Ferromagnetic Resonance in Various Ferrites at Low and High Temperatures

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Synopsis

Ferromagnetic resonances in manganese, copper, and magnesium ferrites and nickel-zinc binary ferrites were tried at low and high temperatures at the frequency of 9310 MC; in the temperature range of magnetic transition for manganese ferrite, double peaks were observed; with lowering of the temperature, a small peak at low field overlapped the ordinary large peak showing an asymmetrical resonance curve which tended to be symmetrical at the lowest temperature. g-factors and the half line widths were determined up to the Curie temperatures. In general, the line width of simple ferrites decreases monotonously to the Curie temperature, but those of binary ferrites containing zinc ferrite first decreases rapidly with rising temperature from the liquid nitrogen temperature and then increases near the Curie temperature; especially, it is most interesting to notice that the curve of line width versus temperature for high zinc ferrite in Zinc-Nickel ferrites shows minimum and maximum, the behaviour seems to correspond to a type predicted by Néel, which appears in the diagram for saturation magnetization versus temperature.

Moreover, we could determined g-factor of various Ni-Zn binary ferrites just at Curie point, by using paramagnetic resonance condition; the value of g-factor monotonously decreases with increasing content of zinc ferrite. The fact is quite in contradistinction to the change of g-value with varying zinc content in Zn-Ni ferrites at room and low temperatures.

The size effect reported by Beljers and Polder could not be observed for nickel ferrite and Ni-Zn binary ferrite at the frequency of 9310 Mc/sec., but recently it was observed at 23,500 Mc/sec. at room and low temperature on several ferrites.

I. Introduction

There have been many studies on the physical properties of spinel type oxide from the magnetic and the electric measurements, furthermore, by means of the ferromagnetic resonance experiment.

From these measurements, the magnetic transition of magnetite at a temperature of -160°C has been studied,[1],[2],[3] and especially, from the experiment on X-ray and the changes of electrical conductivity accompanying the transition, Verwey[4] stressed that the anomaly of magnetite could be attributable to a rearrangement of ferric ion Fe^{+++} and of ferrous ion Fe^{++} in 16C site.

Recently, one of the present writers discovered the magnetic transtion of nickel ferrite which occurred at -120°C and seems to have been finished at a lower

(1) L. R. Rickford, Phys. Rev. Phys. Rev., **78** (1950), 449.
(2) C. A. Domenicalli, Phys. Rev. **78** (1950), 458.
(3) T. Okamura and Y. Torizuka, Rci. Rep. RITU, A-Vol. **3**, No. 2 (1951), 215,
(4) E. J. W. Verwey and P. W. Haaymen, Physica, **8** (1941), 970.

temperature than −195°C, for which the ferromagnetic resonance experiment[5] was carried out, and furthermore, the transition was investigated by measuring the magnetic property and electrical conductivity at a low temperature,[6] and the problem of applying Verwey model to the transition was discussed.

We found recently also magnetic anomaly of the same type of Mn-ferrite at a low temperature[7] in the range of +20°C to −150°C, for which the resonance experiments were made at the wave length of 3.22 cm, and the results have been presented.

The microwave resonance experiment in ferrites at high temperature was first undertaken by the present writers[8] for cobalt ferrite and also in Co-Zn binary ferrite at a low temperature,[9] and many interesting results were obtained. We performed the same experiment on manganese ferrite, copper ferrite, magnesium ferrite and nickel-zinc ferrites, up to the Curie point, and the resonance field, g-factor and the half line widths were determined at various high and low temperatures.

II. Preparation of specimen

$MnOFe_2O_3$:

Manganese carbonate and Fe_2O_3, the latter being prepared by heating ferrous-sulphate at 800°C in the air, were mixed in the desired mol ratio and the mixed powder was heated at 1,200°C for three hours. The sintered block thus obtained was crushed to the size below 200 mesh.

The powder obtained was pressed at 2∼5 ton/cm² in the cylindrical form, whose diameter was 1 cm and 3∼4 mm in thickness. This compact was heated again in the air at 1,300°C for 3 hours and then quenched in the air.

$MgOFe_2O_3$:

MgO powder was prepared by firing chemical pure magnesium powder and was mixed with Fe_2O_3 and pressed at 2 ton/cm². The compact obtained was sintered at 1,200°C for three hours and then quenched in the air.

$CuOFe_2O_3$

CuO powder was prepared by heating $Cu(NO_3)_2$ at 800°C for 5 hours and was mixed with Fe_2O_3 and pressed at 3 ton/cm². The compact obtained was sintered at 1,050° for 3 hours and then quenched in the air.

Ni-Zn binary ferrite:

Nickel carbonate and ZnO powder prepared by firing pure zinc powder, were mixed with Fe_2O_3 thoroughly in the desired mol ratio, and the mixed powder was pressed at 2 ton/cm² in the form of rectanguler plate; the compact was first

(5) T. Okamura, Nature, No 711, July 28 (1951), 162.
T. Okamura and Y. Torizuka, Sci. Rep. RITU, A-Vol. 3, No. 2 (1951), 219,
(6) T. Okamura and J. Simoisaka Sci. Rep. RITU, A-Vol. 3, No. 2 (1951), 223.
(7) T. Okamura and J. Simoizaka, Phys. Rev. 83 (1951), 664.
(8) T. Okamura, Y. Torizuka and Y. Kojima, Phys. Rev. to be published. Details to be published by Y. Torizuka, in Sci. Rep. RITU.
(9) Y. Torizuka, Sci. Rep. RITU, to be published.

sintered at 1,000°C for 3 hours. The sintered block was crushed to the size with the sieve of 200 mesh, and the powder obtained was again pressed at the pressure of 2 ton/cm^2 in a thin cylindrical form. Next, the cylindrical compact was sintered at 1,200°C for three hours and then quenched in the air.

From the sintered block thus obtained, thin disk specimens 2 mm~3.5 mm in diameter, 0.2 mm~0.4 mm in thickness were polished out, whose density always showed above 80%, in accordance with the calcuated value.

The dimensions of specimens used for the present experiment are given in Table 1.

Table 1.

Material		Form	Thickness (mm)	Diameter (mm)
$MnOFe_2O_3$		disk	0.30	2.80
$CuOFe_2O_3$		disk	0.23	2.70
$MgOFe_2O_3$		disk	0.25	3.40
$NiOFe_2O_3$		sphere		1.5, 2.0, 2.5.
Ni-Zn ferrite		sphere		1.5, 2.0, 2.5.
$NiOFe_2O_3$	$ZnOFe_2O_3$ %			
100	0	disk	0.15	1.70
80	20	disk	0.15	2.10
60	40	disk	0.20	1.90
40	60	disk	0.15	2.40
20	80	disk	0.20	2.25

III. Resonance experiment on Mn-ferrite at low temperature*

Experimental apparatus and the method were the same as for the magnetic resonance experiment on the antiferromagnetic materials;[10] the rectangular resonant cavity at low temperature made of transparent silica was used, at the bottom of which the specimen was fixed by means of drop of vacuum compound; the cavity containing the specimen was first cooled down at the liquid nitrogen temperature, and the relative absorptions with varying static magnetic field were observed, while warming it at the rate of 0.5°C per minute from the lowest temperature to higher temperatures.

