Faraday's Lab Report

M. Garcia, C. Graham

University of Bath- Claverton Down, Bath BA2 7AY

Author Note

This report is intended to be submitted for grading by Manuchehr Soleimani as a part of the EE20085 Electromagnets Unit.

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Summary

The Report details the experimental findings of how using Faraday's law and Ampere's Circuital Law, it is possible to both show and use Faraday's law in a long wire experiment. The results returned the findings that using a lower frequency gave less accurate results as they were further from the theoretically calculated results but were also larger B field values at the same distance from the coil. Similarly, it was found that a ferrite core produced a larger B field vector at the same distance from the wires as one without a ferrite core. In addition, the experiment helped to model the B field of the two-wire cases.

Introduction:

The Faraday's Law Laboratory Exercise was conducted with the objectives of using Ampere's Law and Faraday's Law to calculate and examine the B field of long wires, and then compare these values to with experimental results. The lab consisted of using a search coil and a fixed long wire to calculate and experimentally compare by moving the search coil in the field with and without a ferrite core. From the experimental results and calculations, the B field was compared and analyzed to better understand the interactions between the components within the laws stated above. The ability to both use and understand Ampere's law and Faraday's Law is very important in many fields. These laws underpin many pieces of vital technology such as MRI machines [3], transportation using magnetic levitation [2] and charge accelerators [5].

Theory:

Ampere's Circuital Law and Faraday's Law are the main two essential theories that were explored in the experimental exercise. Ampere's Circuital Law demonstrates the relationship between magnetic flux density and the electric current in a loop. The law may be summarized as the closed integral of the magnetic field strength in a wire is equal to the sum of the amp turns enclosed by the path of integration and thus may be written as:

$$\oint H \cdot dl = \Sigma \text{ amp turns enclosed by the path of intergration}$$

The following equation can then be derived from this: $H = \frac{i}{2\pi R}$. Since wire being used in our experiments is situated in air, the team can substitute the following formula into the equation:

to then get $B = \frac{\mu_0 i}{2\pi R}$ (1).

One of the faults of Ampere's Circuital Law is that it requires a steady current in order to hold true. A steady current is a current which is either fixed or has symmetry.

Another important theory which was needed for this lab was superposition theory. When using more than one wire the magnetic flux density at a certain point in space can be calculated by summing the individual magnetic flux density from each wire together. Superposition works as magnetic flux density is a vector however it only works when everything involved is linear. This theory was therefore essential for when preforming calculations with two wires.

Faraday's law states that when there is a change in a magnetic field across an electrical conductor an electromotive force will be induced in the conductor assuming it is part of a complete circuit. The formula for faraday's law is as followed:

$$E = -N\frac{d\phi}{dt} \ (2)$$

Where E is equal to the electromotive force, N is equal to the number of loops in the circuit, $d\phi$ is equal to the change in the magnetic flux, dt is equal to the change in time. Now assuming that the coil is quite small relative to the other dimensions the team can write the integral $\phi = \int B \cdot ds$ as $\phi = BA$ where A is the area of the coil and B is the average magnetic flux density across the coil. If we now assume a sinusoidal variation of magnetic field, we can derive the following equation:

$$|E| = N\omega BA \ (3)$$

Method:

Part 1- Single wire experiment:

This part detailed a single wire experiment where a long wire board was connected to an Agilent signal generator with a 47-ohm resistor in series to protect the circuit. The team would have ideally like to use a infinitely long wire as this would give the most accurate results. This wasn't possible; to achieve that condition the apparatus that could offer a similar condition to an infinitely long wire would be too expensive. It is also worth noting that it is impossible to have an infinitely long wire. The team thus used a board fixed wire and connected a large wire that was draped away from the apparatus to ensure the wires non- fixed section would not interfere with the area the results were to be taken. The return connection was placed far away from the experiment. For the experiment the generator output was set to 20V at a frequency of 60kHz using the sin wave function. With these conditions the current remained a stable 72.34mA. With these conditions the rectangular search coil (coil has 50 turns and is a 30mm-by-30mm square) with the digital voltmeter, visible in [1]. The search coil is moved in the same plane as the wire and using the digital voltmeter the induced voltage (V) was recorded along with the distance (D) from the fixed wire in the board seen in table [1]. The team reasoned that there should be a measurable voltage induced in the search coil due to equation (2) which would indicate that as the coil is being moved through a magnetic field in a manner that a circuit cause a change of flux in a circuit. Therefore, there should then be an electromotive force measurable as the induced voltage in the circuit. The team would then plot using equation (3) to produce figure [1]. This was repeated with same conditions listed above but using a frequency of 30kHz from the generator.

