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107. SOME INVESTIGATIONS OF SOVIET PHYSICS ON THE THEORY OF FERRO- AND ANTIFERROMAGNETISM FOR LAST YEARS.

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During the time since the last International Conference on Magnetism (Grenoble,1958)the research work on the theory of ferro- and antiferromagnetism has been conducted in the USSR along the following lines:

I. Development of the general quantum theory of ferro- and antiferromagnetism using quantum-statistic methods (Green-functions): the spectrum of elementary exitations has been determined,as well as their lifetime in a wide temperature range; the temperature march of magnetization has been calculated - for lower temperatures it coincides with the predictions of the spin-wave approximations,for higher temperatures (near and above Curie point) with those of the molecular field method (Bogolubov and Tiablikov[I]). Ginzburg and Fain[2] have suggested a different self-consistent generalization of the spin-wave method and obtained analogous results. The spin-wave model has been generalized for the case of several electrons near the lattice point[3]; the quantum theory of ferrites[4] and thermodynamic theory of ferromagnetic transformation[5] have been further developed.

2. The work continued on developing quantum theory of ferro- and antiferromagnetic metals within the frame work of (s-d)-exchange scheme using the method of Green-functions[6].A spectrum of spin-waves in Fermi liquid is obtained[7]. The question is investigated connected with the recombination process of current carriers of semiconductors with the energy transfer to

ferromagnons[8)] and the energy spectrum of carrent carriers is calculated for case of intrinsic and impurity conduction of ionic antiferromagnetics[9)]. Study was made of the interrelation between superconductivity and ferro- and antiferromagnetism and of influence of exchange interaction on the parameters of a superconductor[I0)].A method is put forward for determining the Fermi-surface shift of conduction electrons of ferromagnetic with different spin projections [II)].

3. A theoretical study of the phenomena of atomic magnetic order in crystals has resulted in the prediction and discovery of piezomagnetism and magnetoelectric effect [I2)].

4. The work has been continued along the lines of developing phenomenological treatment of the properties of crystals with atomic magnetic order using the crystal-chemical and magnetic symmetry preperties[I3,I4)].

5. Properties of weak ferromagneties at low temperatures were investigated[I5)] and the criterion of existence of weak ferromagnetism formulated[I6)].The pecularities of this phenomenon in rhombic crystals were investigated[I7)]. A transformation from the antiferromagnetic state into a weak ferromagnetic one was discovered experimentally and explained theoretically[I8)]. For the first time the existence of two branches of the spectrum of spin waves in antiferromagnetics was established from the measurements of heat capacities[I9)].Conditions of magnetic resonance in various weak ferromagnetics were investigated [20)].

6. On the basis of the phenomenological theory of spin-waves there have been investigated energy spectrum of ferromagnons,high frequency properties and resonance in ferromagnetics,surface impedance,magneto-elastic waves,ferroacoustic resonance,thermal properties of

ferro- and antiferromagnetics,processes of interaction of spin-waves with each other and with phonons,relaxation processes of magnetization in ferrodielectrics,dispersion of magnetic susceptibility and heat coductivity [14]. Thermodynamic theory of magnetic elastic media has been further developed [21].

7. Solutions of Landau-Lifshitz equation have been investigated for an arbitrary value of the alternating field amplitude[22]; the influence of the conditions of electronic resonance on the Faraday and Kerr effects was investigated [23]; methods of Green-functions and Kubo-Tomita were used for elucidating frequency dependence of the susceptibility of ferromagnetics [24].Theoretical investigations were carried out of resonance line width in ferromagnetic metals [25],of the resonance frequency spectrum [26],and of the role of the dipole-dipole coupling in the ferromagnetic resonance [27].

8. Temperature dependence was calculated for electric resistance of ferromagnetics induced by scattering of conduction electrons with the arbitrary isotropic law of dispersion by ferromagnons; heat resistance was also calculated for the case of quadratic dispersion law [28]. A general phenomenological theory of electric conductivity of ferrites and antiferromagnetics has been developed elucidating the nature of "anomalies" near the Néel - points [29]. Theoretical prediction was made for the additional electric resistance due to the scattering of conduction electrons by spin-waves of a ferromagnetic in the conditions of a ferromagnetic resonance [30].

