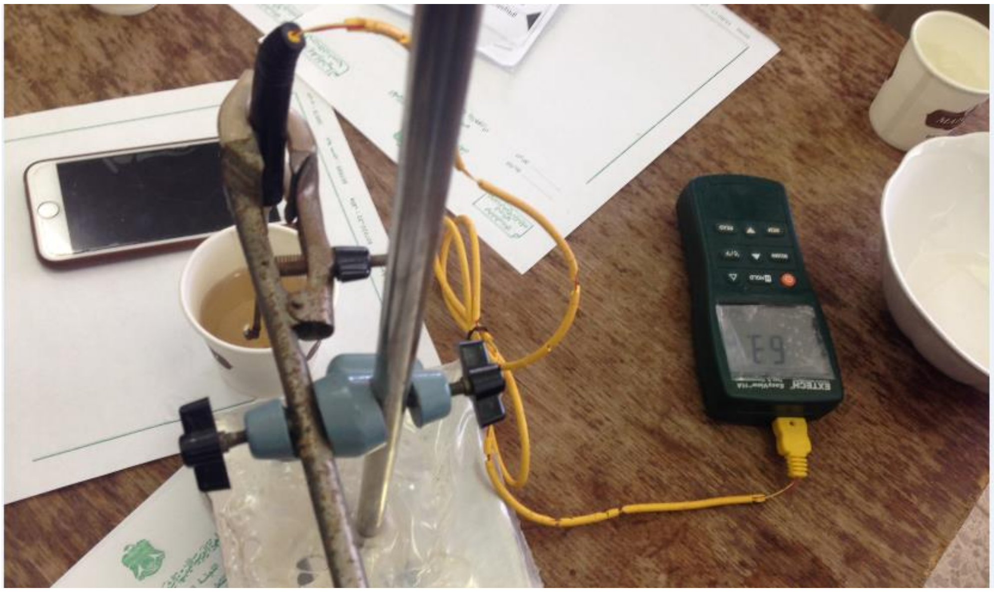


Figure 4. Photo of the setup consists of permanent magnet attached to thermocouple, Smartphone, plastic cub ice or hot liquid.

The thermocouple is attached to the permanent magnet so that the probe is close enough to measure the magnet temperature. The permanent magnet and thermocouple are placed in the plastic cup to be submerged in ice water or boiling water or hot oil see Fig.(4). The cool measurement is carried out by inserting some ice cubes into the plastic cup, and waiting until the magnet temperature decreases and stabilizes at 0^0C. Mean while, the hot measurements is carried out by inserting several milliliters of boiling water or hot oil into the plastic cup, and waiting until the magnet temperature increases and stabilizes. The relation of magnetic fields and temperature of permanent magnet was measured from hot or cool condition to room temperature naturally.

3.4 Curie temperature for ferromagnetic spheres

The major items needed to run this experiment is shown in Fig.(5) are:

- Two small stainless steel spheres (1.1cm , 2.2cm diameter). The spheres have radial holes 0.3cm in diameter and 0.5cm deep drilled into them.

- Type K thermocouple(-270^0C-1260^0Cwith 0.3-cm diameter stainless steel probe)

- Two sport stands

- Magnet in our case we used a bar magnet

-Stop watch

-Flame of the butane torch

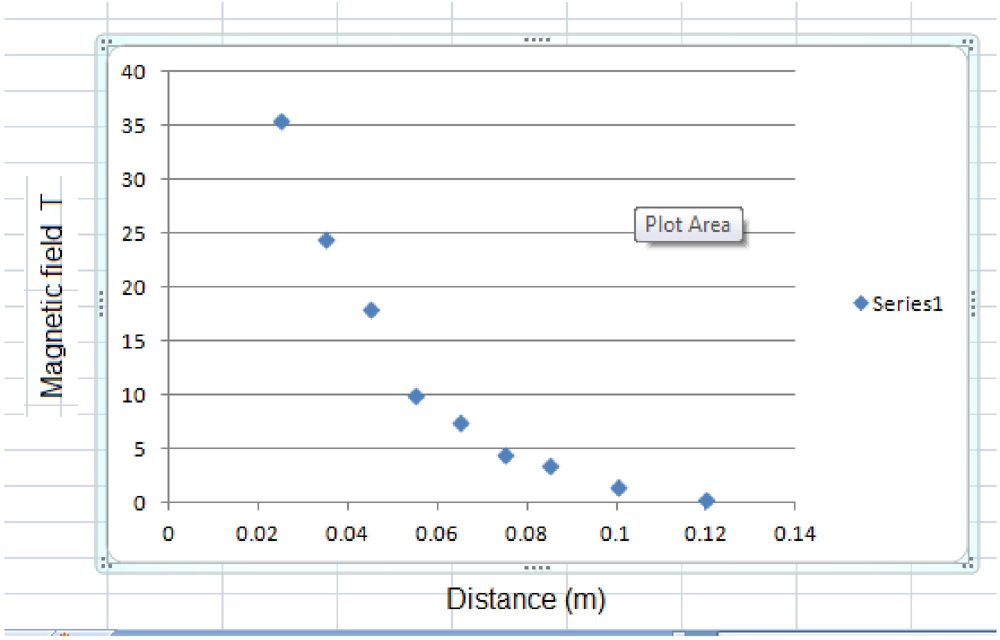
Figure 5. Photo of the experimental setup used to determine the Curie temperature of stainless steel spheres. The end of Type K thermocouple is inserted into a small hole in the sphere, the temperature of which is indicated.

