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KSCIQTE Quincks Tube Experiment

Measurement of paramagnetic volume susceptibility of a sample by Quinck's tube method.

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1. Key concepts

- Theory of magnetism
- Para magnetism

2. Introduction

The phenomena of magnetism were recorded for the first time by the Greeks around 800 B.C. According to a legend, a shepherd strolling about the hills in the region of Greece called Magnesia experienced that nail in his shoes and the tip of his walking staff getting stuck to a particular type of rock. The hypothesis is the rock contained magnetic ore FeO or Fe_2O_3 . These, naturally occurring ores of Fe have natural tendency to attract objects made of iron and steel. And historically, these ores were mined in the above-mentioned region to be used as a lodestone (leading stone/compass), and the phenomena was given the name magnetism.

The first recorded scientific investigation into magnetism was conducted by William Gilbert in 1600 and published in his book titled 'On the magnet'. In 1820 Hans Christian Oersted discovers that passing an electric current through a conductor produced a magnetic field. The studies on magnetic properties of different elements and compounds reveled that there are different types of magnetic behaviors exhibited in nature.

- Ferromagnetism
- Para magnetism
- Diamagnetism
- Ferrimagnetism
- Anti-ferromagnetism

During the time period of (1890-1910) Many theories using classical mechanics were put forward to explain the phenomena of magnetism. Pierre Curie proposed to Curie law to explain Para magnetism, Langevin proposed theory for the behavior of diamagnetism and Para magnetism, and Weiss proposed a molecular field theory of ferromagnetism. All these were based on classical mechanics and were not able to explain the experimental observations.

After the advent of Quantum mechanics, P.A.M Dirac and Werner Heisenberg independently proposed theories that took into account the electro spin and exchange interactions. And were able to give theoretical modes and explanations to the magnetic phenomena from the first principles.

The principal contributors to the magnetic Moment of a free atom are

- Electrons' spin angular momentum.
- Electrons' orbital angular momentum.
- Change in orbital momentum induced by an applied magnetic field.

The study of magnetism and in particular magnetic properties of various materials have, facilitated major advances and inventions in the fields of data storage, imaging, design of novel materials etc.

3. Objectives

- To measure the magnetic susceptibility of a given paramagnetic sample ($FeCl_3$).

4. Theory

$$M = \chi H \qquad (1)$$

Magnetic susceptibility:

When a magnetic material is placed in an external magnetic field, the material gets magnetized. The magnetization is induced by the applied external field H, the dipole moment per unit value of the sample is described by the magnetisation vector $\boldsymbol{M}$. It is observed that $H$is proportional to M.

The proportionality constant χ is called the magnetic susceptibility of the material.

Magnetic materials can be classified into three different types, depending on the magnetic ordering, magnitude and temperature dependency of χ.

In paramagnetic materials χ has a positive value (i.e $\boldsymbol{M}$is parallel to direction of $\boldsymbol{B}$). The value of χ is small $10^{-4} to 10^{-5}$. Ions belonging to transition metals and rear-earth elements are paramagnetic in nature. Owing to the fact that these ions have incomplete atomic shell.

Quicke's tube method

This method is best suited for measuring magnetic susceptibility of liquid samples. When a solution of a paramagnetic substance is filed in a capillary tube and is places between the poles of a magnet, there is an increase in the height of liquid in the capillary tube. This is due to the fact that for a paramagnetic material, $M$and $B$are parallel to each other.

The potential energy of an atom places in the magnetic field is given by equation 2.

$$E = \mu B \qquad (2)$$

Where μ is the effective magnetic moment along the direction of the magnetic field. For bulk samples, energy per unit volume of the substance containing N atoms per unit volume will be $E = (N\mu) = MB$.

The force F acting on the unit volume of the sample, place in an inhomogeneous magnetic field is

$$F = -\frac{dE}{dx} = -M(\frac{dB}{dx}) \qquad (3)$$

The volume susceptibility χ_v per unit volume of the sample is given by

$$\chi_v = \frac{\mu_0 M}{H} \qquad (4)$$

Using equation 4 in equation 3 we get.

$$F = (\frac{\chi_v B}{\mu_0})\frac{dB}{dx} = (\frac{\chi_v}{2\mu_0})(\frac{dB^2}{dx}) \qquad (5)$$

Force on the volume V of the sample is

$$F = (\frac{\chi_v}{2\mu_0})(\frac{dB^2}{dx}) \times V \qquad (6)$$

Figure 1 shows the wireframe diagram of the experimental setup.