Figs. 1, 2 and 3 show the curves of relative absorption with varying applied magnetic field from room temperature down to −190°.

In the temperature-range of +25° to −70°, double peaks were observed; with falling temperature, a small peak overlapped the ordinary large peak, which showed an asymmetrical resonance curve tending to be symmetrical as shown in Figs. 2 and 3.

From the result of magnetic measurement, it had previously been determined that the transition of the manganese ferrite would begin at +25° and finish at −150°, below which the intensity magnetization showed almost constant value.[7]

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* The result was reported in abridgment to Phys. Rev; Vol. 83, No. 4, 847~848, August 15, 1951.

(10) T. Okamura, Y. Torizuka and Y. Kojima, Sci. Rep. RITU, A-Vol. 3, No. 2 (1951), 209.

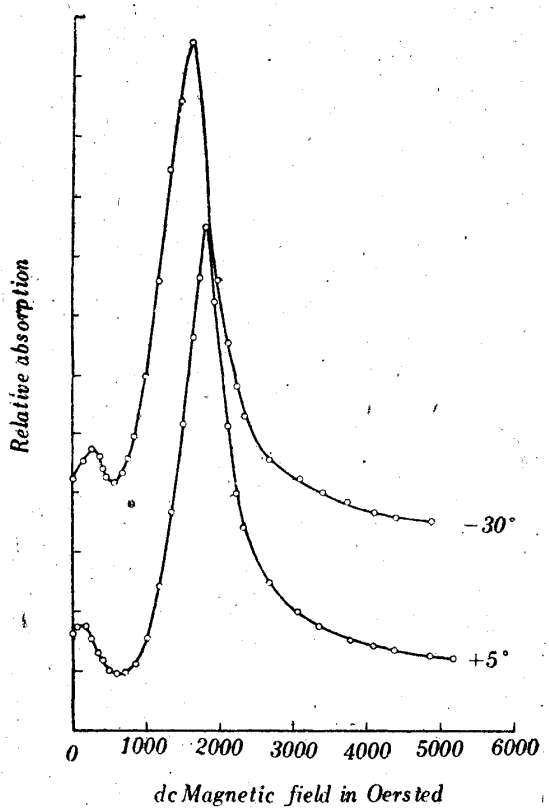

Fig. 1 Curves of absorption versus dc magnetic field for $MnOFe_2O_3$; temperature range +5° to −30°.

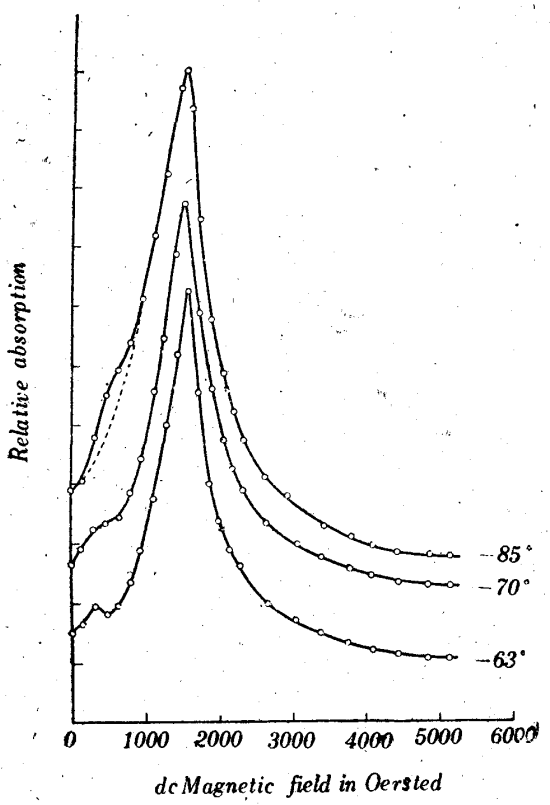

Fig. 2 Curves of absorption versus dc magnetic field for $MnOFe_2O_3$; temperature range −63° to −85°.

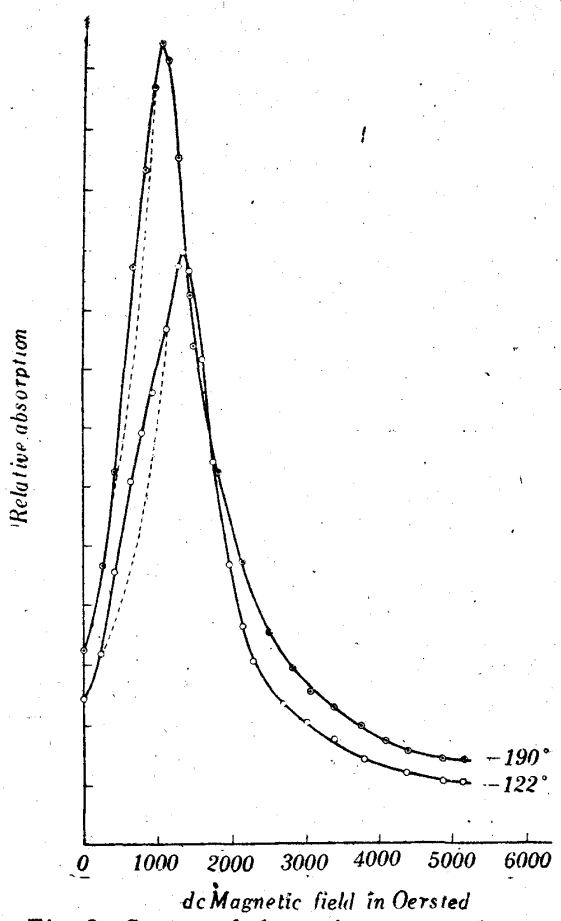

Fig. 3 Curves of absorption versus dc magnetic field for $MnOFe_2O_3$; temperature range −122° to −190°.

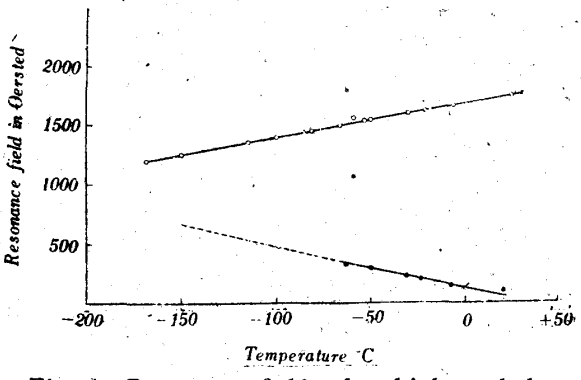

Fig. 4 Resonance fields for high and low peaks versus temperature.

