EXPERIMENT NO. : 4

Susceptibility of a paramagnetic substance

Objective/Aim: To find the susceptibility of a paramagnetic substance ($FeCl_3$) in the form of liquid or a solution.

Apparatus:

Electromagnet, Gauss meter, power supply, wide and narrow limbed U-tube, traveling microscope.

Formula used: The value of the susceptibility K, of liquid or the solution of a paramagnetic substance is given by

$$K - K_A = \frac{2(\rho - \sigma)gh}{H^2} \qquad \text{…….. (1)}$$

Where

K = susceptibility of the paramagnetic liquid.

K_A = susceptibility of air or vacuum i.e., zero.

ρ = density of liquid or the solution i.e., 0.1 g/cc (usually prepared in this concentration. If you have not prepared it yourself, please confirm the value from the lab instructor).

σ = density of air is around 0.0129 g/cc (note the lab temperature and then find the value of σ for this temperature using the table given at the end of the manual)

g = acceleration due to gravity

h =height through which the column rises on switching on the field

H = maximum value of the magnetic field i.e. the field at centre of the gap between the pole pieces

Principle:

The substances which are weakly attracted by magnetic field are called paramagnetic substances. The repulsion of diamagnetic substances by the magnetic field is assigned to the induced molecular current producing magnetic moment in the direction opposite to the applied field.

The force acting on a substance, either repulsive or attractive depending on the type of substance, can be measured with the help of an accurate balance in case of solids. In case of liquids, it can be measured with rise in level of liquid in narrow capillary tube of U-shape.

The force depends on the susceptibility (K), of the material, i.e., ratio of intensity of magnetization to magnetizing field (M/H). If the force on the substance and field are measured, the value of susceptibility can be calculated.

Set-Up and Procedure:

A. Experimental set-up

A schematic diagram of Quinck's method is shown in Fig. 1. Quinck's tube is a U-shaped glass tube with one limb very narrow and the other one wide. The narrow limb is placed between the pole-pieces of an electromagnet shown as N-S such that the meniscus of the liquid lies symmetrically between N-S. The length of the limb is sufficient as to keep the other lower extreme end of this limb well outside the field H of the magnet. The diameter of the narrow limb is decided as per rise or fall of the required liquid. The length of the limb is about 20-30 cm and half the length of the tube is above and half below the meniscus. The diameter of the limb is about a mm or even less in capillary range. The rise or fall h is measured by means of a traveling microscope of least count of the order of 10^{-3} cm or with a microscope fitted with a micrometer scale.

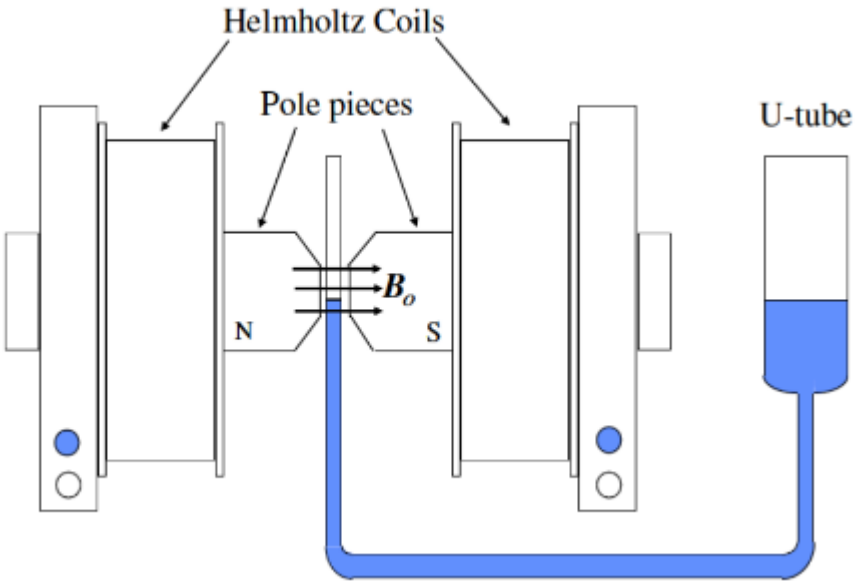

Figure 1: Schematic diagram of experimental set up of Quinck's Method.

