| Volume 6 | Issue 1 | June 2023

MAKTABAH JAFARIYAH Knowledge & Research Academy

The International Journal

ISSN 2581-4354

THE EFFECT OF 22NM SIZED SILICA NANOPARTICLES ON MAGNETIC FIELD INDUCED BIREFRINGENCE IN MAGNETIC FLUID.

Ismailhusain Dedharotiya*
Dr. Rucha Desai**
Urvesh Soni***

P.D.Patel Institute of Applied Science, Charusat Campus, Changa.,**,****

Abstract:

In this study, the magnetic field-induced birefringence effect was studied on the addition of 22 nm sized silica particles in a water-based Fe3O4 magnetic fluid at two different wavelengths, that is, 532 nm and 650 nm. The results were compared using the modified Langevin theory. The optical anisotropic properties of the magnetic fluid due to the agglomeration of chain formation and magnetic-field-induced birefringence are discussed here. In addition, magnetization data recorded using a vibrating sample magnetometer (VSM) were analyzed in view of Langevin's theor.

1. Introduction

1.1 Magnetic fluid: -

Magnetic fluid is a stable colloidal fluid composed of nanoscale magnetic particles suspended in a suitable carrier liquid [1]. In order to produce an effectively aqueous Ferro fluid it is necessary to make two surfactants.

Based on the work reported by Shimoizaka et al. and Woo et al. [2,3], aqueous magnetic fluids stabilized by a bilayer surfactant via a two-step process were prepared. In the first step, the primary surfactants (in this case, lauric-acid) are chemisorbed on the magnetic particle (in this case, Fe3O4) surface through their head groups to stabilize the ultrafine precipitates.

Secondary (in this case also Lauric-acid) surfactant-stabilized particles with the head groups of the secondary surfactants provide a hydrophilic outer shell exposed to the surrounding polar solvent. This results in double-surfactant-coated magnetic particles. [4]

1.2 Stability of the colloidal Dispersion:-

The stability of magnetic colloidal depend on the thermal contribution and the balance between attractive(van dar waals

and dipole-dipole) and repulsive (steric and electro static) interation.[5]

The typical particle numerical density in a magnetic colloidal is ≈1023 to evaluate the typical particle diameter(D) and avoid magnetic agglomeration. Now we compare the thermal energy with the dipole-dipole pair energy and we get:[5]

$$D \leq \left(\frac{72k_BT}{\pi\mu_0 M^2}\right)^{\frac{1}{3}}$$

Where k_B,T, μ_0 and M are boltzmaan constant, the absolute temparature, the permiability of free space and the intensity of magnetization. plugging typical value in equstion one can get D≤10nm.[5]

1.2.1 Van dar Waals Attractions: -

$$E_v = -\frac{A}{6}\left[\frac{2}{l^2+4l} + \frac{2}{(l+2)^2} + ln\frac{l^2+4l}{(l+2)^2}\right]$$

1.2.2 Magnetic Attractions: -

$$E_m = -\frac{8\pi}{9}\frac{\mu_0 M^2 r^3}{(l+2)^3}$$

1.2.3 Steric repulsion: -

$$\frac{E_R}{kT} = 2\pi r^2 N\left[2 - \frac{(l+2)}{t} ln\left(\frac{1+t}{1+\frac{l}{2}}\right) - \frac{l}{t}\right]$$

Where, $t=\frac{\delta}{r}$

l=relative surface separation=(r_c/r)-2

r_c=center to center distance of two particles [5]

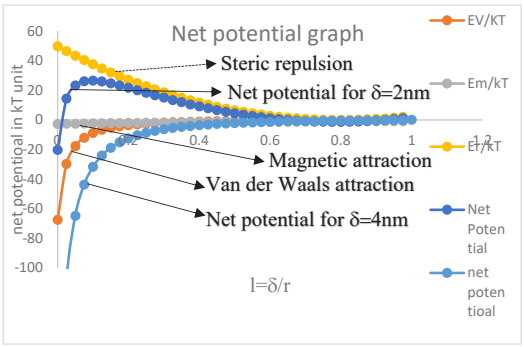


Fig-3 stability of colloidal dispersion

Fig-2 the influence of surfactant thickness on the stability for magnetic particles of radius r = 5nm.

The Ev/kT plot shows van der Waals Attraction, which is powerful but effectively works over a short range only (i.e., 1/r2), while the Em/kT graph shows magnetic attraction with relatively long-range ordering (i.e., 1/r), changing slowly with the separation of the particles. Er/kT in the graph shows that the steric repulsion at radius r=5 nm decreases with increasing separation of the particles and becomes zero at l=0.8. The net potential is shown in the graph for two different d value 2 nm and 4 nm. When d= 2 nm, the net curve displayed an energy barrier of approximately 25kT. This was sufficient to prevent agglomeration. In comparison d=4nm.When d= 4 nm, it corresponds to the attraction between the particles at all separation distances, and hence, the system fails to stabilize. Therefore, we conclude that d=2 nm is more preferable for d=4 nm in Net potential value.

1.3 Application of Magnetic fluid:-

When the external megnetic field is applied the colloidal suspension of magnetic particles having the sufficient magnetic permiability ,the particles will interct ,causing them get together along the magnetic field and form complex chain like and lattice like structure.[5]

The phenomena of propagation of electromagnetic waves in strongly scattering media, such as the photonic Hall effect, photonic magnetoresistance, and zero-forward scattering, have been of growing interest. It is important to

understand thr light scettring behaviour of transmitted light through a strongly scattring media ferrofluid.[5,6]

Mgnetic fluid(MF), which consists of single-domain magnetic particles dispersed in a magnetic liquid solvent, has been studied for a long time. It's megneto optical properties have recentaly attrected a lot of interest to scientiests due to thair potential applications.[7,8.9]

It is indicate that the birefringence effect is attributed the formation magnetic chain under external magnetic field[10,11], In privious reserch has established a quantitative relationship between birefringence and chain formation.[12]

