Chapter VI

Magnetic properties

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MAGNETIC PROPERTIES

6.1 INTRODUCTION

Magnetic properties include i) saturation magnetization (Ms), ii) Neel temperature (Tn), iii) susceptibility (X), iv) coercive force etc. With the help of hysteresis studies, one can estimate reasonably the values for the Saturation magnetisation, Remanance ratio and Coercive force. The hysteresis technique is usefull to understand the basic magnetic behaviour of solids. With the help of modern hysteresis measurement techniques, it is possible to make visible, the real shape of hysteresis on the oscilloscope screen to observe the effect of composition and temperature on it.

The ferrite with low Hc are called as soft ferrite. Soft ferrite have high electrical resistivity and low eddy current losses. Soft magnetic materials have been reviewed by Lee and Lynch (4). The soft ferrites are used in microwave devices, high frequency cores, antennas, Transformer cores etc. Ferrites with high Hc are called as hard ferrites. These are used in loud speakers, Telephones, electrical motors and permanent magnets, for which high remanace characteristics are widely used as memory devices in computers. According to Neel (7) the coercive force is related with saturation magnetisation, internal stress, porosity (8) and anisotropy stoichiometry have been especially important in controlling the magnetic properties of ferrites.

Snoek, Gorter and Goodenough (1,2,3) showed that in order to obtain large range of saturation magnetization a variety of substitutional ferrites can be prepared. To prepare ferrites with the desired device properties, it is necessary to know the magnetic as well as electrical characteristics, of a ferrite.

6.2 MAGNETIZATION IN HEXAGONAL AND RELATED MAGNETOPLUMBITE FERRITES

The most fundamental property of ferrites is the magnetization. The magnetization results from the distribution and alignment of magnetic ions on the octahedral and tetrahedral cation sites. If magnetic atoms are sufficiently close to each other, the spontaneous magnetization Ms occurs even in the absence of external field. The electrons can undergo an exchange interaction between neighbouring magnetic ions. This may be direct or may take place via an interatomic interaction, may be either positive or negative and it is based on parallel and antiparallel alignment of the spins of neighbouring atoms respectively. When the exchange interaction is positive it is ferromagnetic and when it is negative then it is either antiferromagnetic or ferrimagnetic depending upon complete or incomplete cancellation of magnetic moments within the crystal. Gorter arrived at a scheme of spin ordering on the basis of Anderson's concept of superexchange coupling to arrive at a reasonably good value of saturation magnetization.

The value of the saturation magnetization and paramagnetic susceptibility depends on the temperature which indicate that the magnetization of the material under consideration is due to non compensated antiferromagnetism. The value of saturation magnetization at low temperature could be estimated for this compound. It is assumed that an angle $Me^{x} - O - Me^{xx}$, where Me stands for two magnetic ions and O for oxygen ions giving rise to superexchange between them, cause strong negative interaction near 180°, while interaction between two magnetic ions can be neglected when this angle is near 90° (Rev. Mod. Phys. 25 (1953)).

6.3 MAGNETOSTRICTION

The magnetostrictive energy is the magentostriction parameter and is given by

$$E = 3/2 \ \lambda s \ \sigma \qquad \ldots \quad 6.1$$

where,

λs – saturation magnetization

σ - applied stress

Here the energy should be minimized to give the domain freedom of motion. The phenomenon of change in physical dimensions of magnetized material is known as the magnetostriction and is related to the thermal anomalies shown by ferri magnetic substance around Curie point. For cubic materials, the change in dimensions are isotropic i.e only the change in volume take place. But for hexaferrites both changes in volume and shape are observed. This change occur even when the material is cubic. The magnetostriction is closely related to crystal anisotropy and direction of magnetization.

6.4 SHAPE OF HYSTERESIS LOOP AND DOMAIN STATE

Following Bean's [11] work the hysteresis loops of micro-powders can be classified in four types namely -

1) Multi-domain (MD)
2) Superparamagnetic (SP)
3) Single-domain (SD-VA)
4) Single-domain (SD-CA)

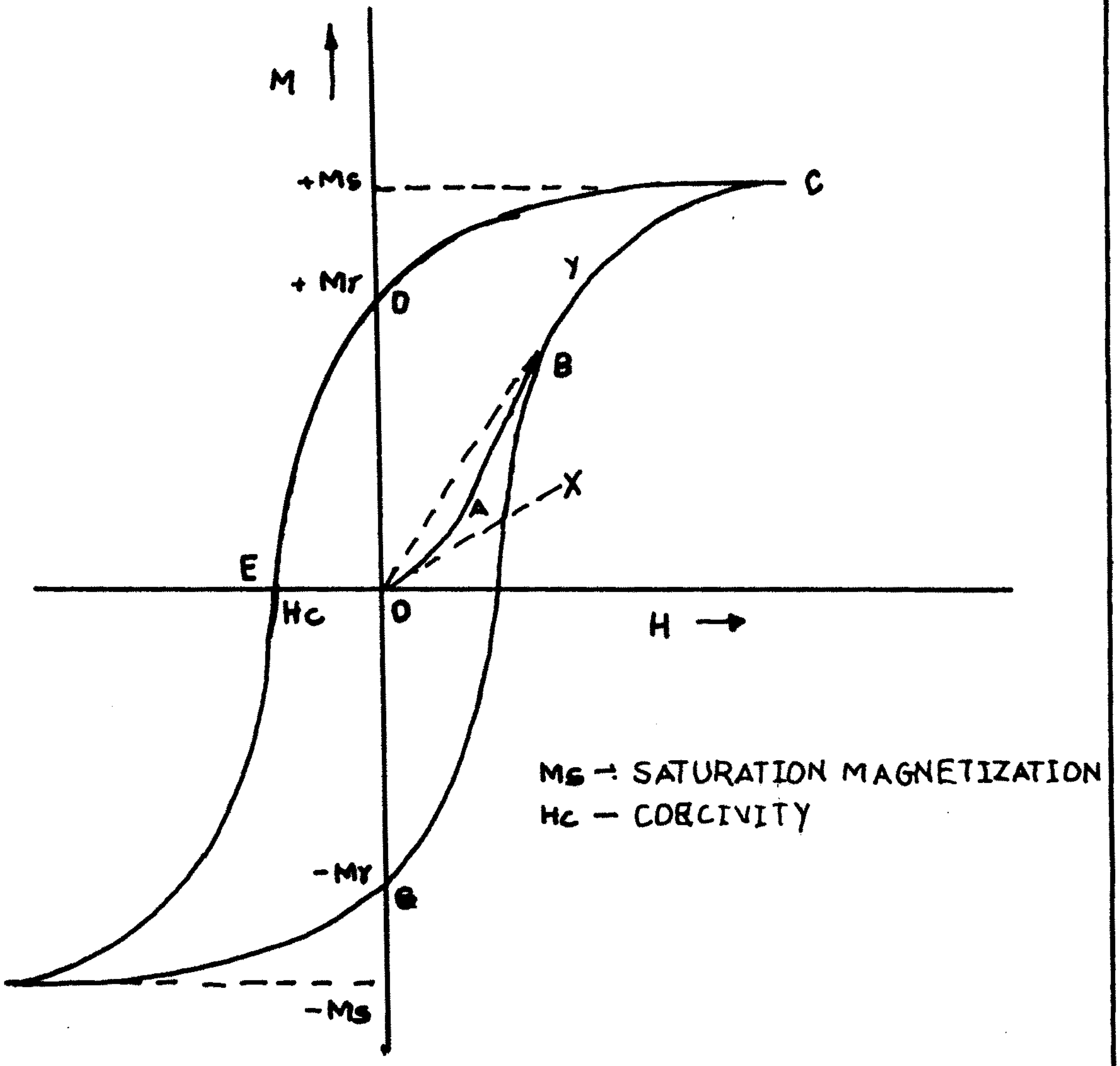
The salient features of the research work carried out in the field are (1) Loop shapes are independent of the parameters of the intensity of magnetization and magnetocrystalline anisotropy constant (K_1).

