Paramagnetic susceptibility of a liquid

Ronak M Soni and S. Prasanth
2^{nd} Year, BSc.(Hons.) in Physics,
Chennai Mathematical Institute

1 Aim

To measure the paramagnetic susceptibility of a liquid.

2 Apparatus

1. Anhydrous ferric chloride.
2. Distilled water.
3. Pipette.
4. Relative density bottle.
5. Physical balance.
6. Electromagnet.
7. U-shaped tube with very thin free arm attached to a stand.
8. Hall probe with attached gaussmeter.
9. Travelling microscope.

3 Setup

1. A $1M\ FeCl_3$ solution was prepared by weighing out 16.22 g of the salt on the physical balance and mixing it with enough water such that there was 100 ml of solution.
2. The free arm of the U-shaped tube was filled to such a level that the solution level was at the centre of the pole pieces without keeping the free arm between the pole pieces.

4 Theory

4.1 Magnetic Susceptibility

When a uniform magnetic field B is applied on one arm of a U-tube filled with paramgnetic liquid, it rises by a height h such that

$$h = \frac{\chi B^2}{2\mu_0^2(\sigma - \rho)g} \tag{1}$$

where χ is the magnetic susceptibility of the liquid, σ is the relative density of air (value $1.205 * 10^{-3}$) and ρ is the relative density of the solution.

This give the value of χ as

$$\chi = 2(\sigma - \rho)g\mu_0^2 \frac{h}{B^2} \tag{2}$$

4.2 Relative Density

When the relative density of a liquid needs to be found, we can find it as

$$\rho = \frac{m_2 - m_0}{m_1 - m_0} \tag{3}$$

where m_0 is the mass of a relative density bottle, m_1 is the mass of the relative density bottle filled with water and m_2 is its mass when filled by the liquid.

4.3 Physical Balance

To properly use the physical balance, one must find the zero resting point a of the balance, the point where the needle is centred when both pans are empty. This is done by letting it oscillate and noting the maximum points on the left and right and taking the average. Then, when the object to be weighed is kept in the left pan, say, and the standard weights in the right, the needle is allowed to oscillate once it is seen clearly that the oscillation will stay within the given scale. Since it is virtually impossible to exactly match the weights on both sides, the unknown mass is given by

$$m = w + 10 * \frac{b-a}{b-c} * 10^{-3} \tag{4}$$

where w is the total standard weight, a the zero resting point and b and c the amplitude of oscillations of the needle on the right and left, respectively.

5 Utilities

6 Procedure

6.1 Determination of the weight of an object

1. The support of the balance was raised and the left and right extremes L and R of the oscillation of the pointer were noted. The zero resting point a was taken as $\frac{R-L}{2}$.
2. The object was placed in the left pan.
3. Weights estimated to weigh as much as the object were placed in the right pan.
4. The support was raised and the movement of the needle noted.
5. If the needle moved to the right (left) end of the scale, the weight was increased (decreased).
6. If it stayed within the scale, the right and left extremes R_1 and L_1 were noted. The mass m was taken as the value obtained by plugging R_1 as b and $-L_1$ as c in equation 4.

6.2 Determination of density of the solution

1. An empty relative density bottle, a relative density bottle filled with distilled water and a relative density bottle filled with solution were weighed. The masses m_0, m_1 and m_2 were noted.
2. The relative density ρ of the solution was taken as $\frac{m_2 - m_0}{m_1 - m_0}$.

6.3 Determination of paramagnetic susceptibility of the solution

1. The Hall probe was placed between the pole pieces of the electromagnet and the current was turned on and varied till the magnetic field was seen to be zero.
2. The Hall probe was replaced by the thin arm of the U-shaped tube,and the height h_0 of the solution's surface was measured using the microscope.
3. The current was varied and the height h of the liquid was measured for five non-zero magnetic fields B.
4. A graph of $h - h_0$ v/s B^2 was drawn and its slope S found.
5. Paramagnetic susceptibility χ was taken as $2\mu_0^2(\sigma - \rho)gS$.

7 Observations

7.1 Zero resting point

$R = 3$
$L = 1$
$a = 1$
The zero resting point is one unit to the right.

