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Quincke's Tube Method to Find Susceptibility of Paramagnetic Substances

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ABSTRACT

A substance's magnetic susceptibility determines how it behaves in a magnetic field. Quincke's method, which is widely used for both paramagnetic and diamagnetic substances, involves putting the liquid in a capillary tube so that the meniscus stands in a powerful magnetic field. In this experiment, we assessed the magnetic susceptibility (χ) of an aqueous $MnSO_4$ solution by measuring the magnetic fields against various current values. This allowed us to calculate the salt's susceptibility. After obtaining a relatively decent result, the data from the literature is compared.

Keywords: Gaussmeter, Hall probe, Magnetic field, Paramagnetic, Magnetic susceptibility

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INTRODUCTION

A paper o*n* the Magnetic Susceptibility and Magnetic Deformation (Rise/Depression) of Liquids in a Magnetic Field [1]. After that he further reported [2] Investigations on the Magnetic Behaviour and Capillary Rise of Liquids in Magnetic Fields.

Quincke's Method: It is predicated on the idea that magnetized material experiences force in a non-uniform magnetic field. Finding a paramagnetic or diamagnetic aqueous solution or liquid's magnetic susceptibility is the goal of Quincke's approach. In this experiment, the narrower section of a U-tube is filled with an aqueous solution of manganous sulphate monohydrate salt (MnSO4.H2O). A magnetic field that is almost homogeneous is applied to the narrower portion while the wider portion is far away from the field. If the solution is paramagnetic, the meniscus in the narrower section will rise when the field is activated with current; if it is diamagnetic, it will fall. Using a digital Gaussmeter and a Hall probe, one can ascertain the relationship between the current and the applied field as calibrated against magnetizing current.

Apparatus required: We have used Quinke's tube method obtained from Osaw Industrial Products Pvt. Ltd. Ambala cantt for performing experiments. It consists of Electromagnet Assembly, Power Supply for Electromagnet, "U" Tube Holder, "U" Tube, *Traveling Microscope, Digital Gauss Meter, Connecting Lead Red,* Connecting lead Black, *Connecting Lead Yellow,* Electronic Balance, Manganous sulphate, Glass

Road (6 x 300mm), Cylindrical Base, Specific Gravity Bottle, *Probe Holder,* Dropper, Spatula (125mm), *Beaker (250ml), Wash Bottle (250ml),* Petri Dish (100mm), Coil Clamp Assembly, Coil 500 Turns (Right), Coil 500 Turns (Left), Power Cord

Experimental Procedure: The Quincke's tube was cleaned and dried completely. $MnSO_4.H_2O$ solutions were made, and their density was meticulously measured. A digital Gaussmeter and a Hall probe were used to calibrate the magnetic field against magnetizing current. In order to maximize the field and make it nearly uniform, the pole pieces were designed to almost touch the edges of the narrower tube. When the field is switched off, the $MnSO_4.H_2O$ solution is poured into the U-tube until the meniscus is slightly above the lower lip of the pole pieces. A traveling microscope is used to determine h for various magnetizing currents.

Theory: We know that magnetisation M is defined as magnetic dipole moment per unit volume and is induced by the field B, parallel to it (B).

We know volume susceptibility is given by,

$$\chi = \frac{M}{H} = \mu_r - 1$$

or

$$\frac{M}{H} = \mu_r - 1 \qquad (1)$$

and $B = \mu_r \mu_0 H$ (2)

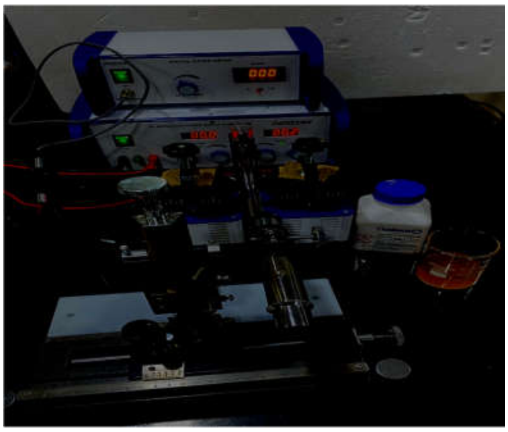


Figure 1: Experimental Set up

where, H = Magnetic Intensity (Amp - turns/m) and μ_r = Relative Permeability.