9. Cross-sections of neutron scatering in ferromagnetics due the absorption and emission of ferromagnons have been calculated [31]; scattering of polarized neutrons has been investigated for different processes and a method is

indicated for separating cross-sections of these processes[32]. With the help of Green-functions the question was investigated related to the width of intensity peaks of neutrons scattered in a given direction and induced by absorption or emission of a ferromagnon depending on the neutron energy; the width of the peak was determined by the damping of spin-wave exitations due to various types of interactions in ferromagnetic [33].A phenomenological theory of critical scattering of neutrons near the Curie and Néel points is set up [34].Cross-sections of elastic scattering of neutrons in ferrites depending on the degree of reversion and composition are calculated [35].Cross-sections of elastic and anelastic scattering of neutrons in antiferromagnetics and ferrites are calculated by the method of spin-waves [36].

IO. Temperature dependence of free energy of magnetic anisotropy and magnetostriction in ferromagnetics in the low temperature range is calculated on the basis of phenomenological theory of spin-waves.The nature of the temperature march of the addition to the magnetic anisotropy constant induced by magnetostriction is elucidated [37].

II. A neutronegraphic investigation is carried out of the magnetic atomic structure of a number of weakly ferromagnetic crystals [38].

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44. The Electrical Properties of Thin Films of Nickel at Very Low Temperatures

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Thin nickel films were obtained by thermic evaporation in glass tanks brought to a pressure of 10^{-7}mm. During the process of depositing the instrument was submerged into a helium bath allowing to obtain ferromagnetic films of very high purity.

Electrical properties of the films were studied including the electrical resistance temperature dependence from 2 to 300°K and Hall's electromotive force.

At low temperatures residual resistivity was observed close to that of nickel bulk specimens. The results were obtained on films ranging from 30A and thicker. Hall's electromotive force on the said films was of the order of Hall's electromotive force in bulk specimens.

155. PIEZOMAGNETIC EFFECT IN ANTIFERROMAGNETS.

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It is known that the piezomagnetic effect (P.M.) may exist only in crystals showing magnetic structure[1]. Dzyaloshinskij[2] investigated the thermodynamic potential having the following form for some antiferromagnets

$$\Phi = \Phi_0 + \Lambda_{ijk} \tau_{ij} m_k \qquad (1)$$

where τ_{ij} - are the stress tensor components and m_k - the components of the magnetic moment in the crystal. He has shown that some components of the P.M. tensor should be different from zero for antiferromagnets having a tetragonal lattice such as MnF_2, and those with rhombohedral lattice such as $FeCO_3$. For the latter only the following components are different from zero

$$\Lambda_1 = \Lambda_{xxx} = -\Lambda_{yyx} = -\tfrac{1}{2}\Lambda_{xyy}\,;\quad \Lambda_2 = \Lambda_{xzy} = -\Lambda_{yzx}$$

The P.M. effect in the antiferromagnetic fluorides has been discivered by one of the authors[3], and it has been found to be considerable for CoF_2. The first part of this paper is devoted to analogous experiments on crystals of $FeCO_3$.

The magnetic moment of the specimen as a function of the external magnetic field was examined by a special magnetic torsion balance at 20°K. An essential part of this apparatus was the miniature press shown in Fig.1. The pressure on the specimen 1 was exerted by an evacuated and soldered up bellow. It was regulated by changing the pressure of helium gas in the vessel in which the balance was placed. Thus we achieved a pressure ~ 700 $kg.cm.^{-2}$ on the

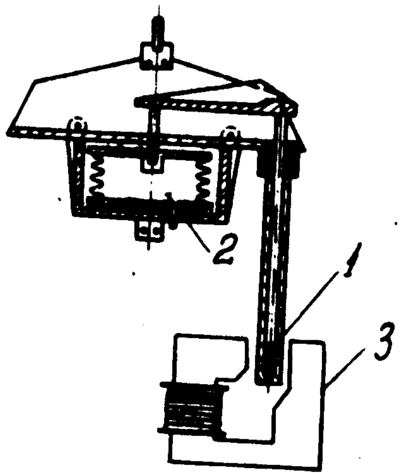

Fig. 1

specimen having a cross-section 1 mm^2. The press was suspended on vertical 50 μ tungsten wires. This enabled us to measure the force on the specimen in the inhomogeneous magnetic field of the small electromagnet 3 . We investigated small crystals of siderite ($FeCO_3$). From these two specimens there were prepared :in the first the stress component was τ_{yy} and the magnetic moment was directed along x - axis, in the seoond the stress component was τ_{yz} and the magnetic moment was also directed along x -axis.