The sphere is heated with the flame of the butane torch and raised above the metal's Curie temperature (~1173K). The torch is turned off, and the magnet is quickly moved close the sphere(~1cm). Now we start recording the thermocouple temperature once every five seconds. While the temperature of the material is above the Curie point , the sphere remains in contact with the thermocouple . When the temperature reaches T_C , the sphere recovers its ferromagnetic and jumps to the magnet. The end of the thermocouple is then free, and it cools very quickly due to the surrounding air, resulting in an abrupt change in the slope of the recorded cooling curve. This change makes it easy to identify the Curie temperature.

4. RESULT AND DISCUSSINS :

2.1 Measurement of the magnetic field of a small magnet with a Smartphone

In the fallowing sections, we will discuss the results obtained in each experiment. First we will start with the measurement of the magnetic field of a small magnet as a function of a distance using Smartphone



Figure(6). shows the experimental result of a magnetic field as a function of a distance .

Figure (6) shows the graphical representation of the data taken with the magnetic sensor of the Smartphone for the component x of the magnetic field B as a function of a distance . To develop some experience, we try to compare the fit of the curve of Fig.(6) with equation (2)

$$B = \frac{\mu m x^{n}}{2\pi}$$

If the theoretical model is correct, the value that is obtained for n should be approximately -3.

4.2 **Curie Temperature for a Long Ferromagnetic Wire**

The following table gives typical data obtained for the spiral wire.

Properties of Spiral wire
Diameter (D)=0.42mm $\pm$0.01
Length (l) =1500mm $\pm$1mm
Surface area (S) =1.98x10^{-3} $\pm$ 4 cm^2
Emissivity (e) =0.70
Voltage at Curie temperature = 50V
Current at Curie temperature =3.2A
Curie Temperature(T_C) =1195K

Substitution into Eq.(9) gives a value of Curie temperature T_C equals to 1195K. We would like to mention that we noticed a very nice phenomena in which the wire started vibrating in addition to its displacement away from the magnet, we suggest a future work to explain this phenomena.

4.3 **Curie Temperature and Smartphone magnetometer**

Fig.(7) shows the square magnetization of the permanent magnet at various temperatures. The line in the Fig(7) represent linear fitting of square magnetization. The gradient of the result has a negative value

