PHY2004W: PHYLAB 2
Experimental Physics Lab Session
Skin Depth in Conductors

1 Introduction

In the present experiment you will investigate the screening of an alternating electromagnetic field (produced by an alternating current in a circular coil), and observe the phenomenon of "skin depth" in conductors. Before doing the experiment read up some background material on the various points mentioned below.

2 References

Most books on electromagnetism have something on this subject.
Griffiths, *Introduction to Electrodynamics*, pp 370-372 and Purcell, *Electricity and Magnetism*, sections 6.5 and 6.6 in particular.
Pollack and Stump, *Electromagnetism*, Addison-Wesley (2002): 10.2, 8.3, 8.7, 13.3.
Am. J. Phys. **56** (1988) 989.

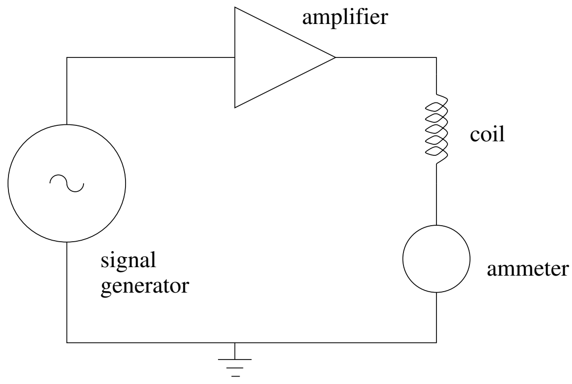
3 Emphasis

New concepts, measurement skills, connection of circuits, manipulation of measured data to infer magnetic field, graphical analysis.

4 Equipment

The pair of large circular coils provided, each have 80 turns. They are connected in series in such a way that the field at the centre is a maximum. Alternating current for the coil is obtained from the signal generator and wideband power amplifier. A digital ammeter **in series** is included in the circuit to measure the current in the driving circuit. Note that the meter is calibrated to read rms current.
Note also that the meter must be connected in series in the circuit — connecting it in parallel across the coil may damage the meter. (More precisely: a rather expensive fuse will blow, and the meter will not work until it has been repaired.)

The current needs to be adjusted during the experiment, with it as high as possible, without distorting the sinusoidal waveform observed on the oscilloscope, but we can not exceed 1A or the coils will heat up too much. The signal generator is kept fixed at $2\,\mathrm{V}_{pp}$, else clipping of the sin wave is observed. The master volume is used to vary the current.



The magnetic field is alternating at the frequency determined by the signal generator. The field may be be conveniently determined by means of the emf induced in the small coil, which has 200 turns. The amplitude of this emf may be measured on the oscilloscope. You will have to apply Faraday's law of induction to determine the amplitude of the field.
Watch the following video of the setup of the experiment **Setup** Skin01

5 Instructions

5.1 The coils.

The two large coils are in a Helmholtz arrangement which provides a reasonably uniform field at the centre of the pair. These should be connected in series so that the field in the centre is a maximum. The coils are driven by an alternating current from the output of the amplifier.
The theoretical expression for the magnitude of the magnetic field on the axis of a circular coil of radius a is

$$B = \frac{\mu_0 N I}{2} \frac{a^2}{(a^2 + z^2)^{3/2}}$$

where z is the distance to the centre of the coil, N is the number of turns in the coil and $I = I_0 \cos \omega t$ the current in the circuit.
The emf induced in the axial coil by an alternating magnetic field is

$$\epsilon = -N_a \frac{d}{dt} \int \mathbf{B} \cdot d\mathbf{A} \approx -N_a A \frac{dB}{dt}$$

where N_a is the number of turns in the coil, A is the cross-sectional area and B is the component of the field normal to the area. Note that the emf is proportional to the time derivative of the field. The field is varying sinusoidally because the current is varying sinusoidally. You can use this fact and the above expressions to relate the amplitude of the emf to the amplitudes of the field and current. You will see that these amplitudes are all proportional to one another. The frequency of the quantities can be read from the signal generator and accurately measured using the osciliscope.

5.2 Skin depth.

When a conducting body is introduced into a time varying magnetic field, induced currents tend to reduce the magnetic field in the body. If a uniform field is set up at the surface of an infinite sheet of conductor the field in the conductor will have the dependence

$$B(z) = B(0)\exp(-z/\delta)$$

where z is the distance from the conductor surface and δ is a length known as the skin depth, given by $\delta = \sqrt{2/\mu\sigma\omega}$ where μ is the permeability of the medium, σ is its conductivity, ω is the angular frequency of the field B and $B(0)$ is the amplitude of the field without any conductor in place .

In this experiment a cylindrical geometry is used. For this geometry, the screening by a metal tube is given by

$$B(d) = B(0)\frac{1}{\sqrt{1 + (Rd/\delta^2)^2}}$$

where R is the inner radius of the tube and $R + d$ is the outer radius. $R = (20 \pm 0.1)\,\mathrm{mm}$ and $d = (1 \pm 0.1)\,\mathrm{mm}$

To observe the effect of screening, we vary the frequency over the range from, 100 Hz to 5 kHz.

Exercise 1 - If we supply a DC current instead of an AC current we will generate a DC field. With the conductor still act as a shield. Explain your answer carefully to be awarded full credit

For each frequency we measure the field with and without the presence of the copper tube over the measurement coil. The ratio of $B(d)/B(0)$ can then be plotted as a function of frequency. By fitting the above theoretical expression to the experimental plot, the value of σ can be obtained. You will need the value of R and d.

Watch the following video to see the procedure taken to capture the data **Procedure** Skin02

The data to be analysed is given here: **Skin Data Text** DATA01 or **Skin Data Excel** DATA01. There are three columns of data. The first is the frequency in [Hz], the second the voltage of the detector coil with no shield (NS) in [V] and the third the voltage of the detector coil with shield (WS) in [V]

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