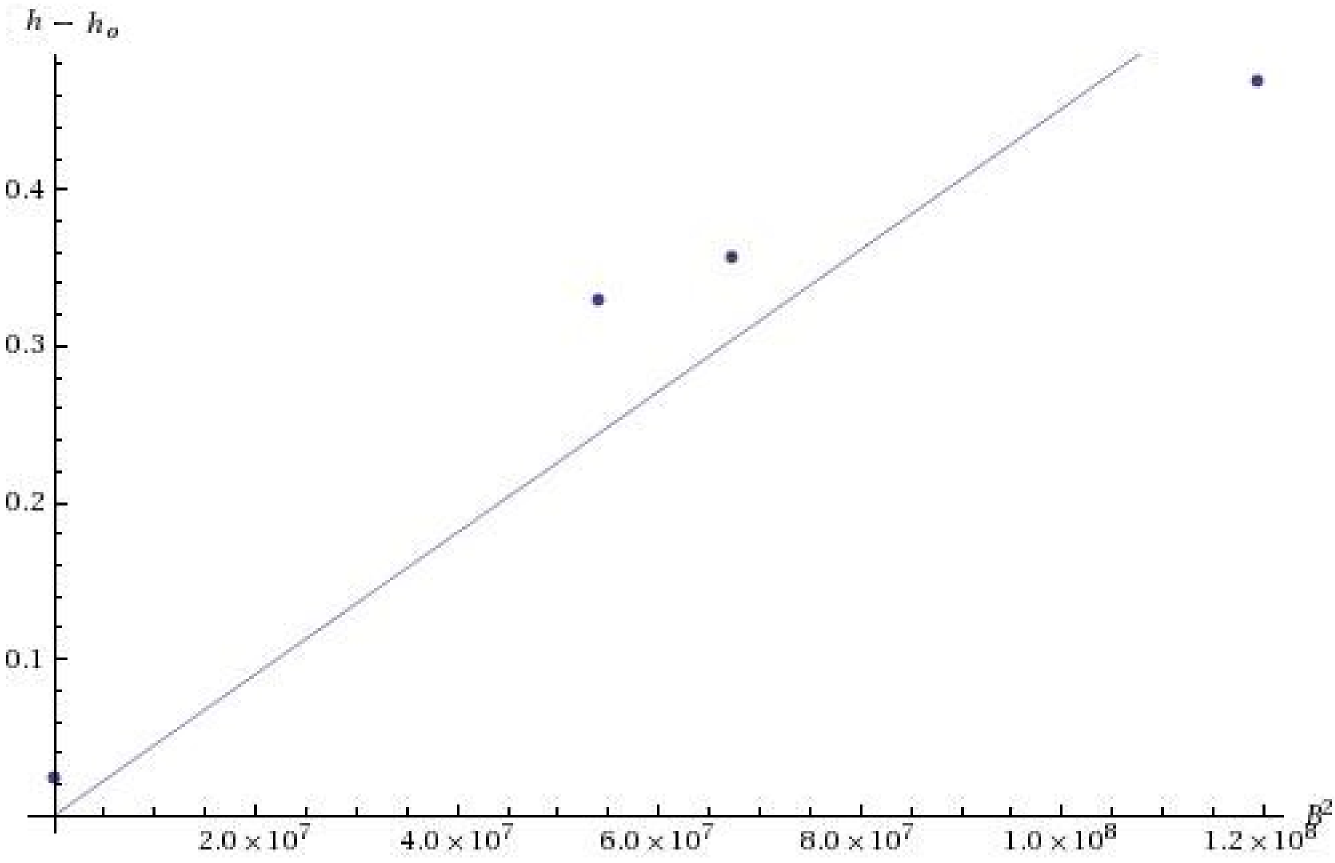
7.2 Measurement of density

Type of bottle	Weight w /g	Left extreme point L'	Right extreme point R'	mass m /g
Empty bottle	22.710	2	1	22.710
Water-filled bottle	43.830	7	2	43.831
Solution-filled bottle	43.240	2	9	43.247

Density $\rho = 0.972$

7.3 Measurement of susceptibility

Magnetic field B /G	Height increase $h - h_0$ /cm	B^2 /G^2
0	0	0
-165	1.530	27225
-218	1.650	47524
-7350	1.955	54022500
-8200	1.982	67240000
-10920	2.095	119246400



Slope $S = -4.520 * 10^{-3}\ mT^{-2}$.

8 Result

The paramagnetic susceptibility of $1M\ FeCl_3$ solution was found to be $1.358 * 10^{-13}\ m^3mol^{-1}$, which is a 0.96 % error compared to the standard value of $1.345 * 10^{-13}\ m^3mol^{-1}$.

9 Precautions

1. When using the physical balance, the weights should be added only when the support of the balance isn't raised.