The optical transmission of magnetic fluid under an external magnetic field is another important aspect of the magneto-optical effect. The optical transmission of magnetic fluid can be modulated by varying the field strent, which implies that magnetic fluid film can be used for optical switches, modulaters etc.[13-15]

According to these results, optical transmission is closely related to the structural pattern of the magnetic fluid under an external magnetic field. Yang at al. have proven that the magnetic field dependent optical transmission originates from agglomoration of the magnetic particles that reduce the area of liquid phase.[16]

The larger the field, the more chains are formed; therefore, the transmission is inversely proportional to the field. It is this agglomoration process that plays an important role in the optical transmission such as the response time of switches or modulaters.[17,18]

So the process in magnetic fluid establish that ferrofluid exhibit magneto optical effect such as faraday rotation, faraday ellipaticity, birefringence, retardation and dichroism etc.[19]

1.4 Superparamagnetism: -

Superparamagnetism is a form of magnetism that occurs in small ferromagnetic or ferromagnetic nanoparticles. In sufficiently small nanoparticles, magnetization can randomly flip the direction under the influence of temperature. The typical time between the two flips is called the Neel relaxation time.

Superparamagnetism is a property occurring principally in small, single domain magnetic particles without magnetic memory It is more closely related to ferromagnetism than to Para magnetism

For example, when a ferromagnetic multidomain sample of Fe3O4 is reduced in size to less than approximately 40 nm, a single-domain magnetic particle will eventually be formed. When placed in an external magnetic field, this particle develops a strong internal magnetization from the exchange coupling of electrons within the domain, and thus becomes.

Ferritin and hemosiderin, which are repositories for iron atoms released by the breakdown of hemoglobin, are naturally occurring superparamagnetic substances in tissues. Superparamagnetic ferrite particles have also been used as contrast agents in the liver and reticuloendothelial systems. Because only a single domain is involved, the susceptibility of a superparamagnetic substance is not as high as that of a ferromagnetic substance. Additionally, because each domain is in a separate particle, there can be no interactions or ordering of the domains within a sample. Unlike ferromagnetic materials, superparamagnetic substances do not retain any net magnetization once the external field is removed. In other words, they have no magnetic memory.

The superparamagnetic and ferromagnetic properties are compared below.

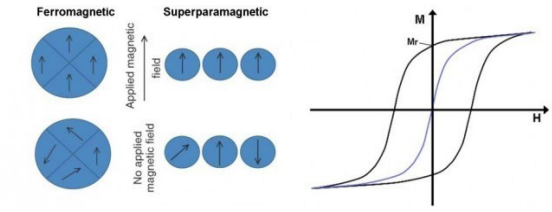


Fig-3 compression between superparamagnetism and ferromagnetism.

Property	Superparamagnetism	Ferromagnetism
Structure	Single-domain particle	Multiple domains
Magnetic memory	None	Yes
Degree of induced magnetization	Moderate	Very high

Fig-4. An external magnetic field induces an alignment of the magnetic moments of both the domains of a ferromagnetic material and the single-domain of a superparamagnetic nanoparticle.

When no magnetic field is applied ferromagnetic materials maintain a net magnetization while superparamagnetic nanoparticles present magnetization zero.

Fig-4. An external magnetic field induces alignment of the magnetic moments of both the domains of a ferromagnetic material and the single domain of a superparamagnetic nanoparticle. When no magnetic field is applied, ferromagnetic materials maintain a net magnetization, while superparamagnetic nanoparticles exhibit zero magnetization.

In fig-4 the hand side multi-domain and single-domain particles are shown, and the aero shows the net magnetic moment. As shown in fig-4 when an external magnetic field is not applied, the moment is aligned randomly, and the net magnetic moment is zero for multi-domain as well as single-domain particles. When the external magnetic field moment tries to align in the direction of the magnetic field, and when all moments align in the direction of the magnetic field, we can obtain saturation magnetization. The difference between single-domain and multi-domain particles is that when we remove the external magnetic field, single-domain particles return to their original position, while multi-domain particles do not return to their original position and remain in magnetization. To obtain a magnetization value of zero, we must apply the field, which is known as a co-erosive field. Thus, hysteresis is observed in the multidomain structure.

In single-domain particles, when a magnetic field is applied, all moments try to align in the direction of the magnetic field. When the field is removed, moments return to their original position, and they do not saturate the magnetization or the co-erosive field. Thus, no hysteresis was observed in the single-domain structure.

Typically, any ferromagnetic or ferromagnetic material undergoes a transition to a paramagnetic state above its Curie temperature. Superparamagnetism differs from this standard transition because it occurs below the Curie temperature of the material.

Superparamagnetism occurs in nanoparticles that are single-domain, that is, nanoparticles composed of a single magnetic domain. This is possible when the diameter is below 3–50 nm, depending on the material. Under these conditions, the magnetization of the nanoparticles is considered to be a single giant magnetic moment, which is the sum of all individual magnetic moments carried by the atoms of the nanoparticle. Those in the field of superparamagnetism call this "macro-spin approximation."

Because of the magnetic anisotropy of nanoparticles, the magnetic moment usually has only two stable orientations antiparallel to each other, separated by an energy barrier. Stable orientations define the nanoparticles as the so-called "easy axis". At a finite temperature, there is a finite probability for magnetization to flip and reverse its direction. The mean time between two flips is called the Neel relaxation time tN and is given by the following Neel-Arrhenius equation

$$\tau_N = \tau_0 \exp\left(\frac{KV}{k_B T}\right)$$

tn is the average length of time that it takes for the nanoparticle's magnetization to flip randomly as a result of thermal fluctuations.t0 is the length of time, characteristic of the material, called the attempt time or attempt period (its reciprocal is called the attempt frequency); its typical value is 10−9–10−10 s. K is the magnetic anisotropy energy density of the nanoparticle and V is its volume. KV is therefore the energy barrier associated with the magnetization moving from its initial easy axis direction through a "hard plane" to the other easy axis direction. where kB is Boltzmann's constant. T is the temperature. [20]

1.5 Birefringence: -

In this experimental study, the birefringence effect in a magnetic fluid was studied. Birefringence is an optical technique for measuring the orientation of optically anisotropic samples by measuring the retardation of the polarized light passing through the sample. Birefringence makes use of the refractive index n of a material, as defined below.

$$n = \frac{c}{v} = \frac{speed\ of\ light\ in\ vacuume}{speed\ of\ light\ in\ sample}$$

Birefringence Δn is define as the difference between the refractive indices in two planes,

Δn' = n1-n2

For a sample to exhibit birefringence, three criteria must be met.

