Experimental Physics - III

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Lecture – 21
Susceptibility of paramagnetic substance by Quincke's tube method

In solid-state physics laboratory, we perform different experiments. We have some experiments for studying the property of magnetic properties of solids. today I will discuss about an experiment how to measure the magnetic susceptibility of paramagnetic or diamagnetic material using a method is called Quincke's method.

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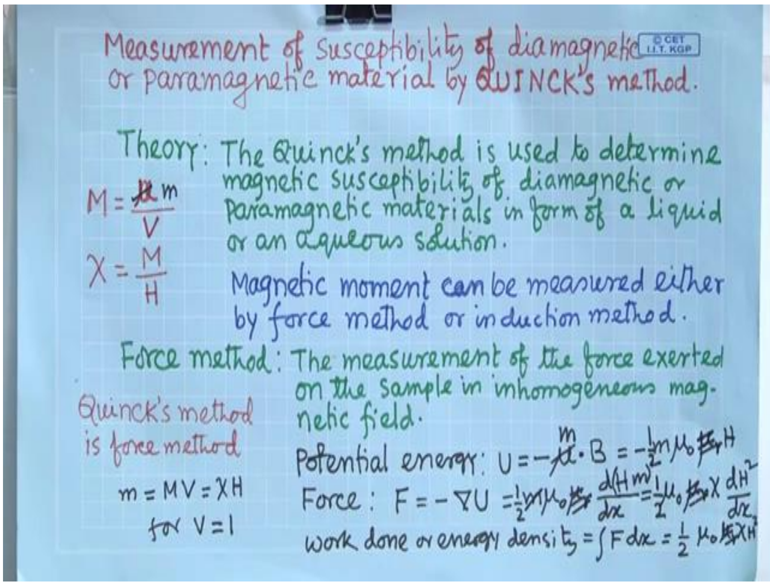

Measurement of susceptibility of diamagnetic or paramagnetic material by Quinck's method, theory of this method one should understand properly. Quinck's method is used to determine magnetic susceptibility of diamagnetic or paramagnetic materials in form of a liquid or an aqueous solution. You have to prepare solution of the material magnetic material, which you want to study.

Now, using that solution we perform experiment. Now, when we are going to susceptibility if you want to get you have to measure magnetization as a function of magnetic field then susceptibility is defined by M by H, magnetization or unit magnetic field. that is the susceptibility.

When we are going to measure magnetization in laboratory, there are two method I should say that there are two ways. magnetization I have to I will change the magnetization applying the magnetic field. Now, for each field what is the magnetization, that I have to measure; that means, I have to I need device which will sense the magnetization which will sense the change of the magnetization. to sense the magnetization there are two ways, one is induction method.

If you take a coil induction coil and keep close to the magnetic material means close to the magnetization. there will be flux link with the coil and if there is change of this flux coming from the magnetization and linked with the coil, if that flux changes then there will be proportional induced emf in the coil. Measuring this induced emf in the coil we can we tell that we are able to sense the magnetization. this is one way induction method. Another method is called this force method

Force method, if magnetization if magnetic material having the magnification is in a inhomogeneous magnetic field means magnetic field will change as a function of distance as a function of distance if you keep the material in this inhomogeneous field then there will be force acting on this material due to the magnetization and your. That force that force have to be balanced with some other force or other yes other force opposite force.

if you can balance these two then from this balancing equation, one can sense the magnetization one can measure the magnetization measuring these the parameter from these balance equation of these two kind of force. One is magnetic force or force due to the magnetization and another compensating force in opposite direction. This is called force method.

Quinck’s method is force method. Magnetic moment can be measured either by force method or induction method force method is the measurement of the force exerted on the sample in inhomogeneous magnetic field. When magnetic material have atoms. each atom is a have the magnetic dipole moment or if it is paramagnetic diamagnetic material then there will be there is no magnetic moment net magnetic moment of the atom, but in presence of magnetic field there would be induced moment in the atom ok.

This induced moment in presence of magnetic field. That is the origin of diamagnetic material origin of the diamagnetism. That means, it is induced either moment magnetic moment or the natural this spin magnetic moment or orbital spin orbital magnetic moment. atom will have the moment.

Now these moments or these moments each dipole moments or the total moment of the whole material. That moment when it is in a magnetic field, it will have it will feel torque it will feel force it will feel torque, it will have the potential energy. potential energy U defined by U equal to minus m dot B minus m dot B M is the magnetic moment magnetic moment dot B, B is the magnetic field induction magnetic field in the material is B.

U I can write this now here dot product you know this m dot B, M B cos theta. Now as I told this in material you have dipole either induced dipole or the atomic dipole due to spin and orbit. Now this dipole moment are randomly oriented in the material randomly oriented in the material. Here m dot B average cos theta you will take we have to take average cos theta.