Part 2- One wire calculation:

For this part of the one wire experiment Using the equation (1) for Ampere's Circuital Law the results were recorded in table [1] and then plotted in Figure [1].

Part 3- Zero volts for one wire experiment:

For this part the team placed the coil in a position where the normal to the coil is parallel to the coil. To see if the digital voltmeter would read 0V induced at the coil.

Part 4- Effect of a Ferrite Core on one wire experiment:

For this part the method detailed in Part 1 was repeated. However, in this iteration a ferrite core was added to the center of the search coil.

Part 5- Two wire experiment:

For this part the method detailed in Part 1 was repeated. However, in this iteration the team used a two wire loop together as detailed in figure [2].

Part 6- Two wire calculation:

For this part the team used equation (1) and the theory of superposition to calculate the B field along the same line of measurement used in part 5 and producing the table [2] and the figure [2].

Results:

Part 1:

For this part of the experiment the team first gained a measured resistor voltage of 3.4V and a resistor current of 0.07234A (the wire has the same current as the resistor is in series with the generator and wire). From this, the figure [1] was produced displaying an inversely proportional relationship between B of the field and R from the wire increases of the magnitude of the B field at those points. This does concur with the theory, as due to equation (1) when plotting The field B of the search coil's movement (the distance D from the wire) it should show an inversely proportional trend as implied from the equation which states that the magnetic field strength, B, is equal to a constant multiplied by the reciprocal of the radius, r. This may be explained by experimental error such as not moving the coil correctly. However, it is the team's opinion that this error may more likely be caused by unideal conditions. For example, there are background electromagnetic fields that can interfere (EMI).

Part 2:

This part produced table [1] and the figure [1]. From this data the experimental values for the B field are higher than that calculated using equation (1). There are many reasons this may have occurred. There could be many sources of error that could lead to this noticeable difference in experimental B field values to theoretical values. Most notably the team identified background EMI of the ambient electromagnetic fields as being major factor in the distinct difference.

Part 3:

For this part of the experiment, as expected, the voltage value the team obtained for the coil when the normal to the coil was parallel to the wire was zero. The reason why this is the case is because an EMF can only be induced in a conductor by the magnetic field when the conductor cuts through the magnetic field lines where the maximum current induced is when the conductor is perpendicular to the field lines. The normal of the coil is thus parallel to the field it is trying to interact with a thus no EMF is read.

Part 4:

As the team can see when comparing the results in figure [3] with the use of a ferrite core to the results in without the use of a ferrite core the results show that the presence of a ferrite core leads to a larger electromotive force being induced, as compared to using a coil without a ferrite core, as the magnetic flux density is greater at each point. This is what the team would expect as the ferrite core dipoles align to the magnetic field which adds to the magnetic field. Moreover, the team can see that when a sine signal wave frequency of 30hz is used the magnetic field density is greater and that the difference between the results using the ferrite core and results which aren't is also greater. In addition, the team can also see as seen in part 1 that the use of a 60hz sine signal wave frequency gives more accurate set of results compared to when a 30hz sine signal wave frequency is used.

Furthermore, a ferrite core can act as a band-pass filter [1]. A ferrite core has a high magnetic permeability and acts to concentrate the field in the core itself thus reducing the impact the noise will have. The concentrated field within the core will increase as the frequency increases and therefore the core acts as a low-pass filter that blocks high-frequency current, enabling attenuation of high-frequency noise.

Part 5:

For this part of the experiment the voltage and current across the resistor are the same as in the previous parts. For when using a wave signal frequency of 60hz the following results were produced figure [2]. As the team can see these results correlate much better with the results produced from using the theory compared to the results produced from the using a single wire. Furthermore, the team can see that as before with a single wire, with two wires the results produced using a 60hz wave signal frequency are much closer to the results produced from using the theory compared to the results produced using a 30hz wave signal frequency.