The measurements on the first specimen showed that within the errors of measuremets the magnetic moments with and without pressure coincided. Thus

$$\Lambda_1 < 10^{-3} \text{ emu. mol}^{-1}\text{. kg}^{-1}\text{. cm}^2.$$

A noticeable P.M. moment was discovered in the second specimen (Fig.2.) Line 1 was measured without pressure; line 2 under pressure. The upper and lower lines were obtained depending on the sign of the magnetic field in which the specimen was cooled. It is evident that the specimen shows a spontaneous magnetic moment even in the absence of pressure which is obviously connected with imperfections in the crystal. However under pressure the magnetic moment increases threefold. This can't be explained by a change in the

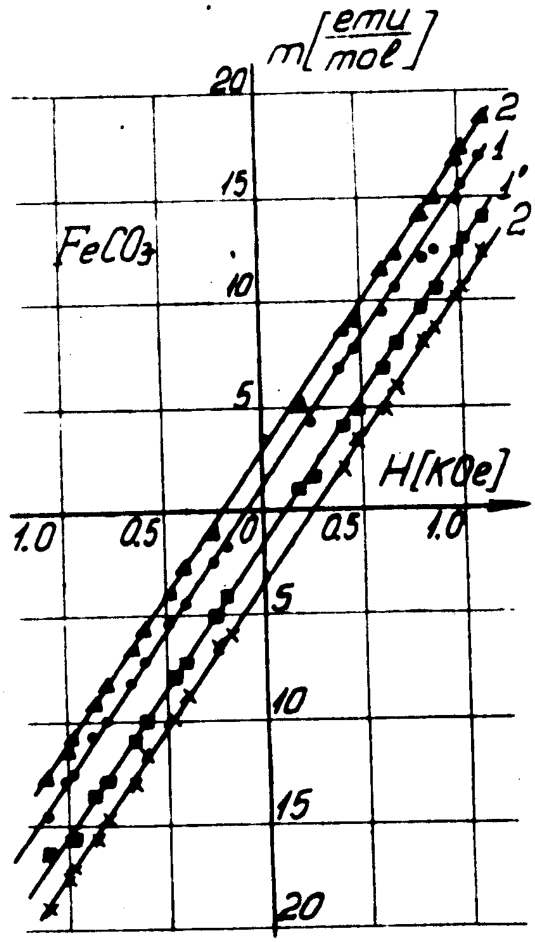

Fig 2

parasitic moment and it has to be ascribed to a P.M. effect. It has to be pointed out that this value of the P.M. moment is obtained only if the specimen was cooled under pressure. When cooled with out the application of pressure the effect was smaller pointing to presence of antiferromagnetic domains.

The second part of the paper deals with the investigation of the P.M. effect in CoF_2 under the influence of ultrasonic pressure. The ultrasound in the range of 10 to 200 kc/s was generated by a barium-titanate transducer. The P.M. moment was measured through the voltage induced in pick-up coils placed around the specimen. The temperature dependence of the P.M. moment in the relative units is shown in Fig.3 (curve a). The most interesting results were obtained around $T_N=38,2^oK$. In the range $\sim 2^oK$ this dependence can be described by

$$(\sigma/\sigma_0)^2 = \xi(1-T/T_N) \qquad (2)$$

where $\xi=3,8$ (see Fig.3 inset curve b). The obtained dependence (2) of the P.M. moment is in agreement with the results

