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Experimental determination of magnetic susceptibility by (1) Gouy method &
(2) Quincks method.

Gouy method :

Theory: Let a small piece of the given material be suspended in the magnetic field between the pole pieces of an electromagnet. If the intensity of the magnetic field between the pole pieces varies from place to place the specimen will tend to move in the region of weaker magnetic field in the case of diamagnetic substance and to the region of stronger magnetic field if it is paramagnetic. Thus the specimen experiences a force in a non-uniform magnetic field and moves in favour of the force by a small distance 'dx', the corresponding work done results in a change in P.E of the sample which can be calculated as follows.

V = The volume of the specimen in the region where B is the induction vector of the magnetic field.

μ' = permiability of the medium (generally air) occupying that space, when the specimen lies outside that space.

$\vec{H}$ = The magnetic field strength in that region.

$\therefore$ Magnetic energy density (energy per unit volume) in that region $= \frac{1}{2}\mu' H^2$ —— (1)

∴ The magnetic energy in that region of volume 'ϑ' before the specimen goes there

$$U_1 = \frac{1}{2}\mu' H^2 \vartheta \quad \text{—— (2)}$$

Let μ = permiability of the Specimen.
∴ when the specimen occupies that region the permiability changes from μ' to μ & the magnetic P.E in that region

$$U_2 = \frac{1}{2}\mu H^2 \vartheta \quad \text{—— (3)}$$

Change in P.E as the specimen moves into that region: $U_2 - U_1 = \frac{(\mu-\mu')H^2\vartheta}{2}$ —— (4)

Since the magnetic field is not uniform the specimen experiences a motion by 'dx' due to change in field strength H with 'x'.

∴ Rate of change of P.E with distance i.e potential gradient $= \frac{U_2 - U_1}{dx} = \frac{d}{dx}\left(\frac{\mu'-\mu}{2}\right)\vartheta H^2$

$$= \frac{(\mu'-\mu)}{2}\vartheta . 2H\frac{dH}{dx} \quad \text{—— (5)}$$

Hence the force experienced by the specimen due to the variation of magnetic field with distance. F = P.E gradient.

$$F = (\mu-\mu')\vartheta H\frac{dH}{dx} \quad \text{—— (6)}$$

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But $\mu = \mu_0 (1 + \chi_m)$

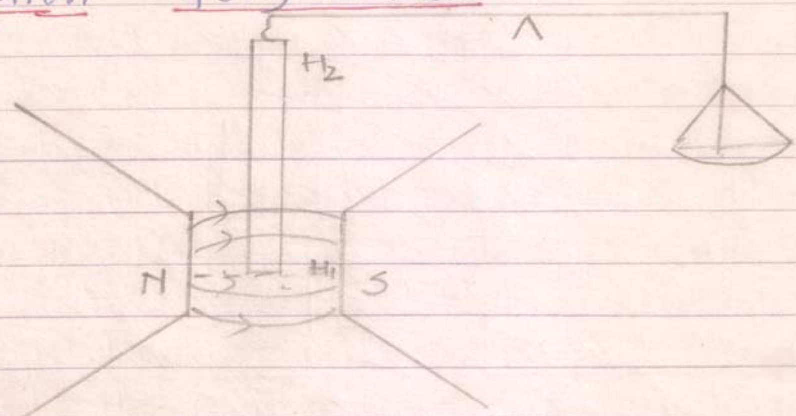
$\mu' = \mu_0 (1 + \chi'_m)$

$\therefore (\mu - \mu') = \mu_0 (\chi_m - \chi'_m)$

where χ_m & χ'_m are the magnetic susceptibilities of the specimen and the medium in the region between the pole pieces respectively

$$\therefore \boxed{F = \mu_0 (\chi_m - \chi'_m) v H \frac{dH}{dx}} \quad \text{——} (6)$$

Description : Gouy method :



The specimen in the form of a thin rod is suspended from one arm of a sensitive micro-balance in the magnetic field between the wedge shaped pole pieces of an electromagnet. The field of the electromagnet will vary rapidly along the vertical direction due to the pole pieces which are wedge shaped. If the pole pieces are sufficiently wide apart the variation in the field in the horizontal direction will be very small and the central part of the field will be uniform horizontally. The size of the specimen is so chosen that

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it can be suspended in the central part of the field i.e where the field is uniform horizontally.

Now since the vertical dimension of the pole pieces is small, the magnetic field will fall off rapidly in the vertical direction. Therefore the specimen will experience a force along its length. First the specimen is balanced by putting weights on the other arm of the balance. Then the magnetic field is switched on and the force (upward or downward depending on whether the specimen is dia or paramagnetic) experienced by it, due to the non-uniform field, is counter balanced by adjusting the weights to balance the specimen. If the weights added or removed in the second case by 'm' the force experienced by the specimen due to the magnetic field is 'mg'. This method was first employed by Gouy.

Calculation:

A = Area of the horizontal cross-section of the rod.