Part 6:

Using the equation $B = \frac{\mu_0 i}{2\pi R}$ and superposition theory the team can calculate B which is shown in figure [2]. Superposition can be seen through figure [4] the search coil is being affected by the fields produced by both wires hence the fields interaction with each other giving a non-circle rounded regions. It is important to note that when using superposition to calculate the B field in the two wires the wires where measured to be 10mm from each other, thus the second wire is at reference +10mm from the other wire which is set to reference distance of 0mm.

It can be seen see these results produced using two wires correlate much better with the results produced from using the theory compared to the results produced from the using a single wire. Furthermore, we can see that as before with a single wire, with two wires the results produced using a 60hz wave signal frequency are much closer to the results produced from using the theory compared to the results produced using a 30hz wave signal frequency.

Conclusion:

In conclusion, the experiment yield results for both the single wire and two wire experiment that concurred with the theory. This was seen in the inversely proportional relationship of the B field and the distance from the wire of the search coil, the zero volt wire experiment giving 0 volts, and the ferrite core giving larger results than that of its non-ferrite counterpart. The team identified EMI as being a major source of error and would suggest using ferrite cores when trying to reduce noise of search coil when used in practical application to ensure more accurate results. Although the experimental values were much larger than the theoretical values it can likely be explained with this EMI interaction. From the experiment it was found that the larger frequency of 60kHz gave a result closer to the theoretical value but was also smaller than the 30kHz results.

Reference:

1. Anon, 2020. Basics of noise countermeasures [Lesson 8] Ferrite Cores | Murata Manufacturing Articles. [online] Murata Manufacturing Articles. Available from: https://article.murata.com/en-eu/article/basics-of-noise-countermeasures-lesson-8 [Accessed 27 Nov. 2020].

2. Anon, 2020. How Maglev Trains Work. [online] HowStuffWorks. Available from: http://science.howstuffworks.com/transport/engines-equipment/maglev-train.htm [Accessed 27 Nov. 2020].

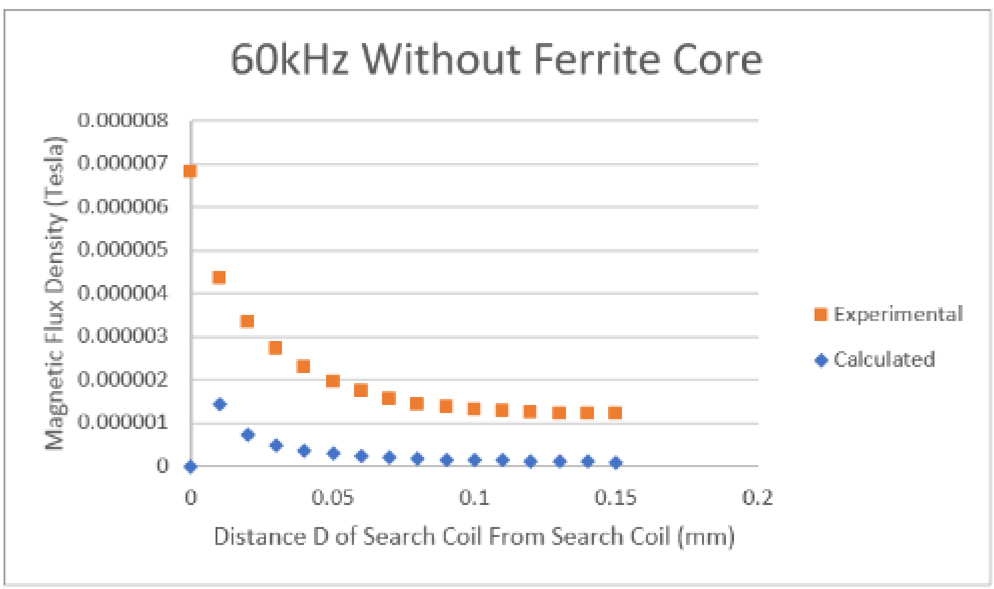
3. Anon, 2020. Teaching Medical Physics. [online] IOPSpark. Available from: https://spark.iop.org/collections/teaching-medical-physics [Accessed 27 Nov. 2020].

4. Anon, 2020. University of Bath. [online] Moodle.bath.ac.uk. Available from: https://moodle.bath.ac.uk/pluginfile.php/489587/mod_resource/content/1/Faraday_s_Lab.pdf [Accessed 27 Nov. 2020].

5. Anon, 2020. What Are The Uses Of Electromagnets? - Universe Today. [online] Universe Today. Available from: http://www.universetoday.com/39295/uses-of-electromagnets/ [Accessed 27 Nov. 2020].