(1) There must be a nonzero difference between the two refractive indices of the sample.
(2) There must be a net orientation in the sample to yield the primary refractive index.
(3) The optics used to view the sample must be correctly oriented. [21]

The practical setup for birefringence measurement is discussed below.

2. EXPERIMENTAL

2.1 Sample preapration of magnetic fluid:-

2.1.1 FNT SYSTEM

Sample code	TM-40 Silica concentration(%)
FN30	0
FNT0.5	0.5
FNT1	1
FNT2	2
FNT3	3
FNT4	4

Table:1 sample code and TM-40 silica concentration

Here for the experiment sample

were prepared at different concentrations. For each system 200□l fluid was prepared. FN30 is the parent fluid in which silica particles are not doped.

After that FNT0.5 system was prepared in that system 199□l is FN30 and 1□l TM-40 silica particles were added. And after that in FNT1 system was prepared in that 198□l FN30 and 2□l TM-40 silica particles were added. In FNT2 system 196□l FN30 fluid and 4□l TM-40 silica particles were added. And in FNT3 system 194□l FN30 fluid and 6□l TM-40 silica particles were added. At last in FNT4 system 192□l FN30 fluid and 8□l TM-40 silica particles were added. Thus, different systems were prepared for the experimental birefringence and magnetization measurements.

In the TM-40 silica concentration, the average particle size of the silica particles was approximately 22 nm.

2.1.2 FNTD SYSTEM:-

Here in FNTD system TM-40 silica particles were added with different concentration. For this system in order to make 1ml diluted TM-40, 0.928ml pure TM-40+0.072ml distil water was added. While in FNT system pure TM-40 silica particles were added. Here also FN30 is parent fluid which is same for both the system.

In order to make 200□l system for FNTD0.5 we have added 199□l FN30 + 1□l diluted TM-40. For FNTD1 198□l FN30 + 2□l diluted TM-40. And for FNTD2 196□l FNT30 + 4□l diluted TM-40. Thus two different systems were prepared for experimental measurement.

2.1.2 FNTD SYSTEM:-

Here in FNTD system TM-40 silica particles were added with different concentration. For this system in order to make 1ml diluted TM-40, 0.928ml pure TM-40+0.072ml distil water was added. While in FNT system pure TM-40 silica particles were added. Here also FN30 is parent fluid which is same for both the system.

In order to make 200□l system for FNTD0.5 we have added 199□l FN30 + 1□l diluted TM-40. For FNTD1 198□l FN30 + 2□l diluted TM-40. And for FNTD2 196□l FNT30 + 4□l diluted TM-40. Thus two different systems were prepared for experimental measurement.

Sample code	Diluted TM-40 Silica concentration(%)
FN30	0
FNTD0.5	0.5
FNTD1	1
FNTD2	2

Table:2 sample code and TM-40 silica concentration

2.2 Magnetization of Magnetic Particles:-

Magnetization data were taken from VSM (vibrating sample magneto meter). The data were taken into the range of 0-12000G which is very high field. The applied field is in gauss while magnetization we have get is in emu (electromagnetic unit). If we divided emu with it's weight which was taken for practical we can get magnetization in emu/g. and if we multiply emu/g with its density which is in unit of g/cc. so one can get magnetization data in emu/cc unit which is basically K.A/m.

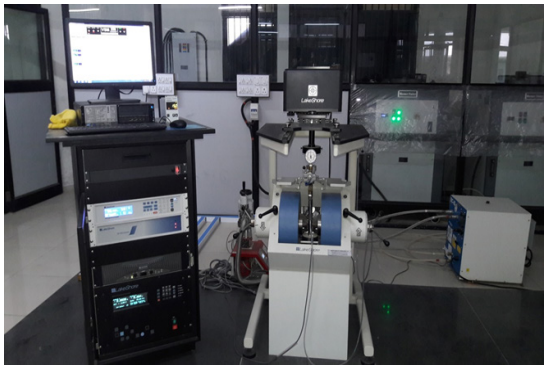
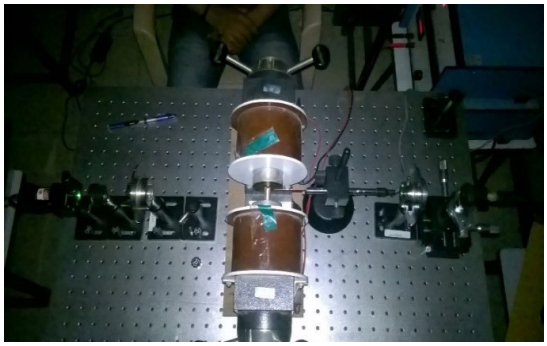


Fig-5 Picture of the VSM set up

2.3 Exprimental setup:-



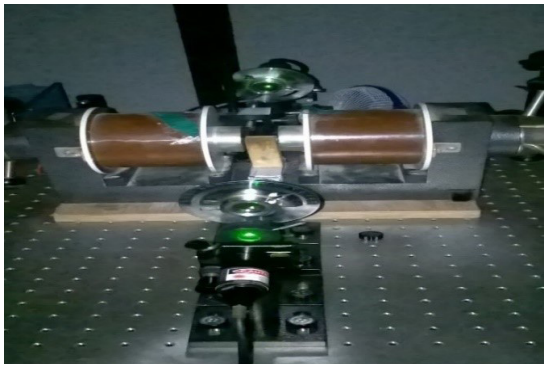


Fig-6 experimental set up for birefringence measurement

Fig-6 shows the experimental set up for birefringence measurement. In that first the diode laser kept and after that pinhole was put, the distance between pinhole and laser is 3.5cm.