For free space μ_r =1 and so, $B = \mu_0 H$

$$M = (\mu_r - 1)H = \chi \frac{B}{\mu_0} \qquad (3)$$

The force m per unit volume in the vertical direction on a magnetic dipole moment 'M' due to applied magnetic field B is given by,

$$Fx = \frac{MdB_z}{d_x} = \chi\ B_z \frac{dB_z}{\mu_0 d_x} \qquad (4)$$

$$= \frac{dB_z^2}{2\mu_0 d_x} \qquad (5)$$

So, the force on element of area A and length dx {i.e. on volume Adx} is = $Fx\ Adx$. So the net force on liquid,

$$F = A\chi \frac{[B^2 - B_0^2]}{2\mu_0} \qquad (6)$$

where, B is the field at the surface between the poles of the magnet and B 0 is the field at the outer
surface away from the magnet.

The liquid rises till this force is balanced [3] by the weight of liquid of height h (difference of heights
in two limbs) and of area of cross section A. Hence,

$$A(\chi - \chi_a) \frac{[B^2 - B_0^2]}{2\mu_0} = Ah(\rho - \rho_0)g \qquad (7)$$

Taking into consideration air of susceptibility and density ρ_0, the following equation can be obtained:

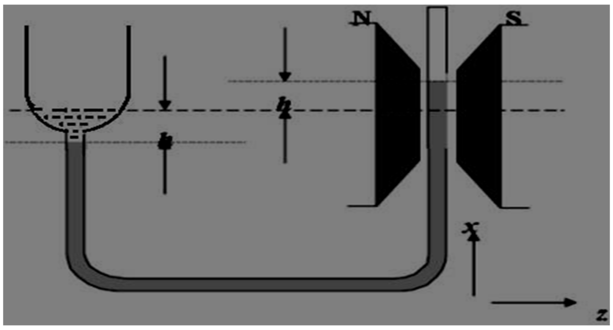


Figure 2: Narrow limb of U-tube under influence of magnetic field

$$h = (\chi - \chi_a)\frac{[B^2 - B_0^2]}{2\mu_0(\rho - \rho 0)g} \quad 8)$$

In actual practise, χa and ρO and $B0$ can be neglected; therefore,

$\chi = 2\mu 0 \rho g h / B^2 = 2\rho g h / \mu 0 H^2 = 2\rho g h / \mu 0 H^2$

It is dimensionless quantity

Mass susceptibility $\chi 1 = X / \rho$

Susceptibility of salt is found by :

χ^1 (sol)= {χ 1(salt) * ms/(ms+ mw) } +{ χ 1(water) * mw/(ms+ mw) } (9)

χ^1 (salt)= {χ 1(sol) -(mw* χ 1(water) *(ms+ mw) }(ms+ mw)/* ms } (E)

Molar Susceptibility = $\chi 1$ *s a o l e c u l a r w e i g ht* = χ 1 (*s a l t*) X x 169cm^3 (F)

In S.I system ρ , g, h and H are measured in Kgm^{-3} , ms^{-2} , m and Amp-turns/m respectively.

The volume susceptibility in the two systems (SI and CGS) are related by,

$$\chi_{SI} = 4\pi \chi_{CGS} \quad (10)$$

The total susceptibility of solution can be written as,

$$\chi = \chi_{Mn} + \chi_{WATER} \quad (11)$$

This assumes that the number of water molecules per unit volume is not very different in the solution form that in pure water.

$\chi_{WATER} = -0.90 x 10^{-6}$

Procedure:

1. Find the relative density of the liquid by using the formula:

$$\rho = \frac{[m2 - m0]}{m1 - m0}$$

where, $m0$ = mass of the relative density bottle(rdb)

$m1$ = mass of rdb + water
$m2$= mass of rdb + liquid

2. Place the Hall probe between the pole pieces of the electromagnet and switch on the current. Adjust the current until the magnetic field becomes zero.
3. Remove the Hall probe and place the arm of the U-shaped tube between the pole pieces.
4. Focus the microscope on the liquid surface and measure the initial height h0 of the solution.
5. Change the current and record the height of the liquid for at least five different non-zero values of the magnetic field B.
6. Plot a graph between h and H^2 and measure the slope $S = h / H^2$.
7. Calculate the volume magnetic susceptibility of the solution using, $\chi = 2\rho g h / H^2$.
8. Calculate of the mass susceptibility of solution by $x^1 = \chi / \rho$.
9. Finally, calculate the susceptibility of the salt and its molar susceptibility using equations (E) and (F).

