Birla Institute of Technology & Science, Pilani

Pilani Campus

PHY F244 : Modern Physics Laboratory

Magnetic Susceptibility by Quincke's tube

1. **Aim and Objectives** : This experiment aims to measure the magnetic susceptibility of the $FeCl_3$ solution using Quincke's tube Method.

2. **Keywords** : Magnetization, Magnetic Susceptibility.

3. **Theory** :

   In the presence of the magnetic field, matter becomes magnetized; that is, upon microscopic examination it will be found to contain many tiny dipoles. The magnetization **M** is referred as the magnetic dipole moment per unit volume. As per as linear media is concerned the magnetization **M** is directly proportional to the applied magnetic field,

$$\mathbf{M} = \frac{1}{\mu_0}\chi_m \mathbf{B} \tag{1}$$

   here, μ_0 is permeability of the free space, χ_m is the magnetic susceptibility (positive for paramagnetic) and **B** is the applied magnetic field. For auxiliary field **H** is related to **B** as,

$$\mathbf{B} = \mu_0(1+\chi_m)\mathbf{H} = \mu\mathbf{H} \tag{2}$$

   where, $\mu \equiv \mu_0(1+\chi_m)$, and for vacuum $\chi_m = 0$ and hence μ_0 is referred as permeability of free space.

   For a given magnetic field, the magnetic energy density is given by,

$$u = \frac{\mathbf{B}^2}{2\mu_0} \tag{3}$$

   which for any magnetized medium can be written as (by using Eq. 2),

$$u = \frac{1}{2}\frac{\mathbf{B}^2}{\mu} = \frac{1}{2}\mu\mathbf{H}^2 \tag{4}$$

   Now our objective is to measure the magnetic susceptibility χ_m of the $\mathbf{FeCl_3}$. Quincke devised a simple method to determine the magnetic susceptibility of a paramagnetic solution by observing how the liquid rises up between the two pole pieces of an electromagnet.

   Suppose that, when the field is turned on, the fluid level in the narrow tube rises by an amount h, relative to its zero-field position. A volume $\pi r^2 h$ of air in the narrow tube (with permeability μ_0) is, therefore, replaced by liquid. Hence, the magnetic potential energy of this volume of space increases by an amount:

$$\Delta U = \frac{1}{2}(\mu - \mu_a)H^2\ \pi r^2 h \tag{5}$$

$$F_m = \frac{\Delta U}{h} = \frac{1}{2}(\mu - \mu_a)H^2\ \pi r^2 \tag{6}$$

   where, F_m is upward magnetic force responsible to increase the magnetic potential energy and μ_a corresponds to the magnetic permeability of air. If we consider $\mu_a \sim \mu_0$, then $\mu - \mu_a \equiv \mu_0\chi_m$ and hence,

$$F_m = \frac{1}{2}\mu_0\chi_m H^2\ \pi r^2 \tag{7}$$

When the liquid in one arm of the tube rises by h, it falls on the other arm by h. It continues to rise till the upward magnetic force is balanced by the weight of the head of liquid. The downward gravitational force on the head of liquid, of mass m, is given by,

$$F_g = \pi r^2 h \rho g \tag{8}$$

From Eq. 7 and 8,

$$\chi_m = \frac{2\rho h g}{\mu_0 H^2} = \frac{2\mu_0 \rho h g}{B^2} \tag{9}$$

in CGS units $\mu_0 = 1$ and above expression reduced to,

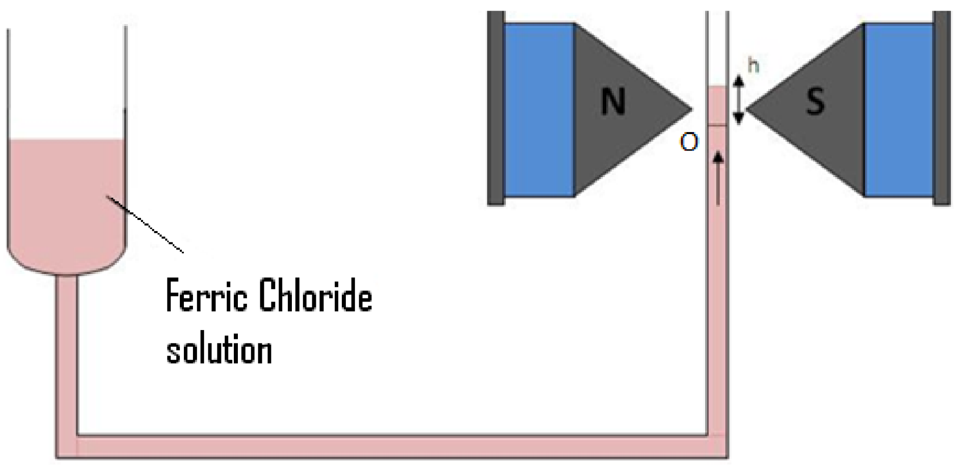
$$\chi_m = \frac{2\rho h g}{B^2} \tag{10}$$

This is referred as volume susceptibility of the of the solution, the mass susceptibility

$$\boxed{\chi_{mass} = \frac{\chi_m}{\rho} = \frac{2hg}{B^2} \quad \mathrm{cm}^3/\mathrm{gram}} \tag{11}$$

Now, let h_1 is height when no magnetic field applied.

4. **Tasks** :
   (a) First calibrate the magnetic field as a function of the current using Gauss meter, and find the proportionality constant which would relate the current (in Amps) to magnetic field (in Gauss).
   (b) Make the concentrated solution of the $FeCl_3$.
   (c) Fill the U-tube with this solution slowly.
   (d) Place the tube between the electromagnets such that the liquid meniscus is at the center of the electromagnet poles.
   (e) Focus the telescope to see the meniscus.
   (f) Change the current and so the magnetic field and then measure the change in the height of the meniscus.



5. **Observations and Results** : Now, let h_1 is height of the meniscus when no magnetic field applied.

S.N.	I (A)	B (Gauss)	h_2 (cm)	$h = h_2 - h_1$	χ_{mass}
1					
2					
3					