After that polarizer was kept, the distance between polarizer and pinhole is 6.4cm. and then after sample is put between two pole of electromagnet, distance between electro-magnet and polarizer is 19.5cm and distance between two pole of electromagnet is 3cm. and after that analyzer was put, the distance between analyzer and electromagnet is 24cm. after that photo diode was put, distance between diode and analyzer is 11cm.

First light pass through the pinhole and then it is pass out through polarizer and polarizer is kept at 450. Then light pass through the sample which was put between two pole gap of electromagnet. And sample put such a way that light passes through the sample. Then light passes through the analyzer and at last the light is detected by the photo diode and the output is shown as an intensity in the millimeter.

As increase the magnetic field. we have to not down the minimum intensity and analyzer angle at different magnetic field that we have applied. And we have also note down the maximum intensity and analyzer angle at different magnetic field.

3. Result and Discussion

3.1 Density Measurement:-

Sample code	Density(g/cc)
FN30	1.1068
FNT0.5	1.1077
FNT1	1.1086
FNT2	1.1103
FNT4	1.1137
FNTD0.5	1.1072
FNTD1	1.1076
FNTD2	1.1084

Table: - 3 sample and their density(g/cc)

Above table shows the density of different different sample. Density measure for 1ml volume for each system and 9 times we have weight this volume and after divided this weight by volume so we have get density in gm/cc.

3.2 Microscope Study:-

An optical microscope (MAGNUIS MLXi) with a 40×, numerical aperture (NA) = 0.65 air objective attached to a digital camera (CCD) is used to record the dynamics of Magnetic field Induced chain formations. The direction of homogenous magnetic field (0.05T) is perpendicular to the sample. [21]

Fig-8 Chain formation occur in magnetic fluid due to eternal magnetic field

When the external magnetic field is applied particles in sample are try to alien in the direction of magnetic field so the chain like structure is was formed in magnetic fluid. Which is shown in fig-8. So one can assume that cluster formation may be occur in particles.

3.3 Initial susceptibility:-

All are knowing that susceptibility can always find out at the lower field. Here from magnetization data we have find out the susceptibility at lower field in region of 0-300G. from the magnetization data we have field and magnetization value according to applied field. Magnetization value was in emu/g but we want it in KA/m. in order to convert magnetization value in KA/m we have to multiply the magnetization value with it's density which was measure early in experimental part. Now magnetization value is in emu/cc and all know that 1emu/cc is equal to 1KA/m. so thus we can get magnetization value in KA/m unit.

In order to find out the theory value of initial susceptibility one can use below question.

$$M = \frac{M_S \chi_i H}{M_S + \chi_i H}$$

Here in this equation MS is saturation magnetization, □i is initial susceptibility and H is the applied field. Here applied field was in gauss which is basically in CGS. in order to convert it into the MKS one can get MKS value by dividing gauss with 40□□ (gauss/40□□). In MKS unit of field is KA/m.

Table-4 for determine the susceptibility value for FNT0.5 System.

Theory to determine initial susceptibility		
Sample ID:	FNT0.5	
M=	**0.434568594**	
Sus=	**0.019369674**	
H(kA/m)	m(Ka/m)	Th
0.00014247	6.75E-04	2.7596E-06
0.080199816	2.08E-03	0.00154791
0.159612992	3.40E-03	0.00306981
0.238766616	4.86E-03	0.00457613
0.319543036	6.23E-03	0.00610253
0.399226944	7.65E-03	0.0075977
0.479707075	9.04E-03	0.00909726
0.559240044	1.04E-02	0.01056885
0.639176316	1.18E-02	0.01203769
0.719596551	1.32E-02	0.01350519
0.798612014	1.45E-02	0.01493715
0.878346235	1.59E-02	0.01637231
0.958040524	1.73E-02	0.01779697
1.037830649	1.86E-02	0.01921365
1.117828414	2.00E-02	0.02062438
1.197961945	2.13E-02	0.02202793
1.278087489	2.27E-02	0.02342186
1.358412689	2.41E-02	0.02480984
1.437531972	2.54E-02	0.02616785
1.517729393	2.67E-02	0.02753521
1.597567434	2.81E-02	0.02888737
1.67670269	2.93E-02	0.0302188
1.756852193	3.06E-02	0.03155842
1.8372892	3.19E-02	0.03289394
1.91612098	3.33E-02	0.03419425
1.997971544	3.46E-02	0.03553548
2.196644241	3.77E-02	0.03875392
2.396139517	4.09E-02	0.04193386
2.595499028	4.42E-02	0.045061
2.796487723	4.72E-02	0.04816367
2.9950566	5.02E-02	0.05118082
3.19448	5.33E-02	0.05416391
3.394638131	5.63E-02	0.05711167
3.594380979	5.92E-02	0.06000812