To ascertain the behaviour of these double peaks more precisely, the resonance field strengths were plotted as a function of temperature as shown in Fig. 4; the open circles denote a resonance field for high field peak, the solid circles low field peak, respectively. From this figure, it can be concluded that the manner of the change of resonance fields with varying temperature is qualitatively the same in the case of nickel ferrite.[5] Thus, the double peaks in $MnOFe_2O_3$ may also be considered to be due to a mixed state of crystal that appears in the process of transition. The problem will be discussed in connection with the single crystal which has recently been prepared in our laboratory.

IV. Resonance experiment on Mn-ferrite at high temperature

The resonant cavity at high temperature was used, by which the resonance experiment on cobalt ferrite at high temperature was made.[11] Details for the apparatus and procedure were therefore, neglected here.

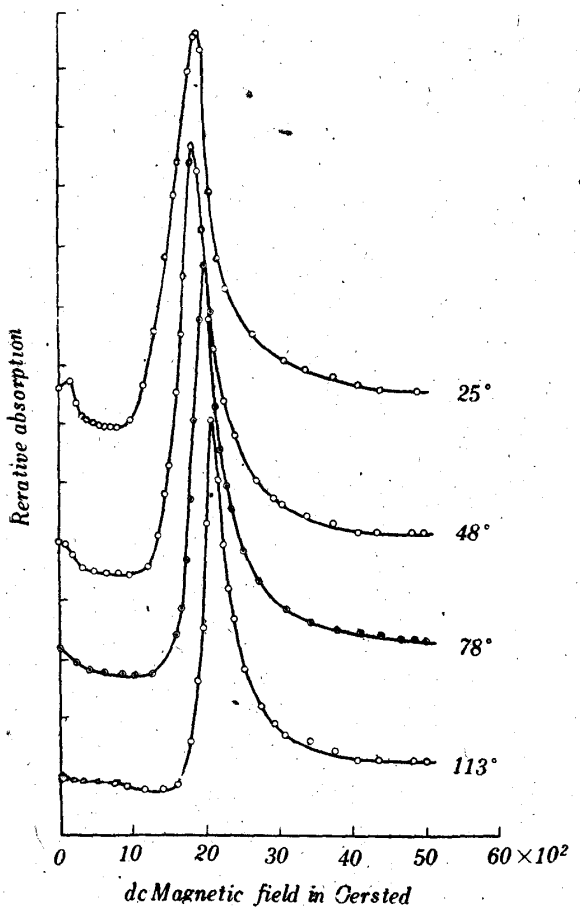

Fig. 5a Curves of absorption versus dc magnetic field for $MnOFe_2O_2$; temperature range 25° to 113°.

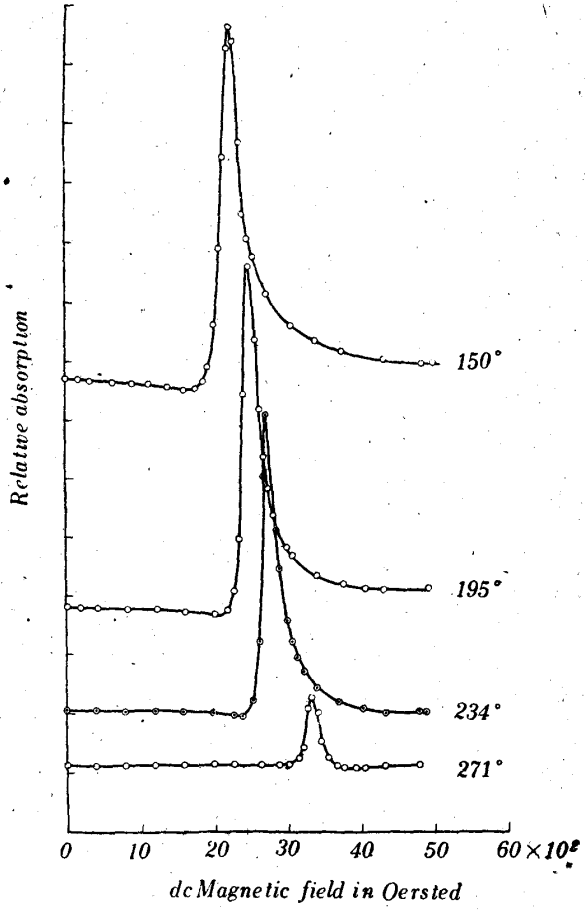

Fig. 5b Curves of absorption versus dc magnetic field for $MnOFe_2O_3$; temperature range 150° to 271°.

Figs. 5a, b show the curves of the relative absorption with varying dc magnetic field at various temperatures, from room temperature up to near the Curie temperature. As seen from these figures, the line shape becomes narrower, and

(11) Y. Torizuka, Sci. Rep. RITU, to be published.

the absorption amount decreases with rising temperature up to the vicinity of the Curie point, at which the resonance disappears.

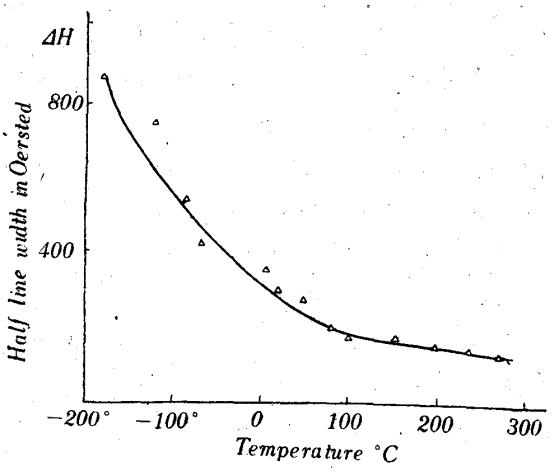

Fig. 6 The half width of the absorption line as a function of temperature for $MnOFe_2O_3$.

Table 2.
$MnOFe_2O_3$
Curie point: 303°C

Temp. °C	Line Width ΔH (Oe)
−190	880
−122	760
−85	540
−70	420
−30	400
+5	360
+25	300
+62	280
+100	200
+125	180
+192	180
+250	160
+300	145

The line widths were determined at the half-maximum values of field for the resonance curves at high and low temperatures, and are shown in Fig. 6. In accompanying Table 2, the decreasing behaviour of the line width is always monotonous, but the amount different from the case of cobalt, because of the extremely large crystalline anisotropy.

Next, g-factor and the absorption amount were determined from the Fig. 5a, b at various temperatures by using the saturation magnetization obtained by Pauthonet;[12] these values are graphically shown in Fig. 7.