(2) SD and SP shapes are temperature dependent, where as MD shapes are temperature independent.

(3) Experimentally determined shapes agree with the theoretically compared shapes for SD and SP cases while for MD cases it is not so.

The general shape of curve is shown. At the beginning the material is in the magnetization state i.e at point 'O'. On the application of magnetic field, the magnetization increases until the saturation is reached, this is shown by the curve OABC. This part of the curve is called the magnetization curve. Then by reducing the magnetic field to zero, increasing it in the reverse direction and decreases to zero and then increasing it to the original value the curve CDEFGC results the curve is known as Hysteresis curve and is symmetric in nature.

In the Hysteresis curve the reversible wall displacements take place in the initial part. In the central part of the curve the irreversible wall displacement and **Berkhausen** jumps take place. On reducing the field the domains relax to the nearest easy direction to the magnetization because of anisotropy forces. On reversing the field, some boundary movements followed by a Berkhausen jump take place. Towards the bottom of the curve, rotations predominate again the saturation is reached in the reversed direction.



MAGNETIZATION CURVE (OABC) AND HYSTERESIS LOOP (CDEFGC)

Fig : 5·1

6.5 CALCULATION OF Ms AND nB

The vertical displacement on oscilloscope were taken for Ni sample of mass 0.2679 gms. As the standard magnetization for Ni sample is 53.35 emu/gm and applied field is 3 K Guass. The total magnetization of Ni sample is

$$53.35 \times 0.2679 = 14.289 \text{ emu}$$

The vertical divisions on C.R.O is 19 and hence the calibration factor (c.f.) is

$$\text{c.f} = \frac{\text{Total magnetization of Ni sample}}{\text{Reading for Ni sample}} \qquad 6.2$$

$$\text{c.f} = \frac{14.289}{19} = 0.75205 \text{ emu/mV}$$

The vertical reading for the samples were taken at room temperature and the liquid nitrogen temperature. By using these readings of magnetization of the samples were calculated.

$$\sigma s = \text{Reading in pellet} \times \text{c.f.}$$

hence σs is emu/gm .

$$\sigma' s = \frac{\sigma s}{\text{mass of pellet}}$$

and Ms is calculated as

$$Ms = (1 - p) dx \times \sigma' s \qquad \ldots \qquad 6.3$$

$$\text{where } p = \text{porosity} = \frac{dx - da}{dx}$$

$$dx = \text{X-ray density} = \frac{2 \times \text{Mol. wt.of sample}}{Na^2 \sqrt{3}/2\, C}$$

N = Avogadros No.

C, a = Lattice constant

$$da = \text{actual density} = \frac{\text{mass of pellet}}{\text{volume}}$$

$$= \frac{\text{mass of pellet}}{\pi r^2 t}$$

The magnetic moment per formula unit in Bohr magnetons (nB) is given by

$$nB = \frac{\text{Mol. wt. X } \sigma\text{'s}}{5585} \quad \ldots \quad 6.4$$

Hence from above formula Ms and n_B can be calculated.

6.6 EXPERIMENTAL TECHNIQUES

The essential parts of the hystersis loop tracer (12) are

1. Electromagnet
2. Pick up coil system
3. Balancing and integrating network
4. Preamplifier

1. Electromagnet

The two C cores (English eletric Co. type WR/110/32/13) of laminated grain oriented silicon steel with cross section of the holes 5X2.5 cm^2 have been used for this purpose. From one of C cores, a piece of 1.2 cm in thickness was cut out to get a pole gap of 1.2 cm. The two C cores were joined together. The energizing coil for the magnet consists of 2200 turns of 20 swg super enamelled copper wire (resistance 11.5 ohms) wound on a perspex former and held together on the wooden base.

2. Pick up coil system

A multicoil, which can be introduced in the pole gap serves as a pick up coil system. It consists of four different windings, one over the other wound with 39 swg super enamelled copper wire on a perspex former. The multicoil is connected to the balancing and integrating network to a amplifier and then to the Y plates of the oscilloscope The input of the x plate is taken from the emf developed across a resistance connected in series with proper inductance and variable resistance is also provided. The multiple unit was slid into the pole gap and the current in the energizing coil was increased to produce the required field. The potentiometer and variable resistance in the balancing network were then