3.793932158	6.21E-02	0.06285774
3.993746882	6.50E-02	0.06566801
4.192715069	6.78E-02	0.06842446
4.391986731	7.06E-02	0.07114414
4.591521938	7.34E-02	0.07382723
4.792023476	7.61E-02	0.0764837
4.991015621	7.88E-02	0.07908177
5.191445282	8.13E-02	0.08166078
5.391523551	8.39E-02	0.08419821
5.591482027	8.66E-02	0.08669793
5.789883193	8.91E-02	0.08914317
5.990137158	9.16E-02	0.09157663
6.18964042	9.40E-02	0.09396712
6.389151669	9.64E-02	0.09632461
6.589972654	9.88E-02	0.09866485
6.788397779	1.01E-01	0.10094557
6.988476048	1.03E-01	0.10321415
7.187452221	1.06E-01	0.10543985
7.387722158	1.08E-01	0.10765002
7.586530621	1.10E-01	0.1098149
7.786521041	1.12E-01	0.11196392
7.985601035	1.15E-01	0.11407509
8.785458896	1.23E-01	0.12228589
9.584318482	1.31E-01	0.130077
10.38277876	1.38E-01	0.1374852
11.18068	1.45E-01	0.14453666
11.97826179	1.52E-01	0.15125851
12.77815959	1.59E-01	0.15769405
13.57741848	1.65E-01	0.16383891
14.37555931	1.71E-01	0.1697089
15.17354041	1.76E-01	0.17532863
15.97184097	1.82E-01	0.18071696
16.77030124	1.87E-01	0.18588687
17.56964	1.92E-01	0.19085575
18.36841972	1.96E-01	0.19562669
19.1662411	2.01E-01	0.20020902
19.96565972	2.05E-01	0.20462756
20.76443945	2.09E-01	0.20887924
21.56385807	2.13E-01	0.21297975
22.36120028	2.17E-01	0.21692384
23.15974041	2.21E-01	0.2207356
23.95931876	2.24E-01	0.22442084

From the above table we can plot graph of applied field(H) vs Magnetization value experimental as well as theoretical value so we can get graph like below.

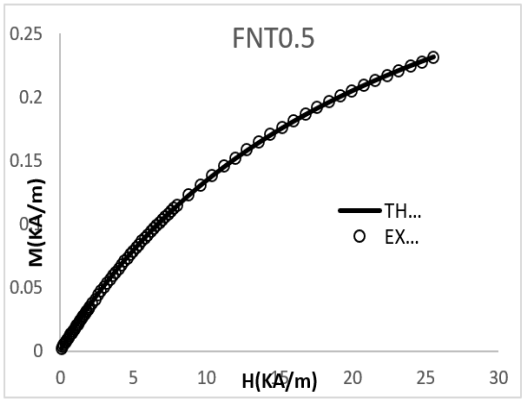


Fig-9 Graph of M (exp & theory) vs H

In fig-9 graph of M (exp & theory) vs H was shown in this graph solid line indicate the theory value and doted point indicate experimental value. As discuss above in the equation MS and □i are variable. By varying the value of both these parameter one can fit the theory value according to experimental value. When experimental value and theory values are match with each other as shown in fig-9 at that time we can find out the value of MS and □i. thus from this method one can find out the value of initial susceptibility and saturation magnetization.

For all sample we have find out the susceptibility and saturation magnetization and it is given in the below table.

Sample code	Initial	magnetization (Ka/m)
FN30	0.0194	0.4355
FNT0.5	0.0194	0.4346
FNT1	0.0192	0.4306
FNT2	0.0193	0.4337

FNT4	0.0189	0.4106
FNTD0.5	0.0197	0.4378
FNTD1	0.0197	0.4383
FNTD2	0.0193	0.4303

Table -5 different sample and their initial susceptibility as well as magnetization.

In the above Table -5 it is shown the initial susceptibility and magnetization of different sample by using above method that we have discuss. As shown in table in that as doping the silica particles the susceptibility of the sample is decreases. And magnetization value also decreases. It is because of silica we all know that silica is nonmagnetic so as adding silica susceptibility and magnetization value are decreases. Thus from above method that we have discuss by using this method one can find out the value of initial susceptibility and value of magnetization.

3.4 Magnetization theory: -

Magnetization data were taken from the VSM as discuss above in the range of 0-12000G which in interval of 1G. but in order to find the different parameter at different magnetic moment the data were interpolate in origin software. Only 29 data point were selected from all data. From 0-700 only 7 data were select and after from 800-12000 range 22 data point were selected. Thus total 29 data were selected and from that we have find out the different parameter from that data point.

Sample code:	FNTD2		
Dm(nm)=	14.45		
		k	1.38
□m(10^-19 Am2)=	2.112832577	lambda(T)=	0
□m=	1.56078737	T(k)	298
Fluid MS (emu/g) =	0.869011862		
H(T)	M/Ms exp	M/Ms theory	M(emu/g)
0.000100423	0.002163377	0.002263138	0.00188
0.011750353	0.133772627	0.146157627	0.11625
0.023400282	0.205520785	0.207950864	0.1786
0.035050212	0.249823978	0.246730517	0.2171
.			
.			
.			
.			

.			
.			
1.2	0.477553896	0.470651993	0.415

Table-6 interpolates data's M/Ms experimental and theory result.

We have get field and magnetization data from the VSM and we have interpolated data in origin and we got 29 selected data point which mention in the table-4. From that we had get M/Ms value of experimental data point. In order to find theory value of M/Ms we can find out it through the Langevin theory.

The average dipole moment and polydispersity of the nanoparticles can be calculated from the magnetization curve of the nanoparticles in dilute dispersion. The measured curve does not show

hysteresis, allowing a polydisperse fit on the basis of the Langevin equation and a lognormal
distribution [16]. The Langevin equation describes how the magnetization M depends on the magnetic field.

$$\frac{M}{M_S} = L(\alpha) = M_S\left[\cot h(\alpha) - \frac{1}{\alpha}\right] \text{..... (1)}$$

where Ms is the saturation magnetization,

$$\alpha = \frac{\mu\mu_0 H}{Tk_B} \text{..... (2)}$$

and μ0 is the magnetic permeability of vacuum, μ is the magnetic dipole moment of a nanoparticle, His the magnetic field, and kBT is the thermal energy.