Let us consider an element of the rod of length 'dx'

∴ volume of the element = $A\,dx$

∴ Force on this element; due to the magnetic field (which is non-uniform) from eqn (6):

$$dF = \mu_0 (\chi_m - \chi_m')\, A\,dx\, H \frac{dH}{dx} \quad \text{---(7)}$$

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Hence the total force experienced by the rod can be obtained by integrating eqn. (7):

$$\therefore F = \int dF = \mu_0 (\chi_m - \chi'_m) A \int_{H_2}^{H_1} H \frac{dH}{dx} . dx$$

or $$\boxed{F = \frac{1}{2} \mu_0 (\chi_m - \chi'_m) A (H_1^2 - H_2^2)} \quad — (8)$$

where H_1 & H_2 are the values of the magnetic field H at the lower and upper end of the rod respectively.

Since the magnetic field strength decreases ~~very~~ rapidly, as we move towards the upper end, the value of H_2 can be neglected compared to H_1.

The force 'F' is measured by balancing against a load 'mg' on the scale pan.

$$\therefore mg = \frac{1}{2} \mu_0 (\chi_m - \chi'_m) A H_1^2 \quad — (9)$$

χ'_m = The susceptibility of the medium between the pole pieces which is generally air and hence its magnetic susceptibility χ'_m can be neglected. Eqn (9) then reduces to

$$\boxed{mg = \frac{1}{2} \mu_0 \chi_m A H_1^2} \quad — (10)$$

The magnetic field strength H_1 can be measured by a magnetic fluxmeter and using eqn (10) χ_m can be calculated.

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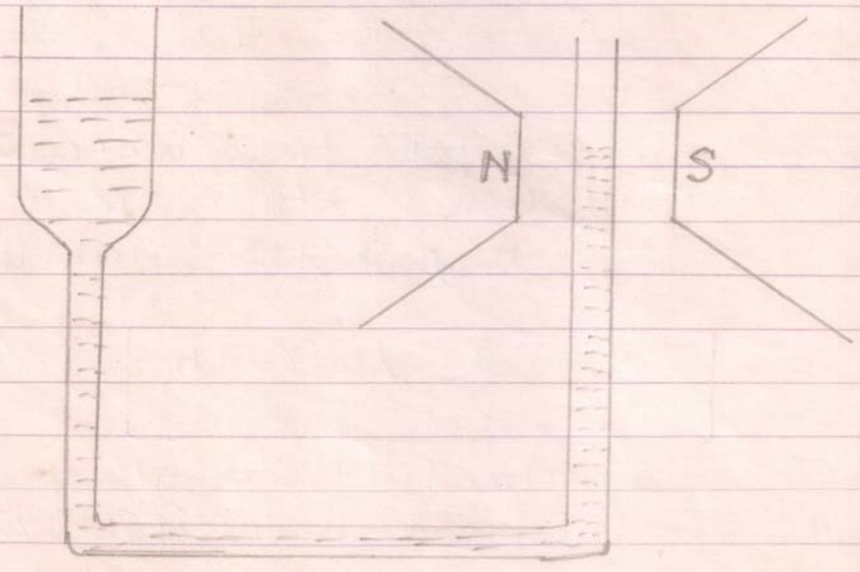
Experimental determination of the magnet Susceptibility of a liquid by Quincke's method:

Susceptibility of liquids:

Quincke's method: The Gouy's method for determining the Susceptibility of a solid described above can also be employed in the case of liquids. In this case, a glass or quartz tube containing the liquid under test will replace the rod.

In this method the liquid under test is taken in a U tube one limb of which is a capillary and the other is a tube of wide bore. The capillary section of the U-tube is placed between the pole pieces of the electromagnet as shown in the fig.



The miniscus of the liquid in the capillary is arranged to lie near the centre of the magnetic field. When the current energising the electromagnet is switched on the level of the miniscus falls or rises depending on whether the liquid is diamagnetic or paramagnetic with respect to the surrounding air. The change in the height of the miniscus is determined with the help of a travelling microscope. Let it be 'h'. Then h is the hight of the liquid column supported by the force due to the non-uniform magnetic field.

Let ρ be the density of the given liquid & σ be that of air.

Then,

the change in the hydrostatic pressure of the liquid corresponding to the change 'h' in the height of the liquid column is $(\rho-\sigma)gh$.

The corresponding change in the force acting vertically on the liquid is $(\rho-\sigma)ghA$.

Where A is the area of cross-section of the capillary tube.

Now the vertical force 'dF' acting on a column of height 'dx' of the liquid is given from eq^n(6) as

$$dF = \mu_0 \left(\chi_m - \chi'_m \right) A\,dx\,H \frac{dH}{dx}$$

where 'V' has been replaced by 'A dx'

The vertical force F (due to the mag. field) supporting the liquid column of height 'h' can be calculated by integrating this expression from H = 0 i.e. the initial zero magnetic field to H = Hm the final field applied.

$$F = \mu_0 (\chi_m - \chi'_m) A \int_{H=0}^{H=H_m} H \frac{dH}{dx} dx$$

$$F = \frac{1}{2} \mu_0 (\chi_m - \chi'_m) A H_m^2$$

& $F = (\rho - \sigma) g h A$ [as shown earlier]

$$\therefore (\rho - \sigma) g h A = \frac{1}{2} \mu_0 (\chi_m - \chi'_m) A H_m^2$$

or, $$\boxed{(\rho - \sigma) g h = \frac{1}{2} \mu_0 (\chi_m - \chi'_m) H_m^2}$$