Theory:

The Quinck's method is used to determine magnetic susceptibility of diamagnetic or paramagnetic substances in the form of a liquid or an aqueous solution. When an object is placed in a magnetic field, a magnetic moment is induced in it. Magnetic susceptibility χ is the ratio of the magnetization M (magnetic moment per unit volume) to the applied magnetizing field intensity H. The magnetic moment can be measured either by force methods, which involve the measurement of the force exerted on the sample by an inhomogeneous magnetic field or induction methods where the voltage induced in an electrical circuit is measured by varying magnetic moment.

Procedure:

1. Calibrate the magnetic field against magnetic current using a digital Gauss meter. Plot the calibration data of current v/s magnetic field. Note that calibration is important for all experiments with electromagnet. Initially we measure magnetic field for a set of values of applied current and subsequently plot it. The plot provides magnetic field for other values of current in the same range.
2. As shown in the Fig. 1, the apparatus is a U-shaped tube. One of the limbs of the tube is wide and the other one is narrow. The experimental liquid or the solution is filled in the tube, so that the meniscus of the liquid in the narrow limb is at the centre of the magnetic field.

Fig 2. Apparatus for the Measurement of Susceptibility of Paramagnetic Solution by Quinck's tube Method

The strong magnetic field is produced by an electromagnet. The electromagnet is given a suitable current by a power supply of suitable rating to produce magnetic field in the gap of an electromagnet

3. The level of liquid in the narrow tube, when the field is off is noted.
4. The field is then switched on and new level (raised) of column is noted.

5. The experiment is repeated at different magnetic field.

Observations:

Magnetic field in the gap of an electromagnet can be calibration according to the following measurements:

[A] Readings for calibration of magnetic field

S. No.	Current (I) (Ampere)	Magnetic field (H in Gauss)
1.		
2.		
3.		
4.		
5.		
6.		

[B] Readings for determination of rise in level of liquid (h)

Least count of travelling microscope- ……

S. No.	Magnetic field (Gauss)	Initial height (X) (without magnetic field) (cm)	Final reading (Y) (applying magnetic field) (cm)	Rise in level (cm) h = (Y-X)	Value of K
1.					
2.					
3.					

Calculations:

Put the values of h, H, g, σ and ρ in formula (1) and calculate value for susceptibility of solution.

Maximum probable error:

$$K - K_A = \frac{2(\rho - \sigma)gh}{H^2}$$

$$\ln(K - K_A) = \ln\left(\frac{2(\rho - \sigma)gh}{H^2}\right)$$

$$\ln(K) = \ln\left(\frac{h}{H^2}\right)$$

$$\ln(K) = \ln(h) + 2\ln(H)$$

$$\left(\frac{\Delta K}{K}\right) \times 100\% = \left(\frac{\Delta h}{h} + 2\frac{\Delta H}{H}\right) \times 100\%$$

Result:

1) Plot graph between magnetic field and current.

2) Paramagnetic susceptibility of the liquid or solution used is **……** dynes per cm^2 per $gauss^2$.

Precautions:

1) The U-shaped tube should be placed correctly between the electromagnet.
2) The value of current should not exceed 4A to avoid damage.
3) Error due to parallax should be avoided.
4) Maximum value of magnetic field should be taken.

Sources of error:

1. The U-tube is not properly placed.
2. Error may be due to parallax.
3. The proper value of magnetic field is not taken.

Questions for viva:

1) What is susceptibility?
2) What is the unit of susceptibility?
3) What solution is used in the experiment?
4) What is para-magnetism? How does its susceptibility depend on temperature?
5) What are the differences between para-magnetism and dia-magnetism?
6) Give more examples of paramagnetic substances?
7) What is the effect of magnetic field on the susceptibility?
8) What is the role of earth's magnetic field? Is it to be considered or not?
9) What is the effect of electric field on the susceptibility?
10) What is g in the formula?
11) How does a paramagnetic substance differ from ferromagnetic substance?

12) Which type of magnetic substances are used in memory devices and why?

Table: Table for density of air at various temperatures

Temp (^{o}C)	**Density (Kg/m^{3})**
0	1.293
5	1.269
10	1.247
15	1.225
20	1.204
25	1.184
30	1.164
35	1.146