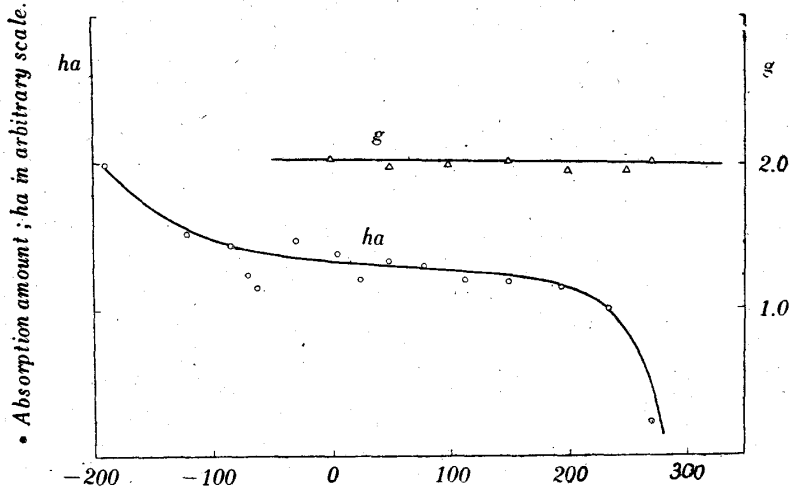

Fig. 7 The amount of the absorption at the maximum and the g-factor as functions of temperature; the open circles represent the absorption amount. the triangles represent g-factor.

The g-factor of $MnOFe_2O_3$ at room temperature was determined by many physicists with microwave resonance experiments, and the magnitude of g-factor indicates that the magnetic moment of Mn-ferrite and of the whole series of Mn-Zn ferrite is due almost entirely to the spin moments of the Fe^{+++} and Mn^{++} ions and that the contribution from the orbital moment is essentially zero in these materials.

(12) R. Pauthonet, Compt. Rend, **230**, 1843 (1950).

In the present experiment, the magnitude of g-factor at room temperature was found to be 2.02 by assuming the density of the specimen to be 5.5. The value satifactorily coincides with the uncorrected value 2.02 obtained by Yager and co-workers[13] at a frequency of 24,164 Mc/sec., but somewhat different from the value 2.05 as the corrected value for the size effect.

The value of g at various high temperatures are listed in Table 3; $g=2.0$ remains almost constant over the whole temperature range from room temperature to the Curie temperature, within the limit of error. Small discrepancy in the value of 2.0 at high temperatures seems to be due to the difficulty in determining Ms and the difference between our material and the one for which Ms was measured. Moreover, the g-factor at just about the Curie point 303°C was determined by using paramagnetic resonance condition for $H=3480$ and was found to be 1.97 ± 0.03.

Table 3.
$MnOFe_2O_3$
Curie point: 303°C

Temp. °C	Ms (gauss)	g
0	430	2.02
50	395	1.97
100	350	1.99
156	300	2.01
200	240	1.96
250	160	1.94
275	90	1.93

The change in absorption amount with varying temperatures shows the similar tendency to the change of saturation magnetization with temperature as shown in Fig. 7; these results are different from those in the case of cobalt ferrite.[11] The crystalline anisotropy of manganese ferrite, is very small in comparison with that of cobalt ferrite; therefore, the effect of magnetic anisotropy upon the resonance condition is small and the amount of the intensity magnetization is only effective. The resonance fields at the absorption maximum at various temperatures were also plotted as a function of temperature and are shown in Fig. 8; the resonance field increases linearly with rising temperature, and its amount especially increases from 200°C to the Curie point. However, the amount of increase near the Curie point is much smaller than that in the case of cobalt ferrite.

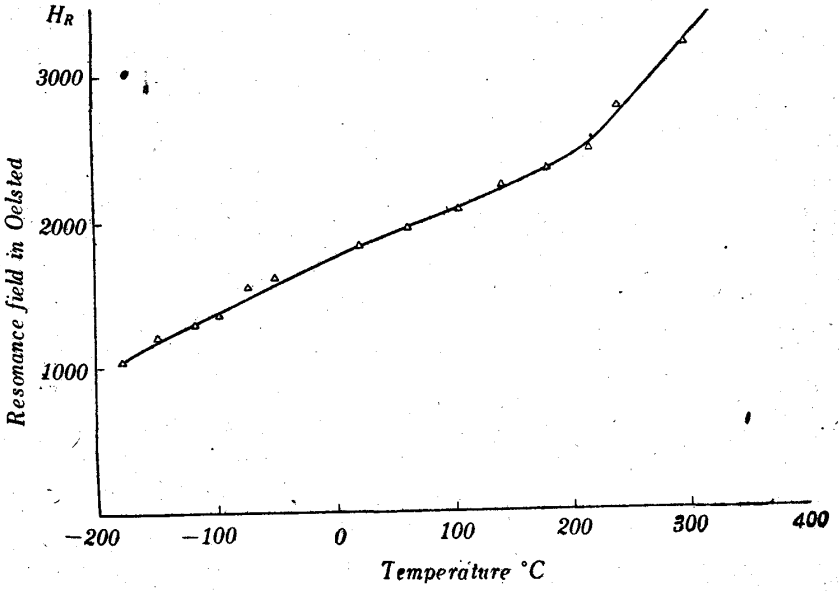

Fig. 8 The change of resonance field at the absorption maximum with varying temperature for $MnOFe_2O_3$.

(13) W. A. Yager, J. K. Galt, F. R. Merritt and F. A. Wood, Phys. Rev. **80**, 744 (1950).

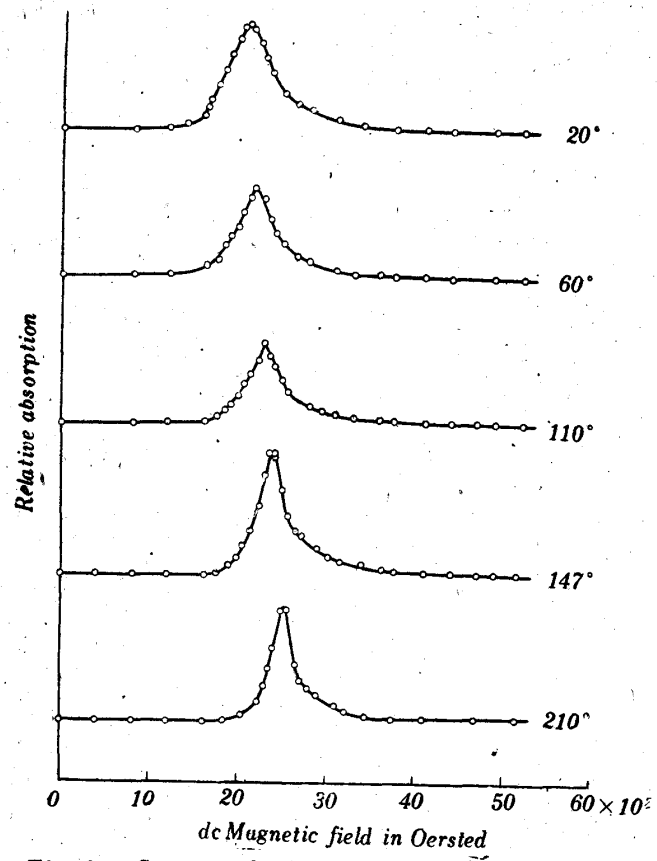

Fig. 9a Curves of absorption versus dc magnetic field for $CuOFe_2O_3$; temperature range 20° to 210°.