If you take average cos theta. that is why this I have written here this half this term I have written. this is minus m B is if it is in B this mu 0 H ok, mu 0 H; mu 0 is the permeability in air permeability in air and this half this term has come due to this average cos theta.

now potential energy if this force it is defined as a minus grad U. grad is you know this d by d x I can write for one dimension d y by d x I can write. d by d x and then this U term is this, where M and H are there. mu 0 is constant half is constant minus sign and this minus sign will go. half m mu 0 d H m by d x. now, m, magnetic moment magnetic moment is you can write total moment of this material here this M we have consider total moment of the material ok.

if magnetization is defined by this total moment of this material divided by total volume of the material, this m small m is capital M into V capital M into V. and this I can write chi M is chi H. if I put M is chi H chi H. this is chi H chi H is that is here m is M V I have written this total moment M V I have written total moment. Now, this chi is in place of M I can write chi H chi H ok.

I am searching where is V. for V equal to 1 for unit volume if we consider unit volume. this I can write H m. M is chi H. chi H square. chi is constant; so d H square by d x this force depends on the magnetic field as a function of x; that means, magnetic field if it is constant over a over a distance. There will not be any force. if magnetic field varies over a distance. Then this, this will give force. differentiation of H square as a with respect to x if it is not 0 then only it is possible if you have inhomogeneous magnetic field.

In constant field, there is no force, but in inhomogeneous magnetic field, there will be force. that is why I told. This the force present only when there is an inhomogeneous field, magnetic material is in the inhomogeneous field and this is for a per unit volume because V equal to 1. that is why energy density. What will be this? If this is force if this is force now here I have written force if you force into d x distance there is work done or energy density you can tell that will be half mu 0 chi H square this will be work done or energy density: half mu 0 chi H square.

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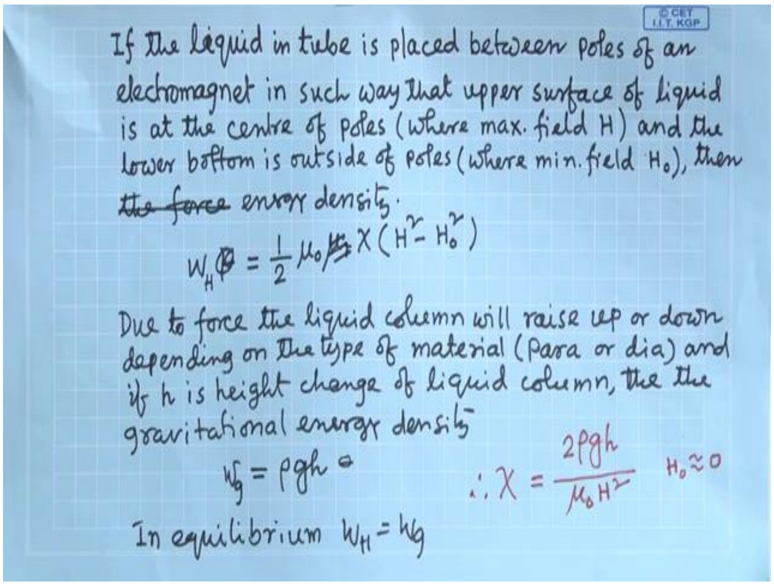

Now, if I take a liquid if I take a liquid or solution of the magnetic material either paramagnetic or the diamagnetic material. in tube, if I put the solution and this tube is placed between pole pieces of an electromagnet for magnetic field, we have to place in such a way that upper surface of the liquid is at the centre of the poles ok, at the centre of the pole pieces where maximum field H and the lower bottom is outside of the poles where minimum field H 0 this is H this is H 0 then energy density ok.

Say W H energy, energy density due to the; due to the magnetic due to the magnetic force. that is half mu 0 chi H square I told there. H Square minus H 0 square. you have seen this integration. Integration over the x integration of f d x equal to integration of d H square. there we have written result this step as 0 2 H then it will be H square.

Now here if not 0, say H 0 field is the minimum field, then this will be H square minus H 0 square. Now, what will happen? this is happening because of the this energy density whatever we have we are getting that is because of force because of force and the d x integration over d x over the length whatever we are writing. it will fill force this liquid will fill force and basically, it will change it height it will change its height you know.

Now because this liquid is filling force due to the magnetic field and from where this force is coming because of the presence of the inhomogeneous magnetic field, this liquid will move up or it will go down ok.

Now, if say it is easy to understand if you consider that it say move up; that means, for me it is before applying magnetic field whatever the surface position that was the balance position not balance the equilibrium position. Now, this surface is going up due to the magnetic field. Now, if you can measure this change of height if change of height then how much liquid has done. Now, this there will be gravitational potential energy there will be gravitational potential energy.