Figures:

Figure 1:



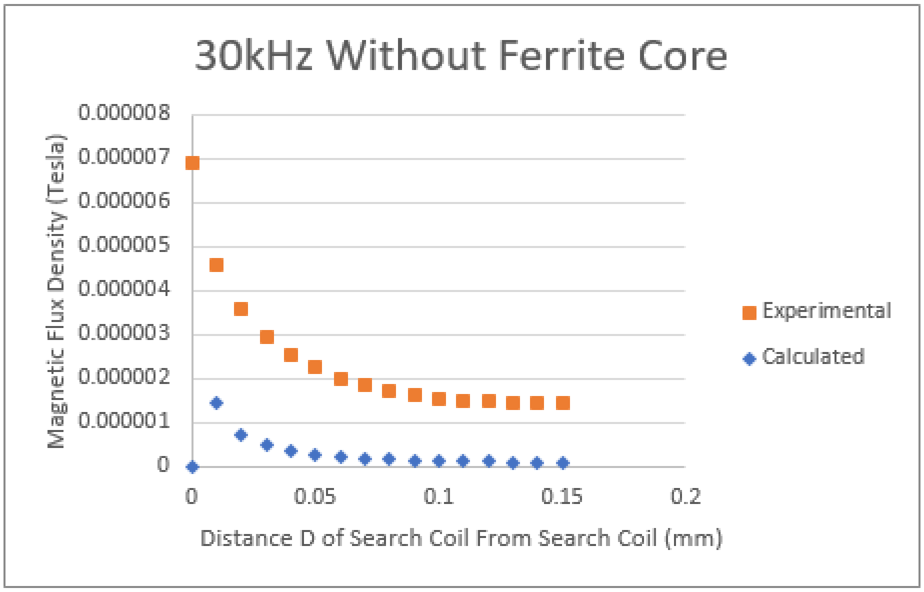
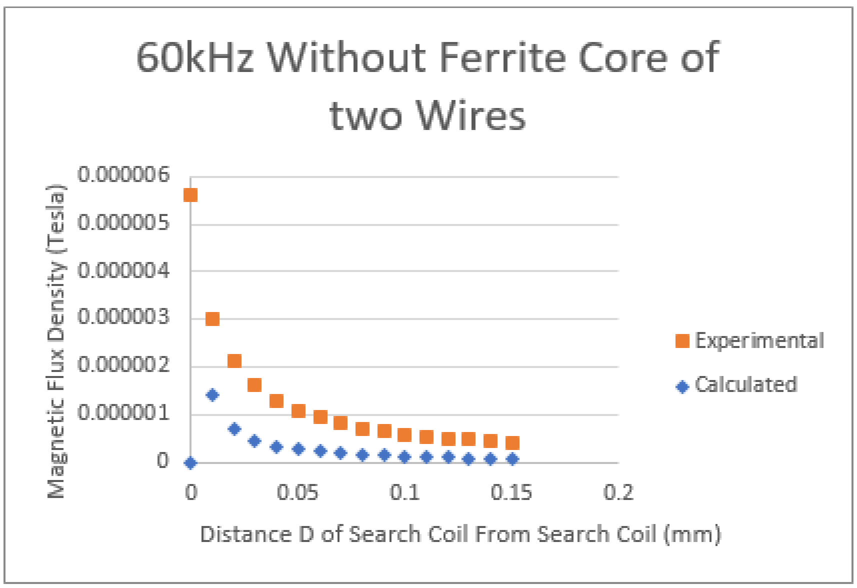

30kHz Without Ferrite Core
Magnetic Flux Density (Tesla)
0.000008
0.000007
0.000006
0.000005
0.000004
0.000003
0.000002
0.000001
0
0
0.05
0.1
0.15
0.2
Distance D of Search Coil From Search Coil (mm)
Experimental
Calculated

Figure 2:


60kHz Without Ferrite Core of two Wires
Magnetic Flux Density (Tesla)
0.000006
0.000005
0.000004
0.000003
0.000002
0.000001
0
0
0.05
0.1
0.15
0.2
Distance D of Search Coil From Search Coil (mm)
Experimental
Calculated