Since the magnetic volume fraction in all fluid is very low (2%), it resembles a paramagnetic gas. Thus, it can be analyzed using Langevin's theory for Para magnetism incorporating size distribution. In a magnetic fluid, particle size distribution is found to obey a log-normal distribution

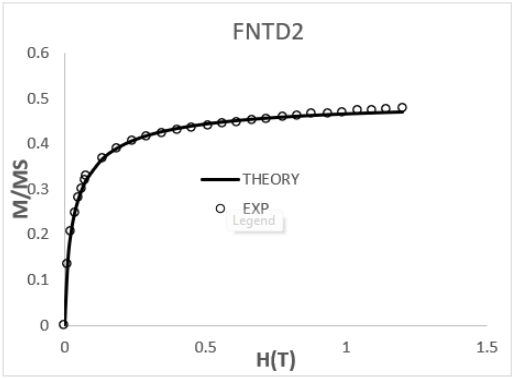
Accordingly, the magnetization of the fluid is given by,

$$\frac{M}{M_S} = \int_{H=0}^{\infty} \mu L(\alpha) P(\mu) d(\mu) \text{ ..... (3)}$$

$$P(\mu)\mathrm{d}(\mu) = \frac{1}{\mu\sigma_\mu\sqrt{2\pi}} \exp\left[-\left\{\frac{\ln(\mu/\mu_m)^2}{2\sigma^2}\right\}\right] \mathrm{d}(\mu) \text{.... (4)}$$

Here, the Langevin parameter α = μH / kBT, μis the magnetic moment of the particle, H is the applied magnetic field, kB is the Boltzmann constant, T is the absolute temperature, μm is the mean magnetic moment and σ□ is the log-normal moment distribution.[21]

In the above theory equation Ms , σ_μ, μ_m are variables and we can change the value of the them according the graph and we can get the value



Above graph is M/Ms vs H(T) in graph solid line indicates the theory result and dotted line show experimental result which are almost within 5% error super impose to each other which means that experimental value are obey theory so we can prove experimental value are right. Thus, for all system we can plot the graph and we can find out the value of Ms, σ_μ, μ_m for all system individually. Which are showing in below table.

SAMPLE CODE	□m (10^-19 Am2)	□m	Fluid MS (emu/g)
FN30	2.063	1.618	0.884
FNT0.5	2.113	1.560	0.869
FNT1	2.064	1.634	0.873
FNT2	2.036	1.671	0.885
FNT4	2.109	1.596	0.837
FNTD0.5	2.221	1.465	0.858
FNTD1	2.191	1.482	0.862
FNTD2	2.113	1.561	0.869

Table-7 different system and values of Ms , σ_μ, μ_m

In the above table for different sample we have find out the value Ms. , σ_μ, μ_m for all the samples from like above Table-4 and fig-6. We can find out the value of all parameter.

we can plot the graph for individual sample and we can plot graph and find the parameter like average magnetic moment, log normal co-officiant and saturated magnetization of all the sample.as shown in the table-5 In parent sample average magnetic moment 2.063 Am2 but if we adding the silica particles the moment value is increasing than parent sample. But log normal distribution co- officiant is decrease and saturation magnetization value also decreases for this system. Thus as discuss above form magnetization data value one can find the above parameter using Langevin theory.

3.5 Birefringence: -

3.5.1 Birefringence measurement

Mag. field(G)	analyzer max	I max (mV)	analyzer min	I min (mV)
3	244.2	362.1	324.8	70
16	243.6	361.9	324.3	94.5
38	242.8	361.2	324.8	113.6
61	244.6	360.9	324.1	125.2
77	245.6	360.5	323.2	156.4
124	247.3	359.8	323.6	172.2
144	249.6	359.4	323.2	179.6
216	250.7	358.6	322.8	192.9
299	251.9	357.9	323.6	202.8
407	253.3	357.1	324.1	210.2
503	253.9	356.5	324.6	215.4
606	255.2	354.9	325.2	218.3
696	255.4	353.3	324.6	218.8
812	256.3	351.8	324.3	222.1
904	257.6	351.2	325.4	222.8
1015	258.9	350.5	325.7	223.8

Table-8 applied magnetic field, analyzer angle maximum and minimum and intensity maximum and minimum

$$\Delta n = \sin^{-1}\left(2 \times \sqrt{\frac{I_{min}}{I_{max}}}\frac{ch(h_1 - h_2)}{1 + {}^{I_{min}}/_{I_{max}}}\right)\frac{\lambda}{2\pi d}$$

Where d is equal to 120□m and it is called as the spacer thickness which was kept between two glass slide , λ is 650nm(for red laser) & 530nm(for green laser), and hi (i=1,2) is the absorption coefficient

along two direction which can be obtain by solving two equation Ii = I0ie2hi(H) (I0i is the intensity of output in zero field). If we put the value of i=1 is for minimum intensity which is perpendicular angle with polarizer as we have discussed above in experimental part. And polarizer angle is fix throughout the experiment. i=2 is perpendicular angle at that we got maximum intensity. We have not down the minimum intensity and angle for that intensity and also same process for maximum intensity and it's angle. And one can make table this way.[13]

From the experimental data point, we got Imin and Imax. one can put the value in above equation and get experimental value of birefringence at applied magnetic field. And after that one can plot graph of applied field H(G) vs Δn (experimental birefringence).

For FNTD system we can plot the graph this way below.

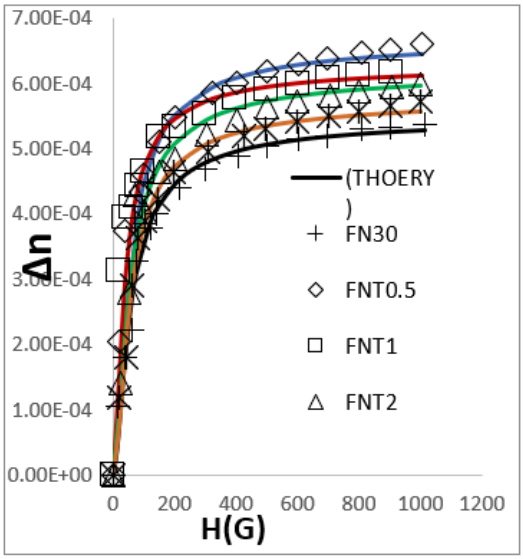


Fig-11 graph of applied field vs birefringence

Here in the figure shows the experimental as well as theoretical birefringence of the magnetic fluid at different silica concentration.