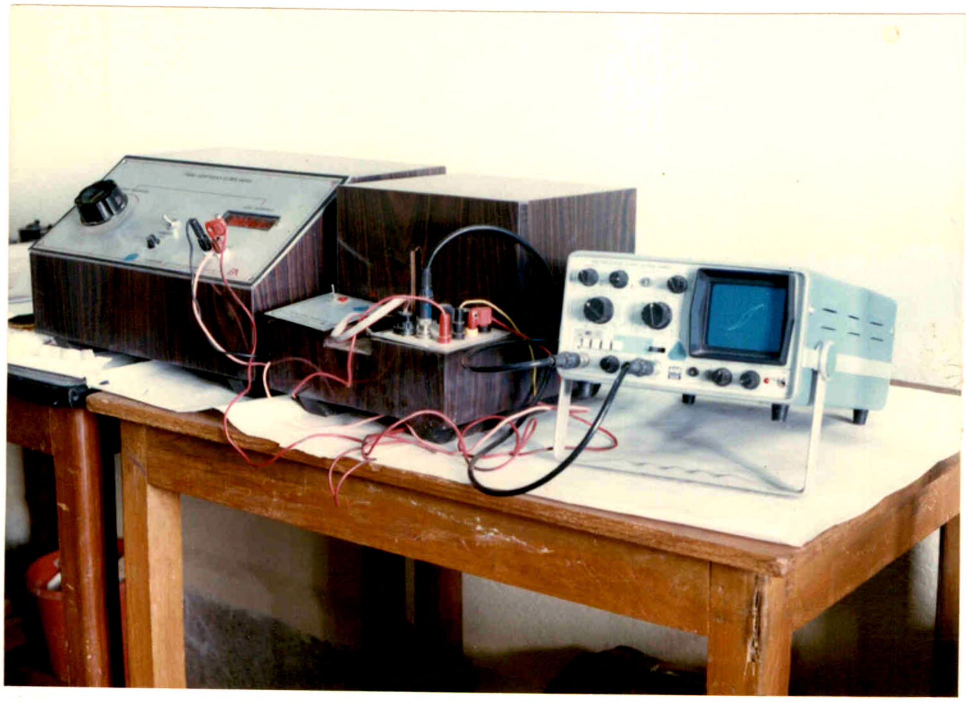
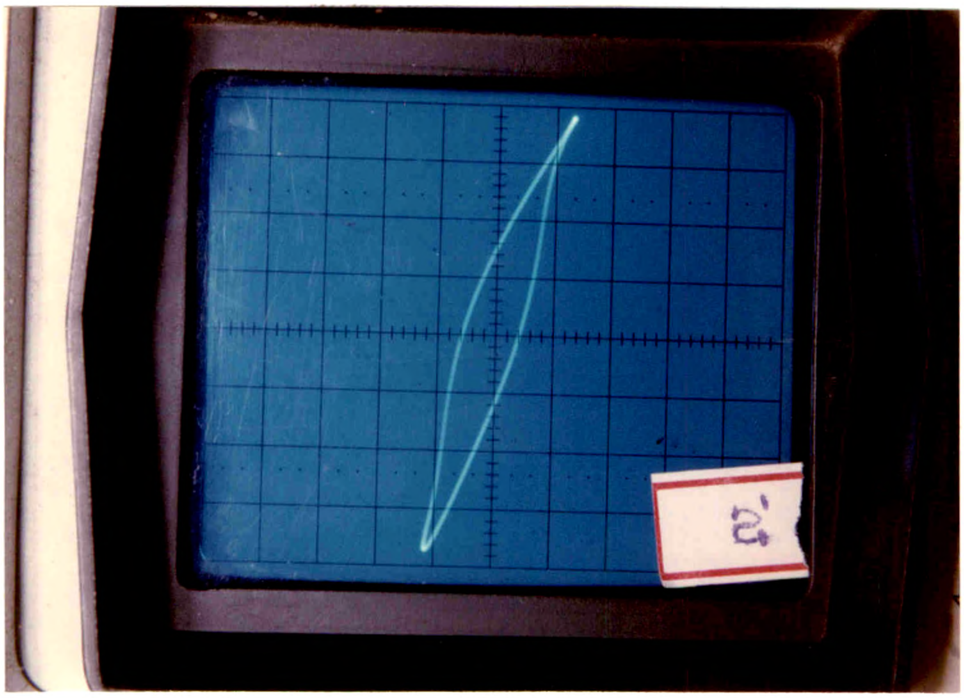
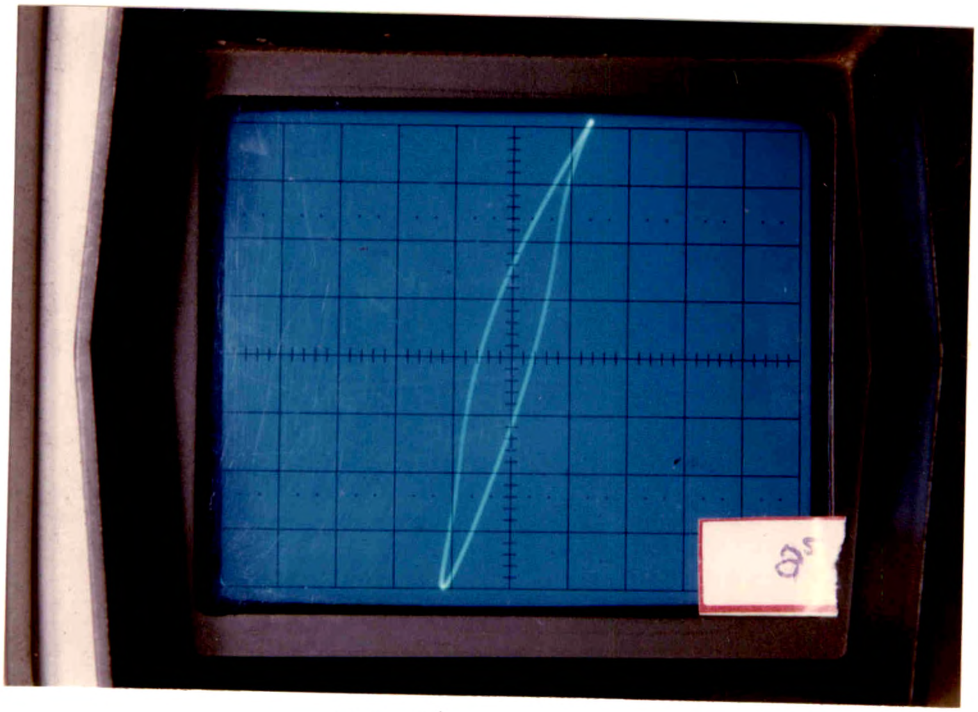