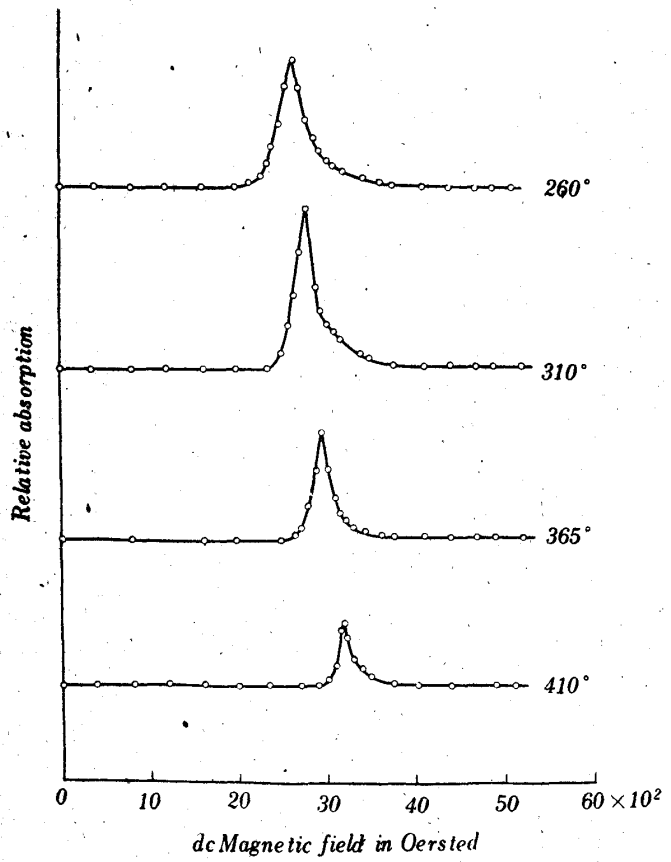

Fig. 9b Curves of absorption versus dc magnetic field for $CuOFe_2O_3$; temperature range 260° to 410°.

V. Resonance experiment on copper and magnesium ferrites

The ferromagnetic resonances in copper and magnesium ferrites at various low and high temperatures have not yet been tried. Then, we carried out these experiments. Figs. 9 and 10 show the curve of the relative absorption with varying dc magnetic field at various temperature from room temperature to near the Curie temperature for Cu-and Mg-ferrite, respectively.

From these figures and other data at low temperatures, the half line widths were poltted as the functions of temperature as shown in Fig. 11, accompanying Tables 4 and 5 $CuOFe_2O_3$ and $MgOFe_2O_3$, respectively; the line widths decreased from liquid nitrogen temperature monotonously with rising temperature up to near the Curie point as in the case of Mn-ferrite described in the foregoing chapter, and the change of resonance fields with varying temperature increases slowly up to the Curie point as shown in Fig. 12. The tendency is almost the same in both materials.

Unfortunately, no values for the saturation magnetization at high temperatures have been published, except at room temperature.

Therefore, only the g-factors at room temperature can be discussed. g-facters for CuO-

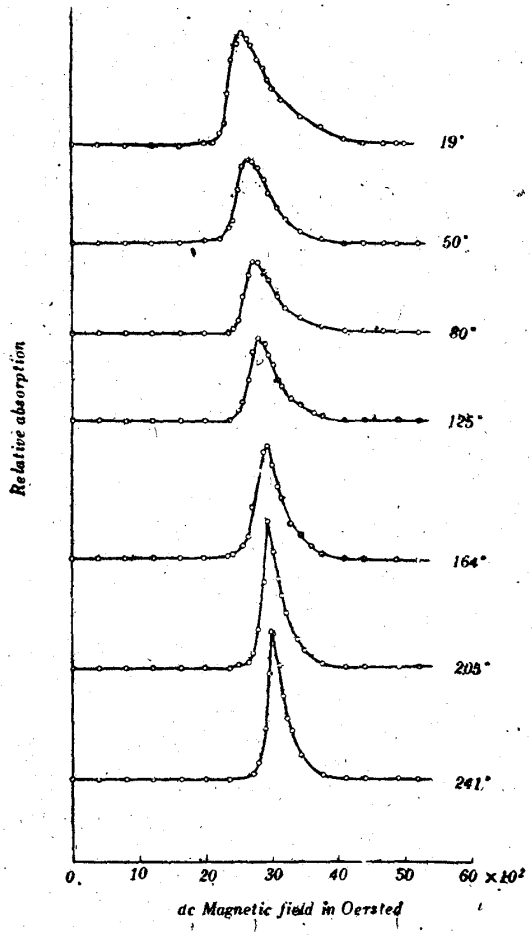

Fig. 10a Curves of absorption versus dc magnetic field for $MgOFe_2O_3$; temperature range 19° to 241°.

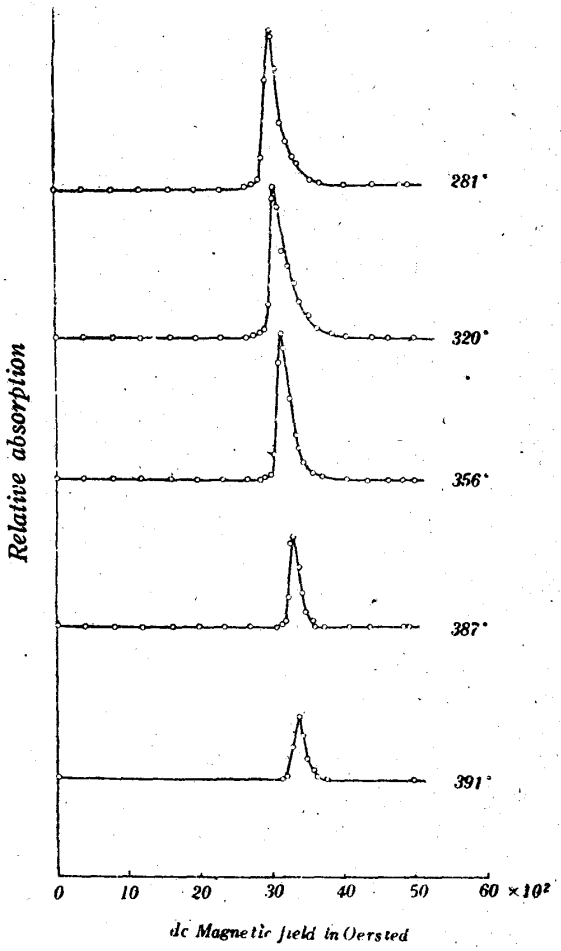

Fig. 10b Curves of absorption versus dc magnetic field for $MgOFe_2O_3$; temperature range 281° to 391°.