The W H it is magnetic energy density and this will be balanced with this gravitational potential energy density. gravitational potential energy density if I write that height is H that height increased that is H, rho g h m g h. m in this case density we are considering that is why we can write rho mass per unit volume.

then this gravitational energy density W g and this is a for magnetic field it is W H. these two will be equal these two will be equal because this due to the magnetic field it is going up. Now due to the gravitational downwards force, it will try to come down, but this is the balanced position.

There these two force gravitational downward force and a magnetic upward force these two force has to be equal in equilibrium condition, then it will reach to the equilibrium condition and for that, whatever height we have to measure. That is h; in equilibrium this equal to this, if you equate these two. we will get chi equal to two rho g H by mu 0 H square when H 0 is approximately 0.

This formula we use a formula we will use as a working formula for this experiment. One has to remember that in which condition we are getting this formula, that that is important that is important.

Now, this formula here we have consider that this the sample liquid that surface in a tube that will put at the field H and other end of the sample it has to be outside of this magnet then only you we will fulfill this condition this H 0 equal to approximately 0. In addition, here H, what is H, in presence of magnetic field what is the height change of the liquid ok?

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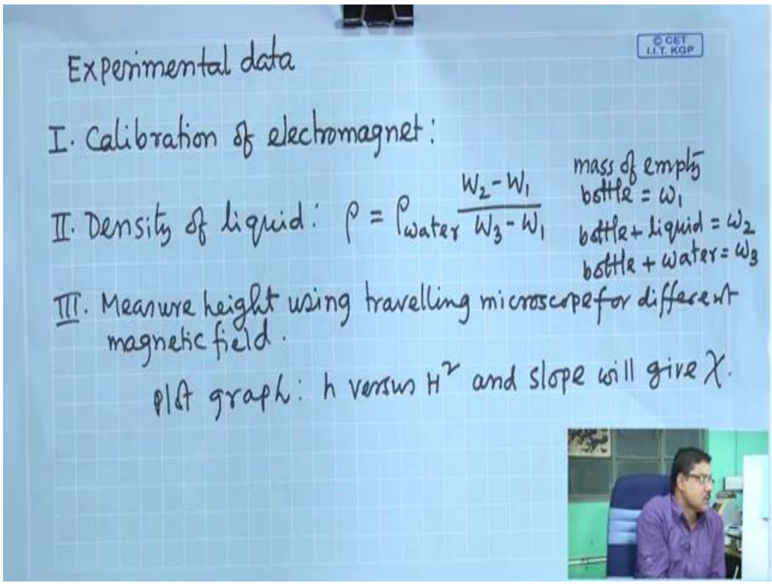

We have to do the experiment we have to collect the data. experimental data we have to (Refer Time: 20:44). What we have to do? We need magnetic field. we will use electromagnet. Whenever you are going to use electromagnet and you have to place your sample, in this case we have to place the tube contained liquid. We have to keep this pole pieces that gap at a particular gap we have to calibrate the electromagnet.

Calibration of the electromagnet using the gauss meters and Hall probe that first one has to do. that is calibration of the electromagnet. Second, that in that formula you have seen rho is there. Though that rho what is that; density of the solution. we have to prepare solution and we have to measures the density of the that solution liquid. That is using a formula one can find out if it is water solution then here W 2 minus W 1 divide by W 3 minus W 1.

Mass of the empty bottle we will take a bottle. we will weight that take the weight of this bottle W 1, now bottle plus liquid W 2, now bottle plus water that is W 3 W 3 minus W one; that means, water W 3 minus W 1; that means, the water volume of the that this that will be the mass; that will be the mass of the of the water And if I take W 2 minus W 1 then it will be the mass of the liquid, liquid means say the solution.

Water and there I have put the material I have put the material this material resolve in this water. That weight is W 2. Here I will get this weight of the is here this is a weight of the liquid divide by weight of the water into the rho water means, density of water. From the using this formula, we will get the density of liquid

One has to find out density of the liquid, which we will use for our experiment. that you have to measure, then measures height using travelling microscope at different magnetic field ok.

This is the main part of the experiment that that we will apply magnetic field for different magnetic field, what is the height change of the liquid. using the travelling microscope we will measure the height of the liquid. Now, we have data h versus m; small h that is the height versus the magnetic field. Now, h versus H square magnetic field square we will plot that graph.

Now, from that graph one can we will get the slope and from that slope, one can find out the chi right. This in slope chi and other constant parameter will be there. That constant parameter are known. We will be able to find out the chi. this is the procedure or theoretical part of this experiment, Quinck’s method how to find out the chi as a function of magnetic field. That experiment we will demonstrate in on laboratory in next class.

Thank you.