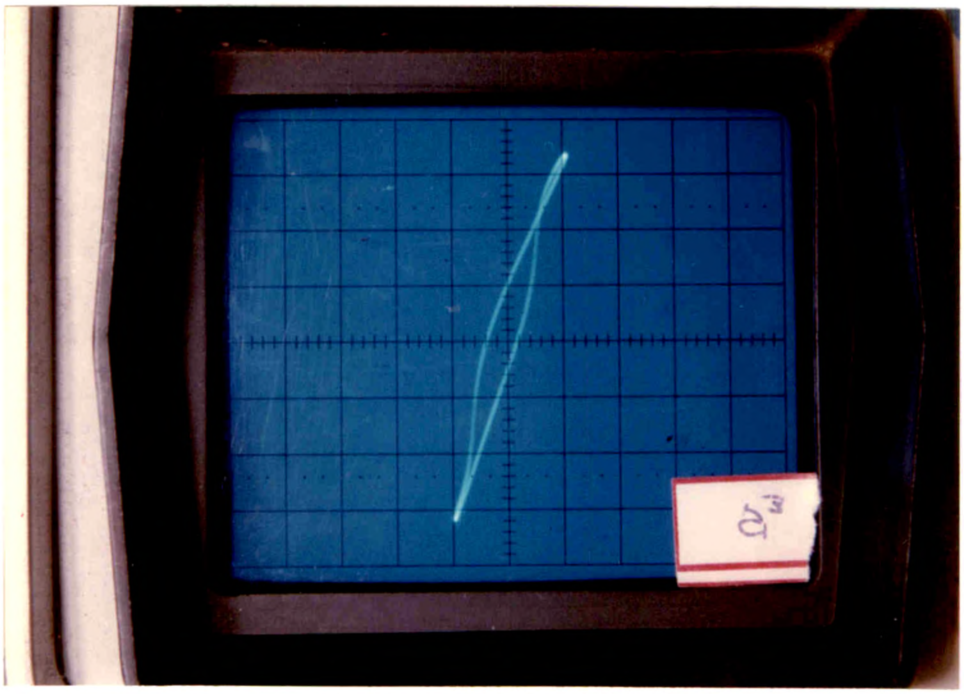
Fig 6·1 :- Experimental setup for Hysteresis loop