Fe_2O_3 and $MgOFe_2O_3$ at room temperature were determined by us at the frequency of 9310 Mc/sec. on spherical polycrystalline specimen; the values obtained by us are 2.09 for $CuOFe_2O_3$ and 2.04 for $MgOFe_2O_3$.[14] According to the results of Yager and co-workers at the frequency of 24,164Mc/sec., the value of $MgOFe_2O_3$ is 2.03~2.06.

We determined the saturation magnetization Ms for $CuOFe_2O_3$ and $MgOFe_2O_3$ by

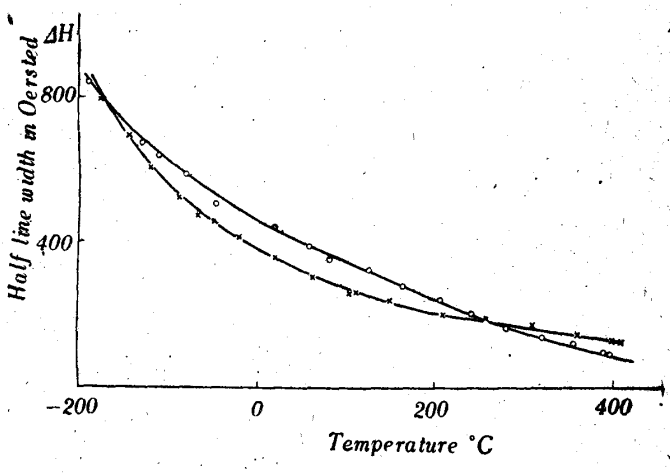

Fig. 11 The half widths of the absorption line as functions of temperature for $CuOFe_2O_3$ and $MgOFe_2O_3$; the crosses represent $CuOFe_2O_3$ and the open circles represent $MgOFe_2O_3$.

(14) T. Okamura and Y. Torizuka, Nature, Vol. 167, No. 4259 (1951), 936.

Table 4
$CuOFe_2O_3$
Curie point: 430°C

Temp. °C	Line Width ΔH (Oe)
−176	800
−145	700
−122	609
−99	550
−87	520
−65	482
−50	465
−20	420
+20	350
+62	315
+102	258
+110	265
+147	240
+210	200
+260	190
+310	170
+362	137
+400	122
+410	122

Table 5
$MgOFe_2O_3$
Curie point: 432°C

Temp. C°	Line Width ΔH (Oe)
−190	840
−130	680
−110	640
−82	588
−50	502
+16	435
+51	388
+79	338
+124	316
+164	270
+204	240
+242	200
+281	160
+320	157
+336	116
+390	98
+398	97

comparing them with the value of $NiOFe_2O_3$ at room temperature, and found them to be 260 gauss and 140 gauss, respectively. These values agree satisfactrily with the values obtained by Gorter.[15] By using these values g-factors of $CuOFe_2O_3$ and $MgOFe_2O_3$ could be determined in the case of the present disk formed specimen and were found to be 2.08 and 2.04, respectively, as in the case of sphere formed specimen.[14] Thus, in the experiments at the frequency of 9310 Mc/sec., the size effect seems to be out of question.

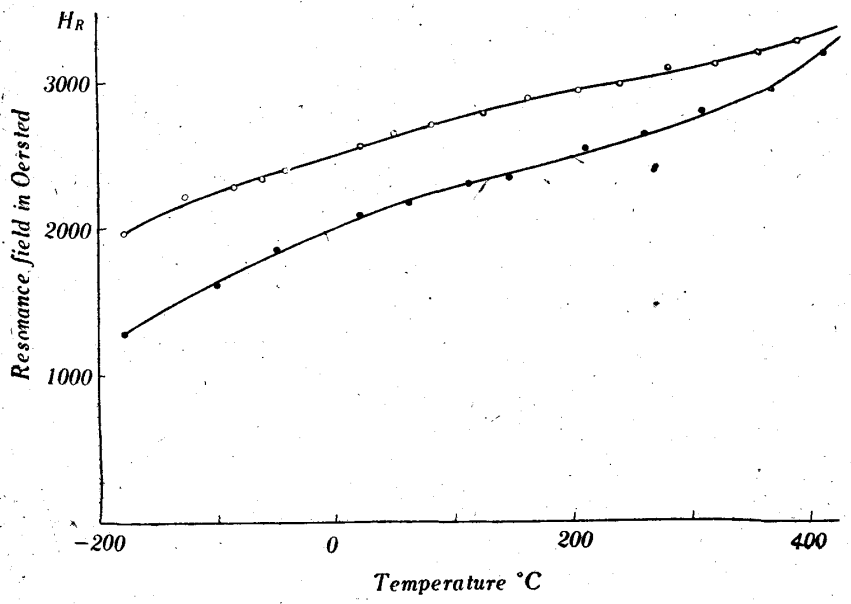

Fig. 12 Resonance fields at the absorption maximum as functions of temperature for $CuOFe_2O_3$ and $MgOFe_2O_3$; the open circles represent $MgOFe_2O_3$ and the solid circles represent $CuOFe_2O_3$.

In high temperature measurements, the absorption disappeared at the Curie point, taking small value of absorption amount at this temperature, because of

(15) E. W. Gorter, Nature, Vol. **165**, No. 4203, 798 (1950).
According to Groter's result, Ms for $CuOFe_2O_3$ and $MgOFe_2O_3$ is 250 gauss and 145 gauss, respectively.

the rapid decrease in magnetization, at which the resonance fields could be determined with the values of H=3450 ±50 gauss and H=3330 ±50 gauss for $CuOFe_2O_3$ and $MgOFe_2O_3$; g-factors were caluculated to be respectively 1.93 ± 0.03 and 2.00 ±0.03, by using paramagnetic resonance condition.

VI. Resonance experiment on binary ferrite: Ni-Zn ferrite

The ferromagnetic resonance experiments on the binary ferrite were made only at room temperature by Beljers and Polder in the case of Zn-Ni ferrites.

The present authors studied the various binary ferrites at various low temperatures by the resonance experiment, for which the g-factors were determined at low temperatures.(14) But the resonance experiments for binary ferrite at high temperatures have not yet been performed. Therefore, the present writers made the resonance experiment on Ni-Zn binary ferrites in the temperature range of −190° to the Curie temperature.

From the experimental results at room temperature, the g-factor and saturation moment of Ni-ferrite and Ni-Zn ferrites are both considerably greater than the spin only values that the orbital moment contribution is important in these ferrite.

Up to the present, g-factor of Ni-ferrite at room temperature was determined by Beljers and Polder,(15) Yager and co-workes(13) and the present authors.(14),(16) The values are given as fololows: 2.31, 2.21 and 2.26, respectively; Beljers and Polder and the present author made the experiment at the wavelength of 3.2 cm and Yager and co-workers at the frequency of 24,164 Mc/sec.