When we applied external magnetic field as we have say above a chain like structure formed in magnetic fluid. From fig-3 we can show that highest birefringence we can get in FNT0.5 in that sample concentration of silica particle is 0.5%. that is indicate that it's magnetic moment are high so it first alien in the direction of magnetic field.

As we increase the concentration of silica particles in magnetic fluid we show in the fig-3 that it's birefringence is decrease simultaneously. It is indicating that as we increase silica concentration it's magnetic moment is also decrease with respect to concentration. In order to find out the theory value of birefringence one can use below equation.

3.3.2 Equation for birefringence measurement by Langevin theory:-

The average dipole moment and polydispersity of the nanoparticles can be calculated from the

magnetization curve of the nanoparticles in dilute dispersion. The measured curve does not show hysteresis, allowing a polydisperse fit on the basis of the Langevin equation and a lognormal distribution [16]. The Langevin equation describes how the magnetization M depends on the magnetic field.

$$\frac{M}{M_S} = L(\alpha) = M_S\left[\coth h(\alpha) - \frac{1}{\alpha}\right]$$

where Ms is the saturation magnetization,

$$\alpha = \frac{\mu_0 \mu H}{k_B T}$$

and μ0 is the magnetic permeability of vacuum, μ is the magnetic dipole moment of a nanoparticle, H is the applied magnetic field, and kBT is the thermal energy. and where interactions are negligible, the magnetization M at field H is given. From below equation one can find the theory value of birefringence. And compare the experimental and theory value.

In this equation □ and Dnmax are variables.

$$\Delta n_{(theory)} = Dn_{max}\left[1 - \left(\frac{3L(\alpha)}{\alpha}\right)\right]$$

As discuss above one can plot the graph of H(G) vs Δn for both theory and experiment and compare the result and find the parameter like average moment □ and Dnmax.[21]

3.3.3 Low field effect:-

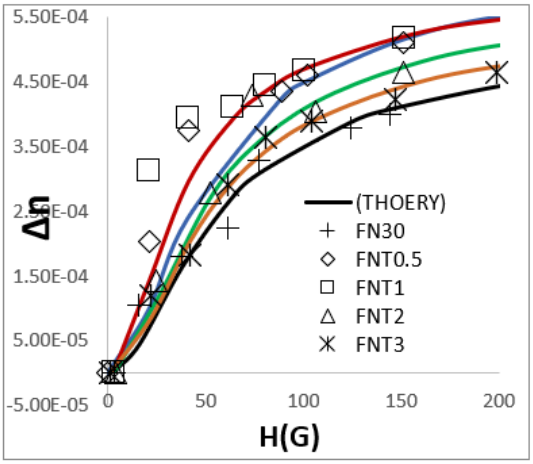


Fig-12 lower field effect in birefringence up to range of 0-200G.

When we apply external magnetic field, magnetic particles in magnetic fluid are trying to alien in direction of magnetic field.so chain or lattice type structure are formed in magnetic fluid. We know that lower field effect is only H dependence.

In Fig-12 we can show that at 20G Magnetic Field Highest Birefringence effect is in FNT1 fluid and at same field in FNT0.5 fluid Birefringence effect is much lower than FNT1.which indicate that magnetic moment in FNT1 is higher than all concentration and in FN30 which is parent fluid in that fluid birefringence effect is lower than FNT0.5 and at same field in FNT2 and FNT3 fluid Birefringence effect is less than other fluid. That is indicate that the their magnetic moment are less so their birefringence is low.

As increase the field we can show that birefringence of FNT1 is now decrease and in FNT0.5 birefringence is increase and in FNT2 & FNT3 also birefringence effect is increase but inFN30 it shows that is decrease that effect is at around 40G field.

At 80G magnetic field we can show that birefringence effect is highest in FNT1 and FNT2 they are super impose at that field and at same field in FNT0.5 birefringence effect is much lower than FNT1 and FNT2 and FNT3 and FN30 are also lower than that at same magnetic field.

At around 100G field FNT1 is still highest but in FNT2 the birefringence effect is decreases and it is lower than FNT1 and FNT0.5 and as shown above birefringence effect in FNT3 and FN30 still lower.

And at around 160G field we can show that birefringence in FNT1 is slightly decrease but in FNT0.5 it is shown that it is increase and in FNT2, FNT3 and FN30 birefringence is lower than FNT0.5 and FNT1 that one can see in fig-8.

Here in lower field only moment-field interaction occurs so big particles are try to alien first and it's birefringence is high. So in moment-field interaction in FNT0.5 is high so it is first try to alien in the and in FN30 moment-filed interaction is low so we can show in the graph particles in FN30 are alien in the direction of field at last.

3.3.4 High field effect:-

Higher field effect is occur at 400-1000G and it is H2 dependence. It is showing liner behavior at high field. We can show that in below graph.

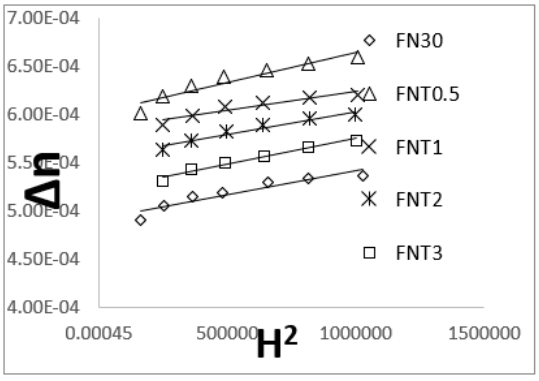


Fig-14 higher field effect in birefringence with H2 dependency for all sample.

Here both graphs indicate the higher field effect. In fig-13, we can show that lower birefringence is occur in FN30 which is parent fluid. And in FNT0.5 sample liner effect is high. Thus, we can say that birefringence effect is increase after percentage of silica particles are increase to 0.5, we can get highest birefringence. That is show the moment-moment and moment-field both interactions occur in higher field. And after that fig-10 indicates that birefringence for all samples in FNT system from graph we can show that highest birefringence effect is occur in FNT0.5 and lower birefringence effect is occurring in FN30 fluid. But as we increase the silica concentration, we can show that the birefringence effect is systematically decrees. Thus, one can show higher field effect in all sample.