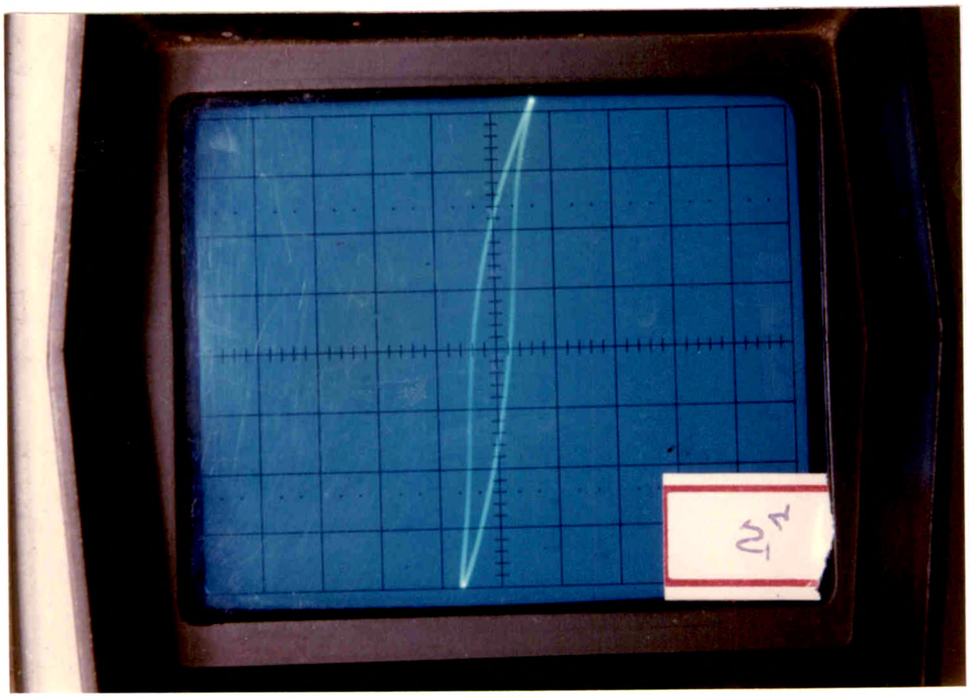
X = 2



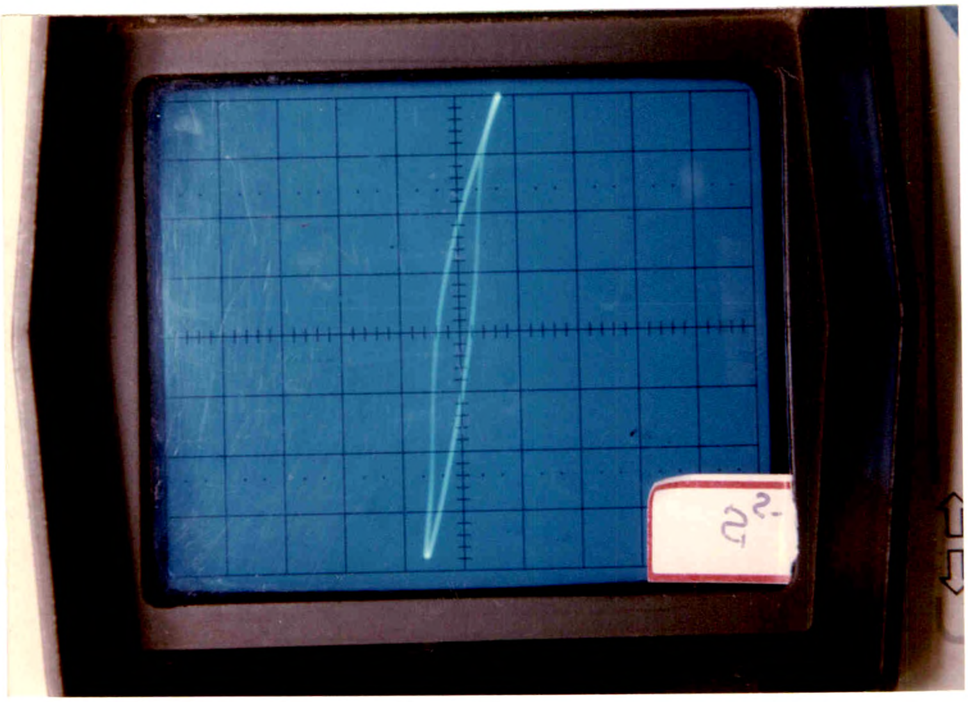
x = 3



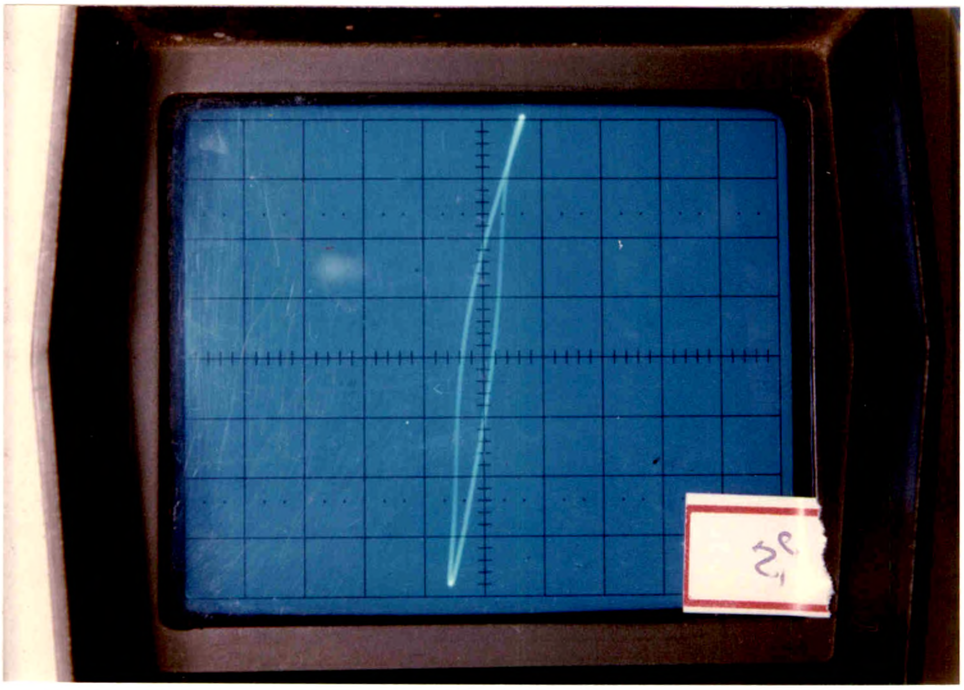
$x = 4$



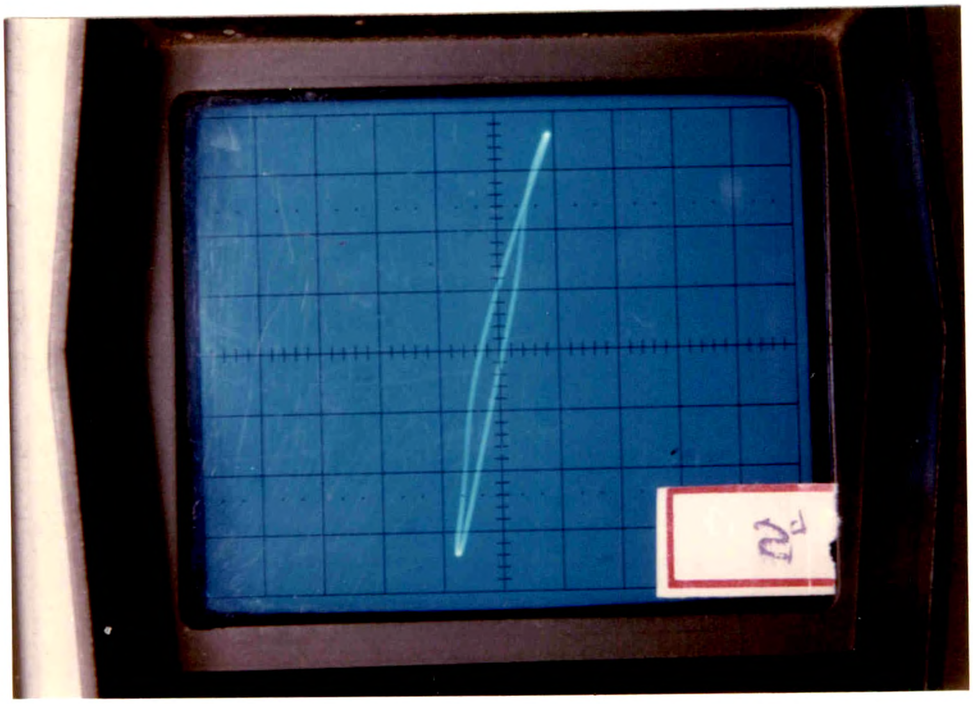
$x = 5$



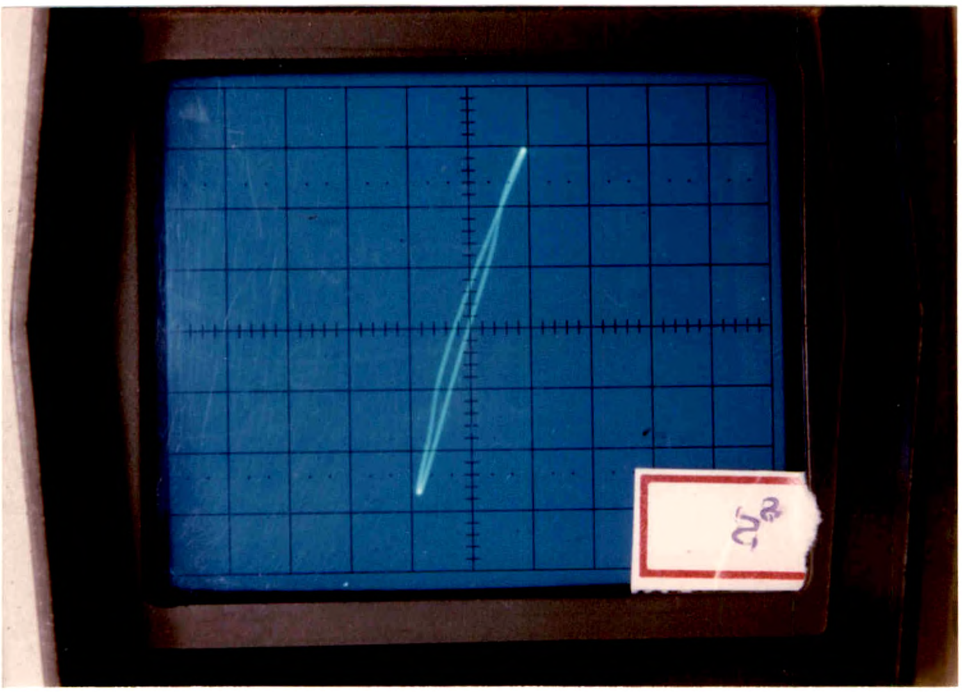
x = 6