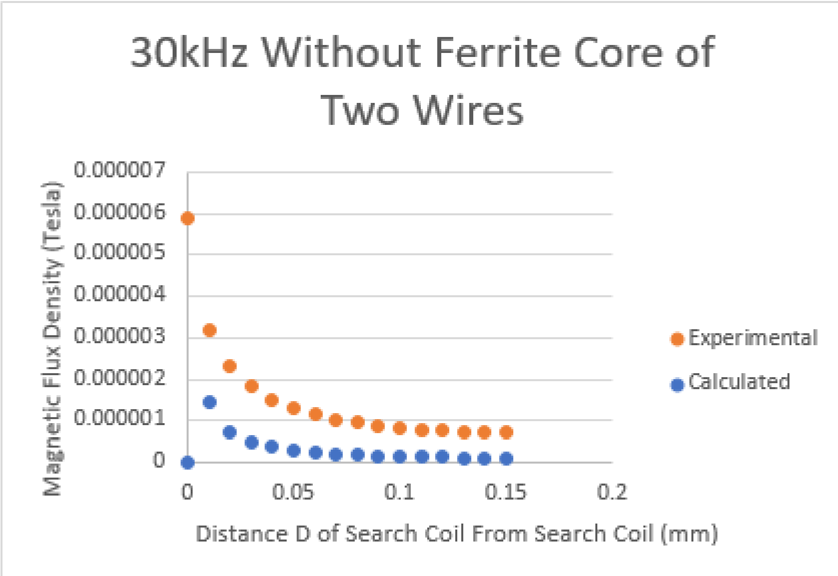


Figure 3:

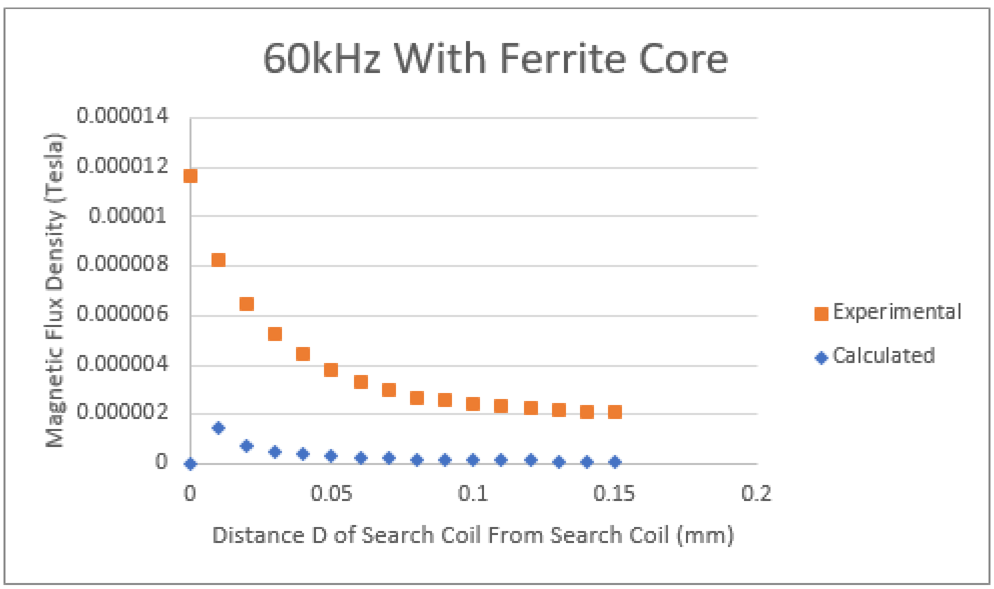
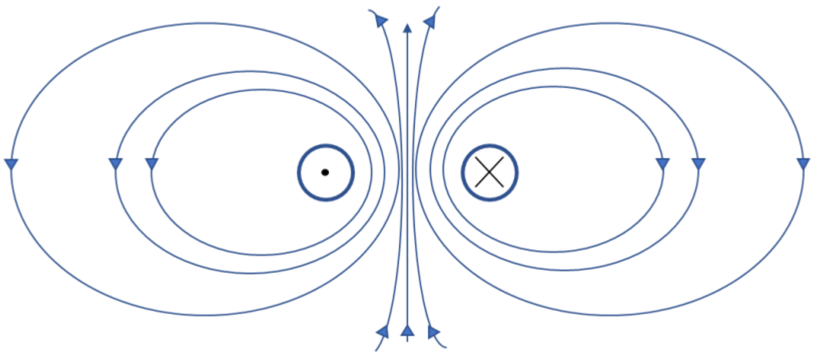


Figure 4: A sketch of the magnetic field around in the two wire experiment.