Beljers and Polder first pointed out the effect of sphere size on the g-factor at the wavelength of 3.2 cm in the case of Ni-Zn ferrites. But we cold not observe such a effect in using three kinds of sphere specimens, namely, 1.5mm, 2 mm and 2.5~3 mm, at the same frequency for nickel ferrite and Ni-Zn binary ferrites. The such size effect rather depends on the density of sintered specimen, and in order to avoid the effect, we must prepare the specimen having the density above 80% for

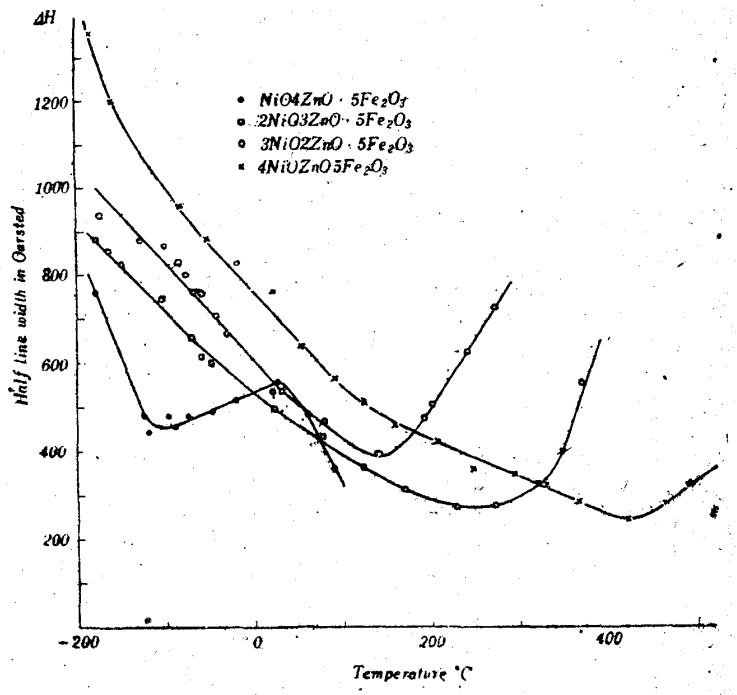

Fig. 13 The half widths of the absorption line as functions of temperature for Ni-Zn binary ferrites.

(15) G. Beljers and D. Polder, Nature, Vol. **165**, No. 4203, 800 (1950).
(16) T. Okamura, Y. Torizuka and Y. Kojima, Sci. Rep. RITU, A-Vol. **2**, No. 4, 663 (1950).

the calculated value from the lattice constant. But recently we observed the size effect for g-factor on several ferrites at 23,500Mc/sec. at room and low temperature, the details will be seen in the following report.

From the experimental data. the half widths of line and the resonance fields for various Ni-Zn ferrites of $NiO4ZnO5Fe_2O_3$, $2NiO3ZnO5Fe_2O_3$, $3NiO2ZnO5Fe_2O_3$ and $4NiOZnO5Fe_2O_3$ that have the Curie points at 120°C, 330°C, 395°C and 526°C, respectively, were determined in the temperature range of −190° to the Curie temperature, and are shown in Figs. 13 and 14, respectively, accomanying Tables 6 and 7.

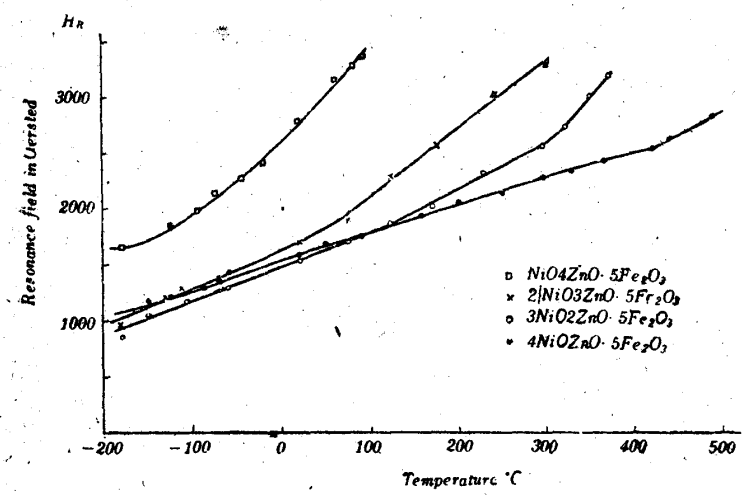

Fig. 14 Resonance fields at the absorption maximum as functions of temperature for Ni-Zn binary ferrites.

The curve of the half line width versus temperature was diffrent from that of other simple

Table 6

$NiO4ZnO5Fe_2O_3$ Curie point: 120°C		$2NiO3ZnO5Fe_2O_3$ Curie point: 330°C		$3NiO2ZnO5Fe_2O_3$ Curie point: 395°C		$4NiOZnO5Fe_2O_3$ Curie point 526°C	
Temp. °C	Line Width ΔH (Oe)	Temp. °C	Line Width ΔH (Oe)	Temp. °C	Line Width ΔH (Oe)	Temp. °C	Line Width H (Oe)
−180	760	−175	935	−180	880	−182	1360
−125	480	−130	880	−165	855	−160	1200
−120	440	−102	865	−150	820	−85	960
−97	480	−87	830	−107	745	−50	880
−90	455	−80	800	−70	655	+20	760
−75	480	−70	760	−60	615	+50	637
−37	490	−62	760	−50	600	+90	560
−20	514	−47	705	+20	495	+125	505
+27	560	−32	665	+77	435	+157	455
+60	480	+20	537	+120	367	+205	415
+90	360	+30	535	+170	312	+247	355
		+77	465	+228	272	+295	345
		+140	390	+272	273	+330	325
		+190	470	+320	320	+365	280
		+200	505	+347	398	+420	240
		+240	623	+370	550	+462	280
		+270	720			+490	320

ferrites found in the foreging chapters and from the experimental result of cobalt ferrites; that is in the case of Ni-ferrite containing low zinc ferrites, the line widths first decrease rapidly with rising temperature and then increase near 140°C, 275°C and 420°C for $2NiO3ZnO5Fe_2O_3$, $3NiO2ZnO5Fe_2O_3$ and $4NiOZnO5Fe_2O_3$, respectively; the amount of the increase is roughly proportional to the content of Zn-ferrite which is added to the Ni-ferrite. But the high zinc ferrite, namely, $NiO4ZnO5Fe_2O_3$ ferrite, shows a different curve from the former; the curve of the

Table 7

$NiO4ZnO5Fe_2O_3$ Curie point: 120°C		$2NiO2ZnO5Fe_2O_3$ Curie point: 330°		$3NiO2ZnO5Fe_2O_3$ Curie point: 395°C		$4NiOZnO5Fe_2O_3$ Curie point: 526°C	
Temp. °C	H_R (Oe)	Temp. °C	H_R (Oe)	Temp. °C	H_R (Oe)	Temp. °C	H_R (Oe)
−180	1660	−180	970	−180	850	−180	850
−125	1860	−130	1210	−150	1050	−150	1180
−95	1980	−112	1290	−107	1180	−125	1200
−85	2140	−70	1380	−60	1290	−85	1310
−45	2280	+20	1700	+20	1550	−60	1430
+5	2420	+75	1900	+76	1700	+20	1590
+45	2790	+123	2280	+122	1870	+50	1690
+60	3160	+177	2560	+170	2005	+90	1770
+82	3290	+242	3020	+228	2320	+122	1870
+93	3380	+300	3290	+295	2560	+158	1940
				+320	2720	+200	2060
				+350	3005	+245	2140
				+369	3190	+295	2280
						+328	2340
						+365	2420
						+420	2540
						+440	2640
						+488	2830

half line width with rising temperature has a minimum and maximum at ca. −100°C and +20°C, respectively; the width first decreases rapidly with rising temperature to ca −100°C and then inereases, passing a maximum at about +20°C, then decreases up to the Curie point.