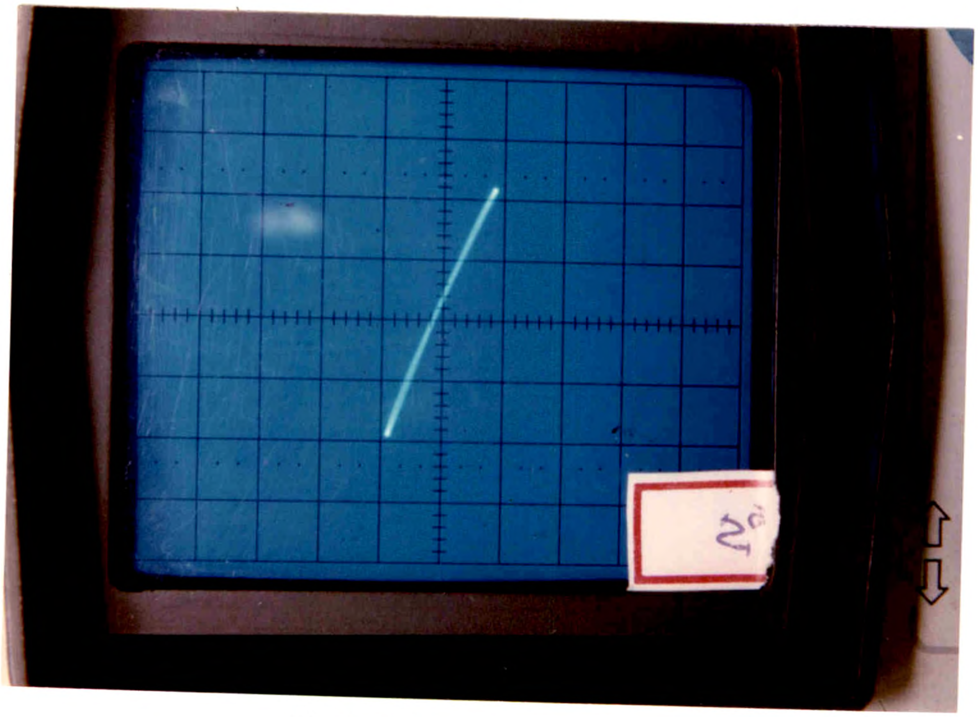
x = 7



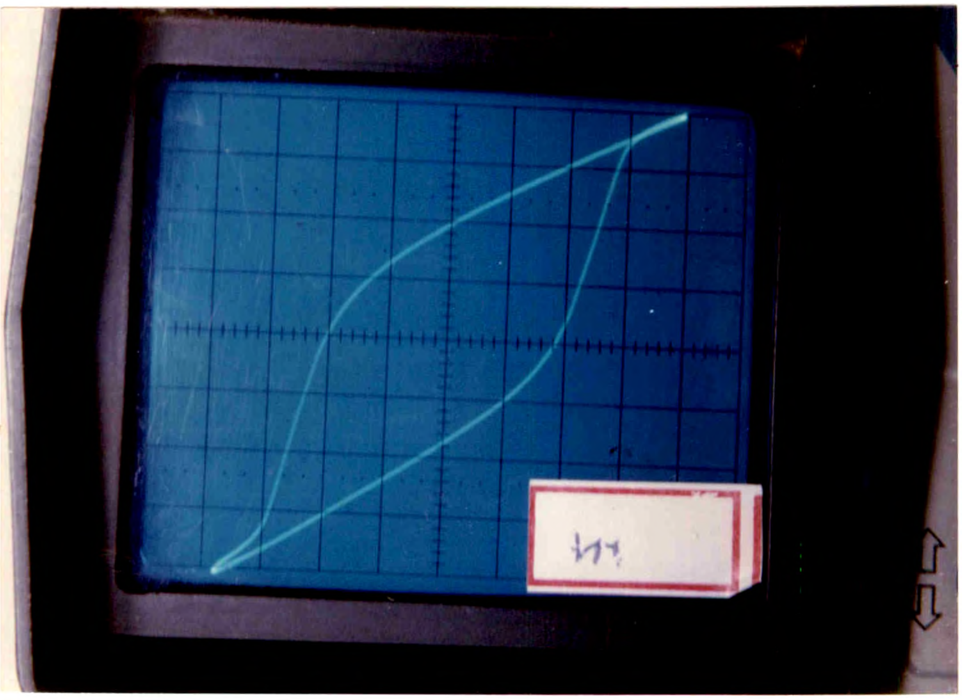
X = 8



x=9



X = 10

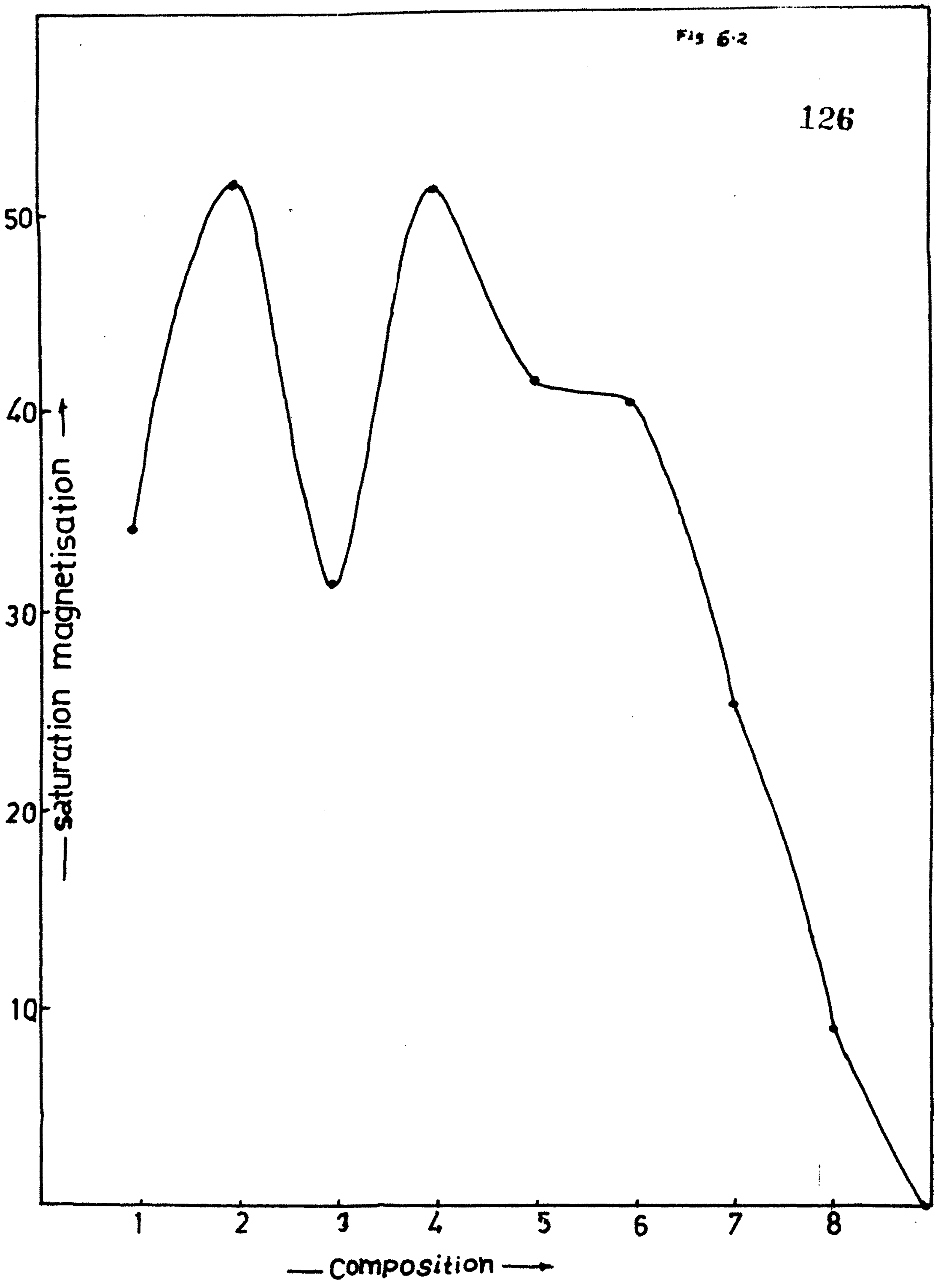


* Ni Sample

Table 6.1

Sample No.	**Actual density da**	**x-ray density dx**	**Porosity in %**	**Saturation magn. Ms**	**nB**
S1	2.880	4.590	37	33.332	2.02
S2	3.198	4.484	28	51.520	2.73
S3	2.671	4.347	38	30.940	1.90
S_4	2.969	4.182	29	51.564	2.76
S_5	2.627	4.045	35	41.247	2.41
S_6	2.769	3.910	29	42.77	2.29
S_7	2.094	3.787	44	28.570	1.95
S_8	2.137	3.652	41	12.258	0.64
S_9	2.196	3.371	34	–	–