Tables:

Table 1:

D/m	60KHz V/mV without Ferrite Core	B	Calculated B
0	18.4	6.81481E-06	#DIV/0!
0.01	11.8	4.37037E-06	1.4468E-06
0.02	9.05	3.35185E-06	7.234E-07
0.03	7.35	2.72222E-06	4.82267E-07
0.04	6.19	2.29259E-06	3.617E-07
0.05	5.31	1.96667E-06	2.8936E-07
0.06	4.7	1.74074E-06	2.41133E-07
0.07	4.2	1.55556E-06	2.06686E-07
0.08	3.87	1.43333E-06	1.8085E-07
0.09	3.7	1.37037E-06	1.60756E-07
0.1	3.58	1.32593E-06	1.4468E-07
0.11	3.46	1.28148E-06	1.31527E-07
0.12	3.39	1.25556E-06	1.20567E-07
0.13	3.34	1.23704E-06	1.11292E-07
0.14	3.31	1.22593E-06	1.03343E-07
0.15	3.29	1.21852E-06	9.64533E-08
30KHz			

D/mm	30KHz V/mV without Ferrite Core	B	Calculated B
0	9.37	6.94074E-06	#DIV/0!
0.01	6.22	4.60741E-06	1.4468E-06
0.02	4.85	3.59259E-06	7.234E-07
0.03	4	2.96296E-06	4.82267E-07
0.04	3.46	2.56296E-06	3.617E-07
0.05	3.1	2.2963E-06	2.8936E-07
0.06	2.73	2.02222E-06	2.41133E-07
0.07	2.5	1.85185E-06	2.06686E-07
0.08	2.33	1.72593E-06	1.8085E-07
0.09	2.22	1.64444E-06	1.60756E-07
0.1	2.1	1.55556E-06	1.4468E-07
0.11	2.04	1.51111E-06	1.31527E-07
0.12	2.03	1.5037E-06	1.20567E-07
0.13	1.98	1.46667E-06	1.11292E-07
0.14	1.96	1.45185E-06	1.03343E-07
0.15	1.95	1.44444E-06	9.64533E-08

Table 2:

60KHz			
D/m	60KHz V/mV without Ferrite Core	B	Calculated B
0	15.1	5.59259E-06	#DIV/0!
0.01	8.2	3.03704E-06	1.4468E-06
0.02	5.73	2.12222E-06	7.234E-07

0.03	4.42	1.63704E-06	4.82267E-07
0.04	3.56	1.31852E-06	3.617E-07
0.05	2.99	1.10741E-06	2.8936E-07
0.06	2.58	9.55556E-07	2.41133E-07
0.07	2.24	8.2963E-07	2.06686E-07
0.08	1.99	7.37037E-07	1.8085E-07
0.09	1.79	6.62963E-07	1.60756E-07
0.1	1.64	6.07407E-07	1.4468E-07
0.11	1.51	5.59259E-07	1.31527E-07
0.12	1.41	5.22222E-07	1.20567E-07
0.13	1.33	4.92593E-07	1.11292E-07
0.14	1.27	4.7037E-07	1.03343E-07
0.15	1.21	4.48148E-07	9.64533E-08
30KHz			
D/m	30KHz V/mV without Ferrite Core	B	Calculated B
0	7.96	5.8963E-06	#DIV/0!
0.01	4.3	3.18519E-06	1.4468E-06
0.02	3.13	2.31852E-06	7.234E-07
0.03	2.47	1.82963E-06	4.82267E-07
0.04	2.04	1.51111E-06	3.617E-07
0.05	1.73	1.28148E-06	2.8936E-07
0.06	1.53	1.13333E-06	2.41133E-07
0.07	1.38	1.02222E-06	2.06686E-07
0.08	1.27	9.40741E-07	1.8085E-07
0.09	1.17	8.66667E-07	1.60756E-07
0.1	1.11	8.22222E-07	1.4468E-07
0.11	1.04	7.7037E-07	1.31527E-07

0.12	1.02	7.55556E-07	1.20567E-07
0.13	1	7.40741E-07	1.11292E-07
0.14	0.99	7.33333E-07	1.03343E-07
0.15	0.98	7.25926E-07	9.64533E-08