The behaviour of change of line width versus temperature for high zinc ferrite seems to correspond to the *V* type which appears in the diagram for *Ms* against temperature proposed by Néel's theory,[17] but from direct static measurement on Ms at high temperatures, Guillaud and Roux[18] could not find such a tendency in the Zn-Ni binary ferrite.

On the other hand, the line broadening appearing near the Curie point must be due to the decreasing behaviour of the factor $\frac{K}{Msa-Msb}$, where K is anisotropy constant, *Msa* and *Msb* respectively denotes the saturation magnetization of two sub-lattices; with the rise in temperature from the lowest temperature, the initial rapid decrease in the line width is essentially due to the decrease of K, and afterwards the line width increases in some temperature region, where *Msa* and *Msb* are antiparallel in approximately equal amount. Thus, the line broadening near the Curie point seems to be due to the appearance of an antiferromagnetic state. In the higher zinc ferrite, after passing through the antiferromagnetic region from −100°C to ca +25°C, the direction of saturation magnetization may change from *Msa* to *Msb* at 25°C, and with further rise in temperature, *Msa-Msb* decreases and then vanishes at the Curie point.

Generally speaking, it should be noticed that the increase of the line width with rising temperature near Curie point for Ni-Zn ferrites can not be observed

(17) L. Néel, Ann. Physique, 3 (1948), 137.
(18) C. Guillaud and M. Roux, Compt. Rend., **229** (1949), 1133.

for other simple ferrites.

The resonance fields increase with the rise of temperature and its amounts also increase rapidly near the Curie temperature.

By using the values for *Ms* taken from the static magnetization experiment of Guillaud and Roux, the g-factors at high temperatures are given in Table 8.

Table 8

$4NiOZnO5Fe_2O_3$ Curie point: 526°C			$3NiO2ZnO5Fe_2O_3$ Curie point: 395°C			$2NiO3ZnO5Fe_2O_3$ Curie point: 330°C			$NiO4ZnO5Fe_2O_3$ Curic point: 120°C		
Temp. °C	*Ms* (gauss)	g	Temp. °C	*Ms* (gauss)	g	Temp. °C	*Ms* (gauss)	g	Temp. °C	*Ms* (gauss)	g
20	420	2.12	20	455	2.17	20	405	2.07	20	190	1.86
100	370	2.06	100	400	2.09	100	230	2.00	50	110	1.89
150	340	2.05	150	350	2.05	150	220	1.97			
200	305	2.01	200	305	2.00	200	160	2.01			
250	275	2.02	250	245	2.00	250	60	2.00			
300	240	2.31	300	190	2.50						
350	205	2.02	350	110	1.91						
400	175	2.01									
450	125	2.03									
500	70	2.05									

In general, the value of g-factor seems to be less than the value 2, when Zn-ferrite is added to Ni-ferrite. But the value of g-factor first decreases at a moderate temperature, then remains constant in the limit of error.

Lastly, in case of these ferrites, the values of g-factor are also determined just at the Curie point where the absorption disappears, by using paramagnetic resonance condition, from Table 7.

Thus, we could confirm the g-factor of Ni-Zn binary ferrites just at the Curie point, depending on the content of zinc ferrite, and the values are shown in Table 9, but the value of g-factor monotonously decreases with increasing content of zinc ferrite. The fact is quite in contradistinction to the change of g-value with varying zinc content of nickel ferrite at room and low temperatures.[13]

Table 9

Specimen	H_R (Oe)	Temp. (°C)	g-value
$NiO4ZnO5Fe_2O_3$	3600	120	1.86
$2NiO3ZnO5Fe_2O_3$	3450	330	1.94
$3NiO2ZnO5Fe_2O_3$	3400	395	1.97
$4NiOZnO5Fe_2O_3$	3000	526	2.20
$NiOFe_2O_3$	2950	590	2.25

Summary

1. In the range of magnetic transition of manganese ferrite at low temperattre, ferromagnetic resonance experiment was made, and the double peaks on the resonance curve was always observed in the same temperature range.

2. The ferromagnetic resonance in manganese ferrite at high temperatures was tied up to the Curie temperature; the line width and g-factor were determined.

The line width decreased monotonously from low temperature to the Curie point and the value of g-factor showed 2.0 in these temperature ranges in the limit of error.

3. g-factors for copper and magnesium ferrites were determined at room temperature; the value of copper and magnesium ferrites was 2.08 and 2.04, respectively.

Moreover, the temperature dependency of the line width for the both ferrites was determined; monotonous decreases of the line width against temperature were also observed.

4. The size effect reported by Beljers and Polder could not be observed for nickel ferrite and Ni-Zn binary ferrite at least at the frequency of 9310 Mc/sec.

5. For Ni-Zn binary ferrite, the changes of line width with varying temperatures were observed from liquid nitrogen temperature up to the Curie temperature; the line width first decreased with rising temperature, but increased near the Curie temperature, and such tendency could not be observed in other simple ferrites.

Especially, it is most interesting to notice that the curve of line width versus temperature for high zinc-nickel ferrites show minimum and maximum; the behaviour seems to correspond to V-type predicted by Néel.

6. g-factors for Ni-Zn binary ferrites were determined from room temperature up to the Curie temperature; especially, at Curie temperaturs, the g-factors were determined by using paramagnetic resonance condition.

Recently resonance experiments on various ferrites were studied at a shorter wavelength of 1.27 cm, details of the experiments in which the size effect, temperature and frequency dependencies of g-factor are discussed will be seen in the following report.

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According to the recent report of Dr. D. Healy,[19] the g-values of nickel ferrite on the single crystal did not change with varying temperature, but the crystal structure does not seems to be cubic at the lowest temperature by his experimental results, so the g-value at the low temperature obtained by Healy who calculated it by Kittel's formula for the cubic structure can not be compared with our results.[5]

We wish to thank Dr. Healy for sending us his interesting report.

(19) D. W. Healy, Jr; Contract N 50RI-76, Task Order No. 1, NR-078-011 Cruft Laboratory Harvard University Cambridge Massachusetts Technical Roport No. 135, August 15, 1951.