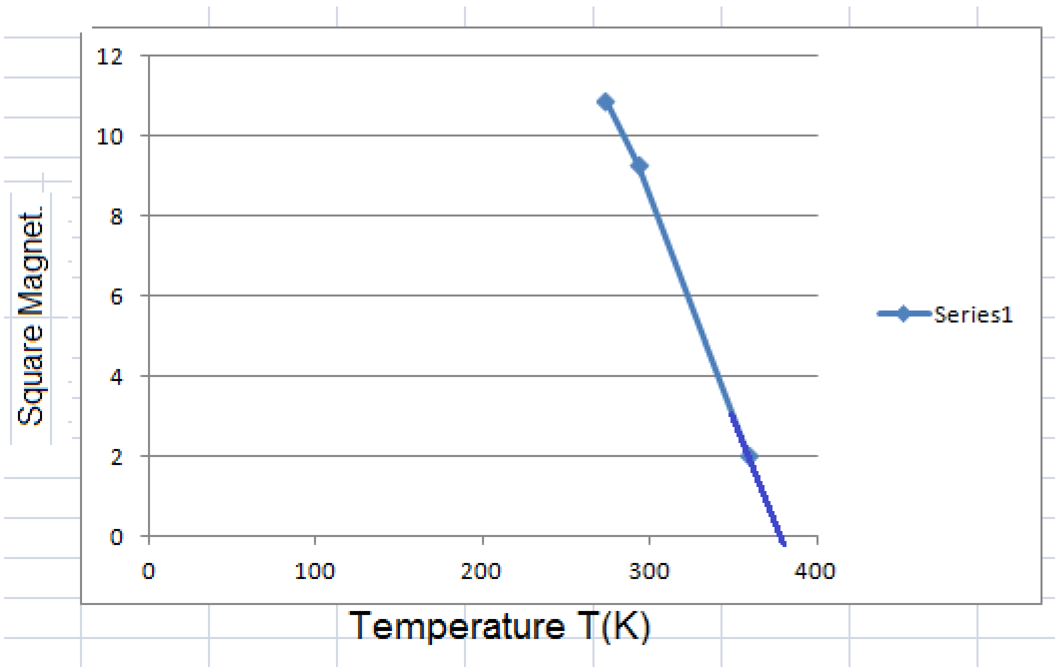


Figure7. magnetization (M^2) of the permanent magnet at various temperatures

Thus, spontaneous magnetization will approach zero when temperature increases to the Curie temperature . The slope from Fig.(7) a=-0.109, and Eq.(11) b=41.18, this will give

T_C = -b/a=378K

4.4 Curie temperature for ferromagnetic spheres

. Figure(8) shows the cooling curve s for the two spheres and the corresponding Curie temperatures (~898K) for small sphere (1.1cm diameter) , and (~ 973K) for larger sphere (2.2cm diameter).

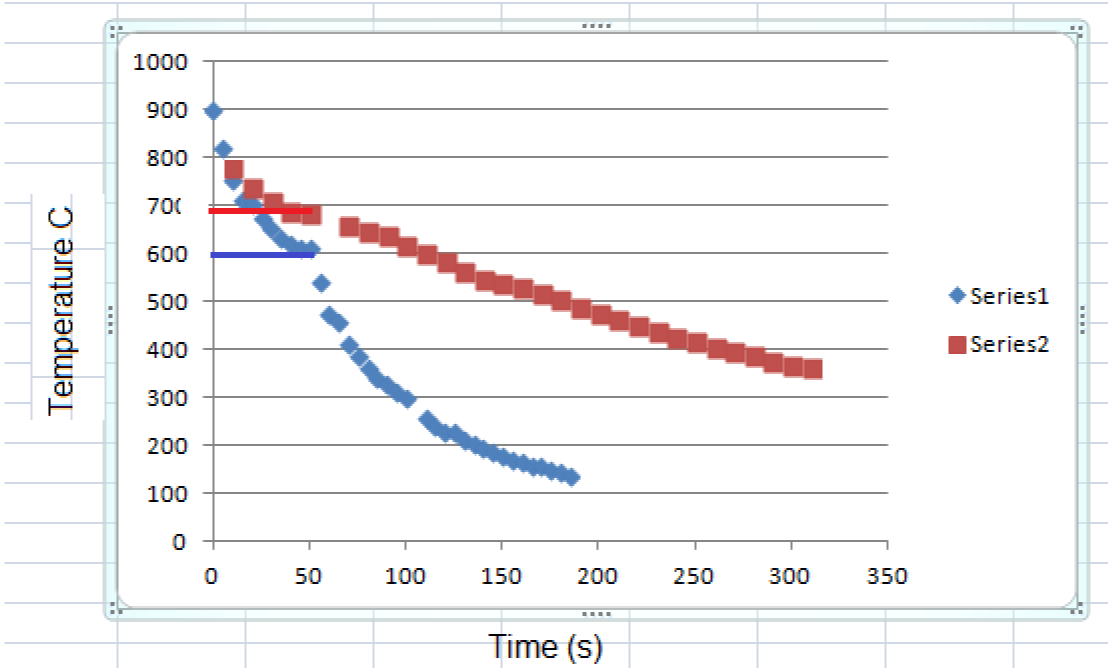


Figure (8) . Cooling curves for the two spheres . The change in the slop occurs when the sphere jumps off the thermocouple toward the magnet, indicating the corresponding Curie temperature (blue one for small sphere, red one for larger sphere).

5. CONCLUSSION

From this study we conclude the following

-We confirmed the dependence of the magnetic field with the distance takes the form x^{-3} , in total agreement with theoretical analysis.

- We determined the Curie temperature of a ferromagnetic material in the form of the spiral-heating wire. its surface temperature was found to be 1195 K.

- Curie temperature was determined using Smartphone magnetometer, the square magnetization (M^2) decreases linearly with temperature, and will approach zero when the temperature increases to the Curie temperature, and calculation show that the Curie temperature ($T_{C.Approx}$) 673K.

- The corresponding Curie temperatures were, 898K for small sphere, and 973K for larger sphere.

ACKNOWLEDGEMENT

We would like to acknowledge the technicians in biding six, and engineers in the electronic work shop at Tajura Research Center for their great collaboration in the design and construction phases of these experiments.

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13. This app can be downloaded from the following link:https://itunes.apple.com/esapp/magnetometer/id342782714?mt=8; this website was last visited 2014-12-31