Determination of paramagnetic susceptibility

1 Aim

The aim of this experiment is to determine the magnetic susceptibility of a solution of manganese sulphate using Quincke's tube method.

2 Introduction

Quincke's method is based on the force experienced by a magnetic material in a non-uniform magnetic field. The solution of manganese sulphate contains divalent Mn^{2+} ions which possess a permanent magnetic dipole moment. A material consisting of such non-interacting magnetic dipoles acts like a paramagnet. The dipoles tend to align themselves parallel to the external magnetic field acquiring a net magnetization which is parallel to the field. Magnetic susceptibility is a quantitative measure of the amount of magnetization generated for a unit change in the external field. It is also called the response function and is a measure of how much the given material responds to the changes in the external magnetic field.

On the other hand, thermal effects tend to disorder this alignment. So the susceptibility of a paramagnet decreases as temperature T is increased. Detailed calculations based on statistical mechanics predict that susceptibility is inversely proportional to the temperature, at high temperatures. This is called Curie's law and has been verified by experiments although only for dilute solutions or for small concentrations of the paramagnetic particles. For larger concentrations, the effect of interactions among neighbouring ions also play dominant role.

The magnetization **M** of a bulk material may be defined as the magnetic dipole moment per unit volume. For a paramagnetic material, **M** is induced by the applied field **B** and is parallel to it. The magnitude of magnetization is given by

$$M = \frac{\chi B}{\mu_0} \tag{1}$$

Let the field be in the z-direction and the height of solution in x-direction. The force per unit volume at a point in the U-tube as shown in the figure is given by

$$F_x = \frac{\chi B_z}{\mu_0}\frac{dB_z}{dx} \tag{2}$$

Thus due to variation in the strength of the field in the x-direction there is force on the paramagnet. The total force acting on the whole liquid is obtained by integrating over the whole volume

$$F = \int F_x A dx = \frac{A\chi(B^2 - {B_0}^2)}{2\mu_0}, \tag{3}$$

where B is the field at the liquid surface between the poles of the magnet, and B_0 is the field at the other surface, away from the magnet. The rise of the liquid is balanced by the pressure exerted over the area A due to a height difference 2h between the liquid surfaces in the two arms of the U-tube. Neglecting the corrections due to susceptibility and density of the air, one obtains the relation

$$\chi(B^2 - {B_0}^2) = 4\mu_0 h\rho g, \tag{4}$$

where g is the acceleration due to gravity and ρ is the density of the solution.

Note that there is a small but significant dismagnetic contribution to the suceptibility of solution due to pressure of water. The total suceptibility is given by $\chi = \chi_{Mn} + \chi_{water}$. Thus $\chi_{water}(-0.9 \times 10^{-5}\ m^3/kg)$ has to be subtracted from the measured χ to get χ_{Mn}. Here the dimensionless quantity χ denotes the volume suceptibility of the solution. The mass suceptibility of the solution is obtained by $\chi_m = \chi_{volume}/\rho$.

3 Procedure

1. Calibrate the magnetic field produced by the electromagnet for different values of the current using the Hall probe. Fit the field versus the current data to a straight line. The probe should be placed steady using a stand for all measurements and such that it gives positive values of the field.
2. Cleanse the rube well and rinse it with distilled water. Dry it with compressed air. The tube should be wiped clean from outside too.
3. Prepare three solutions of manganese sulphate with different concentrations.
4. Place one arm of the U-tube between the pole pieces so that the meniscus of the liquid is in the centre.
5. Note the initial reading of the meniscus with a travelling microscope.
6. Measure the diplacement h (relative height) of the column of the liquid as a function of the applied magnetic field B.

7. Measure the field B_0 at the surface which is further from the pole pieces.
8. Calculate the suceptibilty using Eq. 4. Alternately, a graph between $(B^2 - B_0^2)$ and h fitted with a linear equation confirms the dependence.

3.1 Preparation of the solution

Find out the solubility of manganese sulphate in water at the given room temperature. Dissolve appropriate amounts of the solute to $50ml$ of water such that the density of the solution is about 1.1-1.2 g/ml. Prepare three solutions with different densities.

4 Precautions

1. Care should be taken in handling the fragile U-tube and it should be cleaned using thepreocedue mentioned above.
2. Dispose of the solution after use and the tube should be cleaned at the end ofthe experiment.
3. The calibration of the magnetic field should be done with small increments of current (of the order of 0.2A). The calibration curve is linear for small values of current and saturates for larger values.