Summary

From above experiment we can conclude that highest birefringence is observed in the FNT0.5 sample. Also, the magnetic moment determined from the magnetization data suggests highest magnetic moment. This indicates the magnetic field induced structure formation in the sample. Also, it suggests that the structure formed ion addition of critical silica concentration, augments the chain formation compared to the pure water based magnetic fluids. Further, on increasing the silica concentrations, the birefringence effect and the magnetic properties are systematically decreases. The parameters determined from the magnetization

data are average particles size, average magnetic moment, log normal distribution coefficient and saturation magnetization.

Significance

Magnetic fluids, also known as ferrofluids, are colloidal suspensions of magnetic nanoparticles in a carrier fluid. When exposed to a magnetic field, the magnetic nanoparticles in the fluid align themselves, leading to anisotropic optical properties such as birefringence. Birefringence refers to the phenomenon where the refractive index of a material varies with the polarization and direction of light passing through it.

The addition of silica nanoparticles to magnetic fluids has been shown to enhance the magnetic field-induced birefringence. This enhancement can be attributed to several factors, including the shape and size of the silica nanoparticles, as well as their surface properties.

The potential applications of this effect are numerous. For example, magnetic fluids with enhanced birefringence could be used in optical devices such as displays and sensors. Additionally, these fluids could be used in biomedical applications such as drug delivery and magnetic hyperthermia, where the enhanced birefringence could be used for imaging and tracking purposes.

References: -

[1] Ri-QingL, Yong Z ho, HoLi, Ard Hai-Fang-Hu IEEE Transaction on magnetic July-2015

[2] Shimolika J, Nakatsuka K, Jujta J and Kounosu A 1980 IEEE Trans.mag.16 (368)

[3] Wooding A, Kilner M, Lmbric D.B 1991 colloid interface science

[4] Rajesh Patel, Journal of optics and applied optics 125004 (2009)

[5] R. E. Rosenwein, Ferrohydrodynemics Cambridge Uni. London

[6] C. Sherer and .M. Figueierdo Neto, Brazilian Journal of Physics vol.35 September (2005)

[7] W. Luo, T. Du and J. Hung. Phys. Rev. Letter 82 41 34 (1999)

[8] W. Luo. J. Du and J Hung Mag. Matt. 201 88 (1999)

[9] Shengli Pu, Ziyun Di, Xianfeng Chen, Jingfai Chen and Yuxing Xia. Applied Physics letter 90, 161129 (2007)

[10] S. Taketomi J. Appl. Phys. 22 1137(1983)

[11] J. H. E. Promislow, A.P. Gast and M. Fermigier J. Chem. Phys.102 5492(1995)

[12] Wikipedia

[13] Z. Di, X. Chen, S. Pu, X. Hu and Y. Xia, Appl. Phys. Letter. 89 211106(2006)

[14] J. E. Martin, K. M. Hill and C. P. Tigger Phys. E 59 5676(1999)

[15] J. W. Seo, S. J. Park and K. O. Jang, J. Appl. Phys. 85 5956(1999)

[16] S. Y. Yung, Y. P. Chiu, B.Y. Jerng, H. E. Horng, Chin Y, H. Hong and H. C. Yang Appl. Phys. Letter. 79 2372(2001)

[17] S. Pu, X. Chen, Z. Di and Y. Xia. J. Appl. Phys. 101 (053532) (2007)

[18] S.Y. Yung, Y. T. Hsiao, Y.W. Hung, H.E.Horn, Chin Yih Hong and H. C. Yang J. Mag. Matter. 281 48(2004)

[19] Jian Li, Jun Fu, Yueqing Lin, Xiaodong Liu, AIP. 52 08563(2012)

[20] The Cambridge Polymer Group. Inc(2004)

[21] Rucha Desai, R V Upadhay and R V Maheta. "Augmentation of chain formation in magnetic fluid by the addition of Halloysite nanotubes. Journal of Physics 47 165501(2014)

[22] Chapter-3 Diamagnetism and Parmagnetism. INTRODUCTION TO MAGNETIC MATERIALS by B. D. CULLITY and C. D. GRAHAM

Appendix A List of Tables

Appendix B List of Graph

Appendix C List of equation

1. Introduction

2. Experimental

Figure - 4

2.3 Experimental setup

Figure 5 Experimental Setup of Birefringence measurement

Figure – 5

Figure 6 Experimental Setup of Birefringence measurement

Figure – 6

3. Result and Discussion

3.1 Density measurement

Table 3 Samples and their densities

Table – 3

3.2 Microscope Study

Figure 7 Chain formation occur in magnetic fluid due to external magnetic field

Figure – 7

3.3 Initial Susceptibility

Equation 1 To Find theory value of initial susceptibility

Table 4 To determine susceptibility of FNT0.5 system

Table – 4

Graph 1 Applied Field vs Magnetization Value for FNT0.5 system

Graph – 1

Table 5 Different samples and their initial susceptibility as well as magnetization

Table – 5

Table 6 Interpolates data M/Ms experimental and theory result

Table – 6

Equation 2 The Langevin Equation

Equation – 2

Graph 2 M/Ms vs H(T)

Graph – 2

Table 7 Different systems and theirs value

Table – 7

3.4 Magnetization theory

3.5 Birefringence

Table 8 Applied magnetic field, Analyzer angle Min. and Max. and Intensity Min. and Max.

Table – 8

Equation 3 For Birefringence measurement

Equation – 3

Graph 3 Applied field vs Birefrirengence

Graph - 3

Equation 4 Birefringence measurement by Langevin theory

Equation – 4

3.5.1 Birefringence measurement

3.5.2 Equation for Birefringence measurement

3.5.3 Low field effect

Graph 4 Low field effect

Graph – 4

3.5.4 High field effect

Graph 5 High field effect

Graph – 5

Summary

Significance

References