JOURNAL OF THE PHYSICAL SOCIETY OF JAPAN VOL. 17, SUPPLEMENT B-I, 1962
PROCEEDINGS OF INTERNATIONAL CONFERENCE ON MAGNETISM AND CRYSTALLOGRAPHY, 1961, VOL. I

# Oxides and Other Compounds II

## Some Investigations of Non-Metallic Ferro- and Antiferromagnetics*

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**1.** Some ferrimagnetic garnets with high initial permeability have been discovered[1]. Temperature and frequency dependences of complex initial permeability $\mu$ of solid solutions

$$\{Y_{3-2x}Ca_{2x}\}[Fe_{2-2x}M_{2x}]Fe_3O_{12}\,,$$

where M=$Ti^{4+}$, $Zr^{4+}$, $Sn^{4+}$, have been investigated. The value of $\mu'$ as high as 750 has been obtained.

**2.** Relaxation phenomena at weak ac magnetic and electric fields in garnets due to diffusion of electrons (with activation energy 0.3–0.4 eV) have been investigated. The frequency dependences of $\mu'$, $\mu''$, $\varepsilon'$ and $\varepsilon''$ of single and poly-crystalline samples have been studied at different temperatures[2]. These dependences essentially change after heat treatment in different gases. The single and poly-crystalline samples with high resistivity (few defects) are characterized by lower values of $\mu'$ (60–100) at low frequencies and domain-wall resonance at $10^6$–$10^7$ cycles (at 20°C). Samples with low resistivity (more defects) have higher values of $\mu'$ (150–170) and relaxation frequency dependence of $\mu$ in the range $10^5$–$10^6$ cycles. It can be explained by diffusion of electrons and by domain structure changes due to the defects ($Fe^{2+}$).

**3.** Solid solutions

$$BaFe_{12}O_{19}-M^{3+}Fe_{11}M^{2+}O_{19}\,,$$

where $M^{3+}$=$Bi^{3+}$, $La^{3+}$, $Pr^{3+}\cdots$ and $M^{2+}$=$Ni^{2+}$, $Co^{2+}\cdots$, and some rare earth garnets have been investigated at high impulse fields (up to 150 koe). The dependence of magnetization of these solutions upon composition has been determined and a supposition about the spin configurations has been made. The considerable differential susceptibility of holmium and erbium garnets in high magnetic fields has been obtained. It can be explained by non-collinear spin configurations in these garnets.

**4.** The crystals with perovskite structure with coexisting ferroelectricity and antiferromagnetism or ferrimagnetism have been discovered[3]. Ferrimagnetism in these substances appears owing to spin ordering in octahedral sublattice. Solid solutions

$$Pb(Fe_{2/3}W_{1/3})O_3-Pb(Mg_{1/2}W_{1/2})O_3\,,$$

have been investigated. The dependence of magnetic moment, permittivity and Curie temperatures (ferroelectric and magnetic) on composition in this system has been determined.

**5.** The principles of thermodynamics of ferroelectrics-ferromagnetics have been developed (without taking anisotropy and strains into account). The dependence of ferro electric properties on the magnetic state and magnetic properties on the ferroelectric state was shown to have place. The induced electric polarization should appear when magnetic field is applied, and the magnetic moment should appear when electric field is applied.

**6.** In order to ascertain the role of different relaxation processes in ferromagnetic resonance in ferrites, the temperature dependences of resonance line width $2\Delta H$ have been examined. Pure yttrium iron garnet ($2\Delta H$= 0.5 oe), yttrium garnet with rare earth additions and some ferrites with spinel structure have been investigated. The contribution of surface irregularities to $2\Delta H$ was found to be proportional to magnetization. The contribution of incoherent processes near the Curie point ($T_c$) depends on temperature as $1/\sqrt{T_c-T}$. This is in agreement with theory of Skrotsky and Kurbatov[5]. Temperature

* This paper was not read at the Conference.

dependence of the rare earth ions contribution to $2\Delta H$ in yttrium garnet is in qualitative agreement with theory of Kittel *et al.*[6] We use this temperature dependence to determine the relaxation frequency of rare earth ions. But the magnitude of low temperature maximum of this contribution appears to be many times more than the value given by the theory[6]. There is a strong anisotropy of $2\Delta H$ at low temperatures, which also does not result from the theory[6].

The narrow line widths have been obtained in single crystals with spinel structure too, for example $2\Delta H=6$ oe, for Mg-Mn ferrite. Thus the part of $2\Delta H$ due to the disorderly distribution of magnetic ions, is not so large in this ferrite as it was supposed earlier.

**7.** Ferromagnetic resonance in polycrystalline yttrium garnets with different content of $Fe^{2+}$ ions has been investigated. A strong decrease of resonance field at low temperatures has been noticed. This decrease is caused by the induced anisotropy (activation energy nearly 0.05 eV).

**8.** Ferromagnetic resonance in single crystals at high microwave magnetic fields ($h$) has been studied. It was found out that $\chi'' h^2$ linearly depends on $h$ above the first instability threshold. The transitions from one "linear" region to another are supposed to be connected with instability thresholds of new groups of spin waves.

At room temperature the dependence of $g$-factor on $h$ has been obtained and at low temperatures the dependence of anisotropy field on $h$. The former can be explained qualitatively by the increase of spin temperature with the growth of power level.

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