Fig 6·2


50
40
30
20
10
— Saturation magnetisation →
1
2
3
4
5
6
7
8
— Composition →

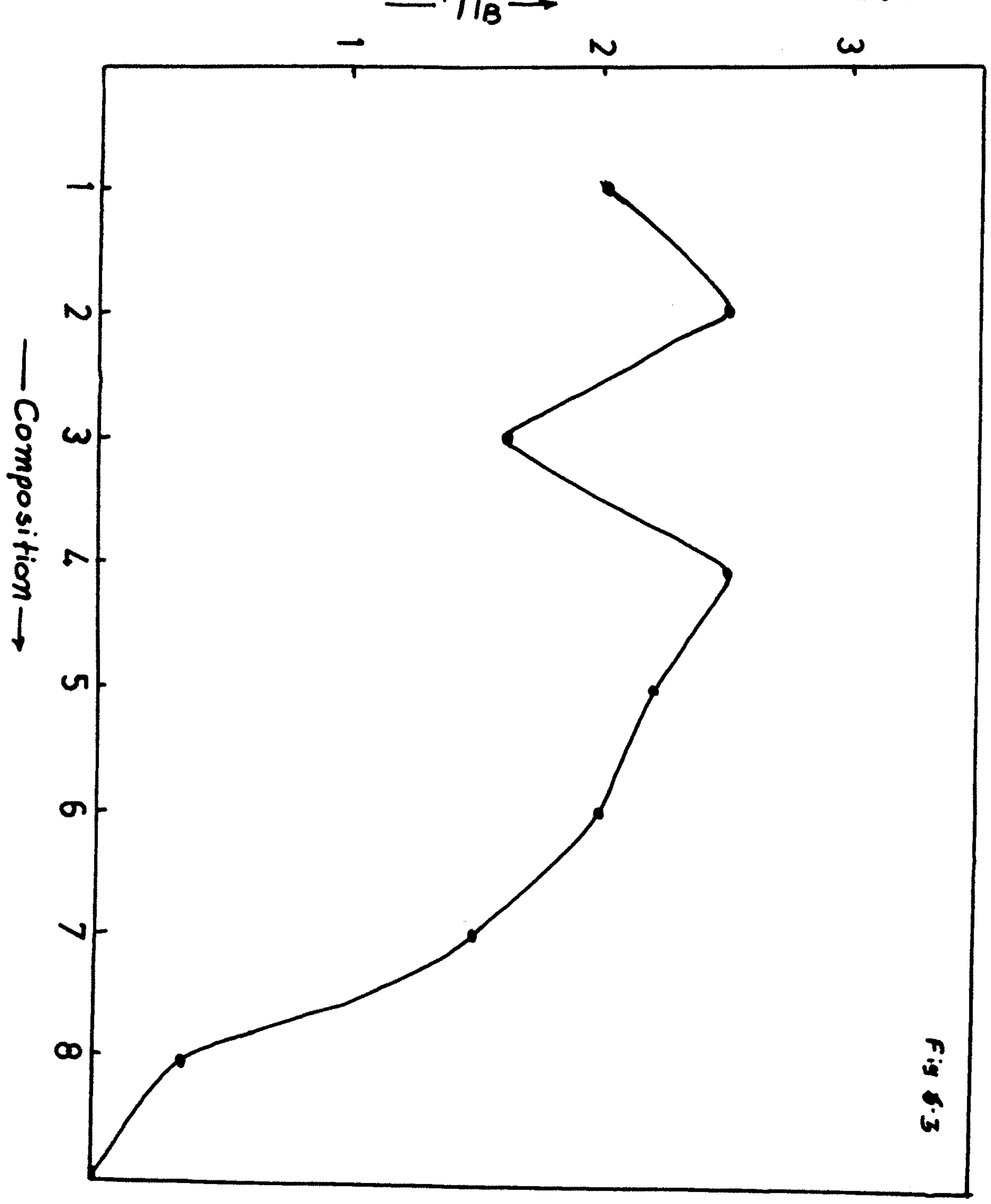


Fig 5·3

adjusted to get a horizontal trace on the oscilloscope. After reducing the current to zero, the multicoil was pulled out and the ferrite pellet kept at the central gap in the multicoil spool and next introduced into the pole gap. The current in energizing coil was raised to a sufficient value till the sample saturates. The hysteresis loop produced on the oscilloscope was recorded for accurate measurement of magnetization.

Pure nickel (99.9%) in the form of cylindrical pellet (Ms = 55.35 emu/gm) at 27° C was used for calibration of Y axis. The horizontal scale was calibrated by measuring the magnetic field. The pole gap with a sensitive gaussmeter while d.c. were passed through the energizing coil. For obtaining hysteresis loop ac fields are used and hence the necessary corrections for d.c. fields were incorporated. The experimental set up is shown in Fig. 6.1. Composition vs magnetisation and nB are shown in Fig.6.2 and 6.3.

Tentative explanation of nature of magnetic moment

There are at least three causes for the deviations of the magnetic moment from theoritical valves.

1. The ions distribution may not be the same.
2. The ions may have in addition to a spin moment an orbital m0ment, which is not completely quenched.

3. The angles may occurs, which has not yet been proved experimentaly (P.No. 150 Ferrite, J.Smit and H.P.S WIJN. 1959)

A corsory anlysis of magnetic moments may be presented as below which is only rough and does not constitutes as a rigorous theoretical estimate.

For x = 2

$NiAl_2Fe_{10}O_{19}$

$NiFe_2O_4 : Al_2Fe_8O_{15}$

$(Fe^{3+})[NiFe^{3+}]O_4 : A_{12}Fe_8O_{15} = 2.02$

For x = 3

$NiAl_3Fe_9O_{19}$

$NiFe_2O_4 : Al_3Fe_7O_{15}$

$(Fe^{3+})[NiFe^{3+}]O_4 : Al_3Fe_7O_{15} = 2.73$

For x = 4

$NiAl_4Fe_8O_{19}$

$NiFe_{1.38}Al_{.62}O_4 : Al_{3.38}Fe_{6.62}O_{15}$

$(Fe^{3+})[NiFe^{3+}{}_{.8}Al_{.62}]O_4 : Al_{3.38}Fe_{6.62}O_{15}$

$= 1.90$

For x = 5

$NiAl_5Fe_7O_{19}$

$NiFe_2O_4 : Al_5Fe_5O_{15}$

$(Fe^{3+})[NiFe^{3+}]O_4 : Al_5Fe_5O_{15} = 2.76$

For $x = 6$

$NiA_{16}Fe_6O_{19}$

$NiFe_2O_4 : Al_6Fe_4O_{15}$

$(Fe^{3+})[NiFe^{3+}]O_4 : Al_6Fe_4O_{15} = 2.41$

For $x = 7$

$NiAl_7Fe_5O_{19}$

$NiFe_2O_4 : Al_7Fe_3O_{15}$

$(Fe^{3+})[NiFe^{3+}]O_4 : Al_7Fe_3O_{15} = 2.29$

For $x = 8$

$NiAl_8Fe_4O_{19}$

$NiFe_2O_4 : Al_8Fe_2O_{15}$

$(Fe^{3+})[NiFe^{3+}]O_4 : Al_8Fe_2O_{15} = 2$

For $x = 9$

$NiAl_9Fe_3O_{19}$

$(Fe^{3+})[NiAl]O_4 : Al_8Fe_2O_{15}$

$(Ni_{.02}Fe^{3+}{}_{.75}Al^{3+}{}_{.23})[Ni^{2+}{}_{.98}Fe^{3+}{}_{.25}Al^{3+}{}_{.77}]O_4$

$: Al_8Fe_2O_{15} = 0.58$

For $x = 10$

$NiAl_{10}Fe_2O_{19}$

$(Al^{3+}Ni_{.5})[Ni_{.5}Al^{3+}]O_4 : Al_8Fe_2O_{15} = 0$

6.7 Results and discussion

On the basis of $BaFe_{12}O_{19}$ a range of hexagonal structures have been investigated(Braun, 1957). These are M, W, X, Y, Z and U which have nearly the same value of unit cell 'a' but different 'c' values. Various substitutions in the magnetoplumbite structure for Ba/Sr/Pb and Fe/Al/Ga by suitable diavalent and trivalent ions or a combination of ions have been carried out.

Investigations in which Ba/Sr/Pb are substituted by a combination of Ba, Sr (Borovik, 1962 a,b, Kajima 1965) and Ag, Ba (Sinha et al 1963), Na,La (Sumergred 1957) etc show that the magnetic properties are very much similar to the original compounds , since the exchange interaction takes place only in Fe -O -Fe and Ag, La. Na, Br, Sr etc. does not influence appreciably the interaction. However substitutions of Fe^{3+} by Al, Ga, Cr (Bertaut, 1959, Gato et al 1973, Albanese 1974) etc. affect the lattice dimensions, site distribution Curie temperature, saturation magnetization etc.

The most of the M type compounds exhibit ferrimagnetic behaviour, which is due to the fact that the net magnetic moment from an incomplete cancellation of moment of ferric ions. The moment from the octahedrally surrounded ferric ions in the spinel blocks and those in the trigonal bipyramidal sites are opposed by a minority of ferric ions in tetrahedral sites in the spinel block along with octahedral sites.

It would be reasonable to suppose that replacement by non-magnetic ions of ferric ions in the tetrahedral sites in the spinel blocks would leads to an increase inthe magnetic moment of the compound which shown by sample S_2 and S_4.

Similarly replacement in the latter sites by a non magnetic cations (Al^{3+}) would reduces the magnetic intensity of the compound.

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