OBSERVATIONS

Preparation of Manganese sulphate monohydrate ($MnSO_4.H_2O$) solution

1) Mass of Beaker m_1 = 95.50g
2) Mass of beaker + water m_2 = 144.9g
3) Mass of Beaker + Water + salt = m_3 = 164.8g

$m\,w$ = mass of water = $m_2 - m_1$ = 49.4g
$m\,s$ = mass of dissolved salt = $m_3 - m_2$ = 19.9 g

Calculation of Density ρ

Mass of specific gravity bottle (S.B) m0 = 19g
Mass of specific gravity bottle + Water m1 = 69.2g
Mass of specific gravity bottle + Solution m2 = 83.6g

$$\rho = \frac{[m2 - m0]}{m1 - m0} = \frac{[83.6 - 19]}{69.2 - 19} = 1.29 \text{gcm}^{-3}$$

Table 1: Results between Current (A) and Magnetic Field (kg)

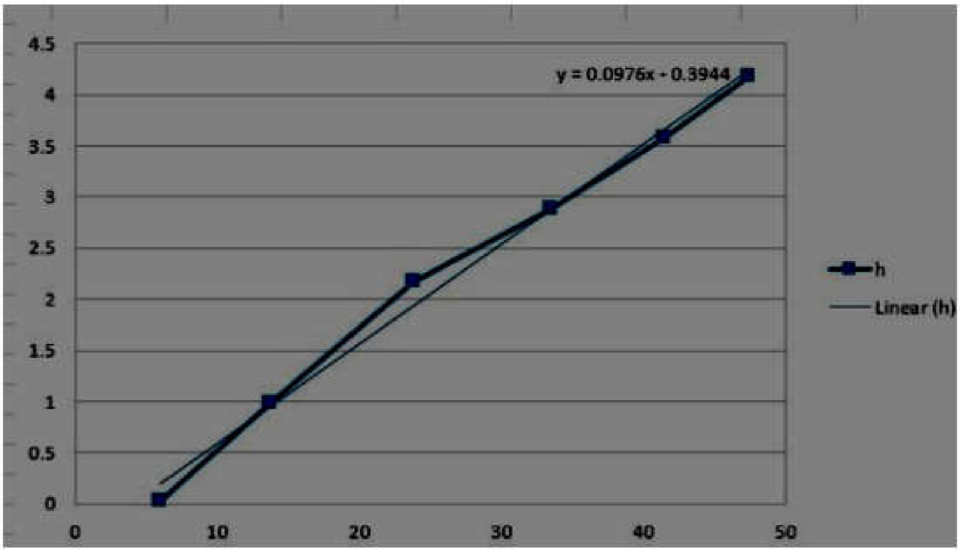
SN	Current (A)	Magnetic Field (kg)
1	1	1.14
2	2	2.27
3	3	3.38
4	4	4.45
5	5	5.34
6	6	5.94
7	7	6.36

Least count of travelling microscope = 0.5/50= 0.01mm

Table 2: (For Graph h (mm) Vs H^2) Initial position at current 0 = 31.153mm

S.N.	Current (A)	H (kg)	H^2	Height of liquid level(mm)	Rise of solution, h (mm)
1	1	1.14	1.3	31.85	0.32
2	2	2.27	5.15	32.225	0.72
3	3	3.38	11.42	33.03	1.5
4	4	4.45	19.8	34.05	2.52
5	5	5.34	28.52	35.13	3.60
6	6	5.94	35.28	36.13	4.60
7	7	6.36	40.45	36.48	4.95

h



H^2

Figure 3: Plot of Rise of solution (h) Vs square of Magnetic field (H^2).

From the graph h/H^2=12.2*10^{-9}

Calculation

(i) Putting ρ = 1.29gcm^{-3} g = 981cms^{-2}

Volume Susceptibility of solution:

$\chi = 2\rho gh/H^2$ we get, $= 31.9 \times 10^{-6}$

Mass Susceptibility of solution:

(ii) $\chi' = x/\rho = 24.8 \times 10^{-6}$ cm^{3}g^{-1}

Susceptibility of salt:

By using equation 9 and E, susceptibility of salt is calculated. The value of $\chi'water$ taken as -0.90 × 10^{-6}. The negative sign for water indicates that it is paramagnetic [4]. By putting

$m'water = 49.4g \; and \; ms = 19.9g$
and
χ' = 24.8 × 10−6 cm3 g^{-1} in eqn E

$\chi'salt$ = 88.59 × 10−6 cm^3 g^{-1}

Molar susceptibility of salt
$\chi salt = \chi'salt \times molecularweightofMnSO4.H2O$
= $\chi'salt$ × 169
= .01497cm^3, which agreess well with the literature value of 0.0142 cm^3.

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