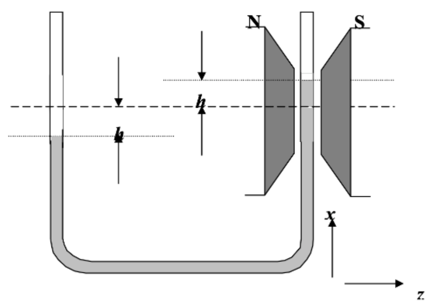

Figure 1: Liquid column in a magnetic field.

let the x be the direction of orientation of the liquid column and a be the area of cross section of the capillary tube. The force on the element of length dx of volume adx on the liquid column is given by the equation 7.

$$F = (\frac{\chi_v}{2\mu_0})(\frac{dB^2}{dx}) \times (adx) \qquad (7)$$

If, B1 is the magnitude of the at the top of the liquid column (between the poles) and 0 is the magnitude of the magnetic field at the bottom of the liquid column. The force on liquid experiences due to the magnetic field is given by.

$$F = \int_0^{B_1} (\frac{1}{2\mu_2})(\chi_v) a \frac{dB^2}{dx} dx = (\frac{\chi_v a}{2\mu_0}) \int_0^{B_1} db^2 = \frac{1}{2\mu_0} \chi_v a {B_1}^2 \qquad (8)$$

The gravitation force experienced by the top liquid column is

$$F = mgh = (ah)\rho g \qquad (9)$$

Where ρ is the destiny of the liquid, In equilibrium the two forces i.e, the gravitational force and the magnetic forces are balanced and this gives

$$F = \frac{1}{2\mu_0}\chi_v a{B_1}^2 = ha\rho g \qquad (10)$$

$$\chi_v = 2\mu_0 g\frac{h\rho}{{B_1}^2} \qquad (11)$$

Equation 11 gives the volume susceptibility of the sample.

5. Equipment

S. No	Equipment	Code	Quantity
1	Electromagnet Setup(Quinck's Tube)	KSCI-94012	1
2	Quinck's Tube	KSCI-AC030	1
3	Advanced Power Supply	KSCI-61035D/7	1
4	Digital Gauss Meter	KSCI-TMM	1
5	Vernier Microscope	KSCI-30780	1

- Components like horizontal bench, power supply, electromagnet assembly and travelling microscope are heavy. Take adequate safety measures while handling them.
- Don't bring any magnetic materials near the electromagnet.
- The coils of the electromagnet will be hot. Use thermal protection gloves when handing them.
- The Quincke's tube is fragile bandit with care.
- Use gloves and safety goggles when handling chemicals and while doing the experiment.

6. Experimental Setup

- Place the electromagnet on a sturdy horizontal surface, and make the appropriate electrical connections with the power supply.

- Place the probe of the Tesla meter in between the two pole pieces and supply current to the electromagnet in steps of 0.5 A till a maximum of 7 A, and note down the corresponding magnetic field values.

- Fill the Quincke's tube with the solution prepared, and make sure that there are no air bubbles in the tube. (see the solution preparation in appendix).

- Make sure that the liquid level in the capillary arm is at the same level as the pole pieces of the electro magnet.(see figure 1)

- Place the traveling microscope in front of the setup and focus the optics to get a clear view of the meniscus of the liquid in the capillary tube.

- Plot the magnetic field measured as a function of the current supplied to the electromagnet.

7. Experiment

8.1 To measure the magnetic susceptibility of a liquid solution containing paramagnetic specimen.

- Turn off the current supply to the electromagnet, and focus the optics of the travelling microscope on the meniscus of the liquid column (placed in between the pole pieces).

- Note down reading indicated on the vertical vernier of the travelling microscope. This reading corresponds to the height of the liquid column. Denote this reading as h_0.
- Supply current to the electromagnet in steps of 1A till a maximum of 7A, and note done the height of the capillary column corresponding to each value of current supplied to the electro magnet.
- Record the heights in the tabular column.

8.2 To determine the density of the prepared solution.

- Take a known volume of the prepared solution and measure its weight and to calculate the density of the solution.

8. Tabulation

8.1 Calibration curve for magnetic field.

1. Current supplied to the electromagnet (A)	2. Measured magnetic field (mT)

8.2 Quincke's tube method.

Name of the sample:________.

Concentration of the prepared solution:____________.
Height of the liquid column in zero field h_0: ____ mm

3. Magnetic field B (mT)	4. Height of the liquid column (mm)	5. Change in height of the liquid column ($h-h_0$) in mm	6. B^2

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Density of the solution:_____________ .

9. Sample data

9.1 Calibration curve for magnetic field.

7. Current supplied to the electromagnet (A)	8. Measured magnetic field (mT)	9. Magnetic field in KG
0	0	0
1	94	940
2	165	1650
3	246	2460
4	310	3100
5	386	3860
6	445	4450
7	520	5200

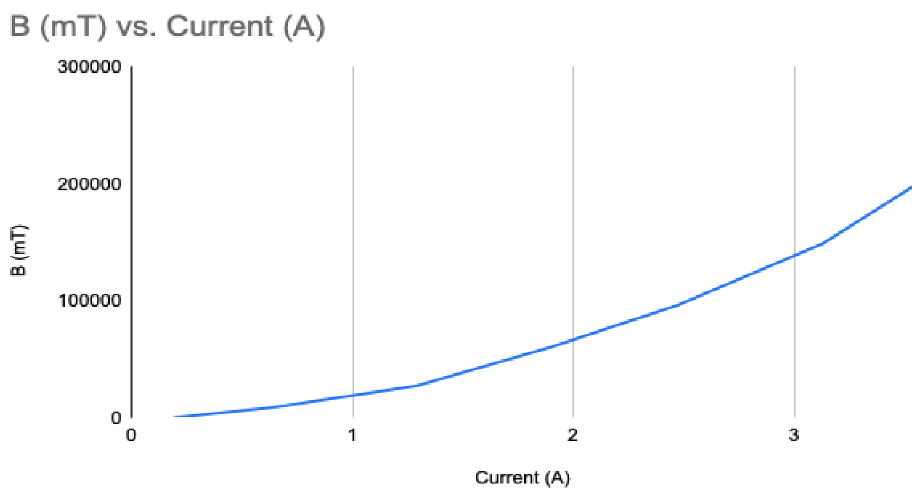

Figure 4: Calibration curve for magnetic field

9.2 Measurement of paramagnetic susceptibility of the given liquid sample.

Name of the sample: $FeCl_3$
Concentration of the prepared solution: 3 molar
Height of the liquid column in zero field h_0: 1.58 mm
Density of the solution: 1.48 kg/m3

- Now, using the equation 11 calculate the χ_v (volume susceptibility) of the given

Magnetic field B (KG)	Height of the liquid column (mm)	Change in height of the liquid column (h- h0) in mm	B^2 in * (10^ 3) KG
0	1.58	0	0
940	1.77	0.19	883.6
1650	2.22	0.64	2722.5
2460	2.87	1.29	6051.6
3100	3.48	1.9	9610.0
3860	4.05	2.47	14899.6
4450	4.71	3.13	19802.5

sample for each trial and take the average of all the readings. Convert to cgs system of units.

10. Result

In CGS units, $<\chi_v> = 1.42 \times 10^{-4} \frac{cm^3}{mol}$**. Magnetic susceptibility per unit volume.**

Figure 5: Variation of change in height of the solution column as a function of the magnetic field.

11. Sources of error in the experiment

- The density of the solution may not be uniform throughout the length of the capillary tube. Due to this the concentration of the magnetic species in the solution changes. To minimize the error due to this, the readings have to be taken at the meniscus level very quickly.

- Due to the hysteresis in the electromagnet, the magnetic field produced in between the poles of the electromagnet will be different each time for a same value of the supplied current. To minimise the error due to hysteresis, a reverse current should be supplied to the magnet by changing the terminals of the power supply and bringing the magneticfield again as close to zero.

- The purity of the solute also matters. Use analytical grade of chemical for the experiment.

10. References

1. Theory of magnetism, Daniel C. Mattis, Springer publication.
2. Magnetism, Stefanita, Carmen-Gabriela, Springer publication.

Appendix

Preparation of solution

Molecular mass of Ferric Chloride is 162.2 g/mol

To prepare 100 ml of n molar solution, use the following formula

$\frac{162.2\times n}{V}$. Here V = 0.1 L

Where $n = 1,2,3,4,5, etc.$..

V = volume in liter.