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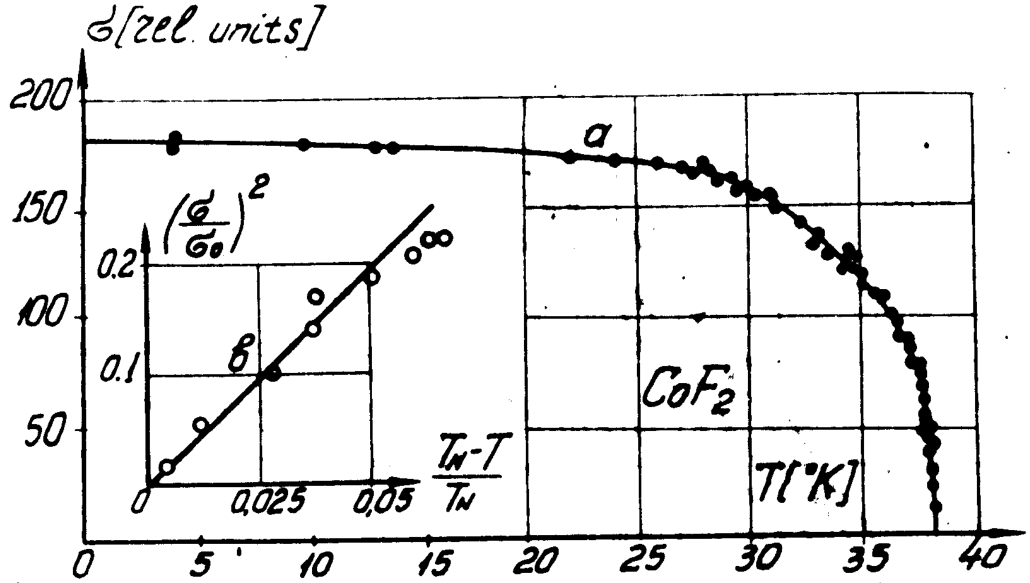

Fig. 3

of the thermodynamic theory of phase transitions of the second kind.

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167. ANTIFERROMAGNETIC RESONANCE IN CARBONATES OF TRANSITION ELEMENTS.

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The anhydrous carbonates of manganese and cobalt change into the antiferromagnetic state with weak ferromagnitism at 32.5°K and 18°K respectively [1,2,3]. The magnetic structure of these substances [4] differs from the usual antiferromagnets by the spins lying in the planes normal to the main (trigonal) axis of the crystal. The angle between spins lying in neighbouring planes differs by a small amount from 180°. The theoretical explanation of such a structure was given by Dzyaloshinsky [5] based on general thermodynamical considarations and ideas of magnetic symmetry. Using the Hamiltonian of the form given in [5] the author [2] and Turov [6] derived the spin-wave dispersion law in the rhombohedral carbonates. It was proved that the spin-wave spectrum differs from one for the usual antiferromagnets and contains two branches, one of which has practically no gap. In the particular case of antiferromagnetic resonance ($\vec{k}=0$) the following relation between the frequency $-\omega$ and the value of the magnetic field applied in the basal plane was obtained for this branch:

$$(\omega/\gamma)^2 = H_o (H_o + H_D) \qquad (1)$$

Here H_D is the effective field responsible for the weak ferromagnitism. The value of H_D can be derived also from static measurements of the spontaneous ferromagnetic moment - σ_0 ($H_D = \sigma_0/\chi_\perp$). If we take the anisotropy in the basal plane into account an additional term of the form $H_\Delta^2 \cos 6\varphi$ has to be added to (1) [7].

Recently Date [8] found such resonance studying natural crystals of $MnCO_3$. The purpose of the present work was the investigation of this resonance on pure synthetic crystals of $MnCO_3$ and $CoCO_3$. The single crystals (size of about 1 mm^3) were obtained by Ikornikova [9] using a hydrothermal method. The measurements were performed on a 3-cm microwave automatic frequency controlled spectrometer with the transmitted signal being utilised. Low frequency magnetic field modulation was used and the derivative of the absorption line was automatically recorded.

For $MnCO_3$ in the paramagnetic state (at room temperature) we obtained a fairly narrow line ($\Delta H \sim 200$ Oe). Its position corresponds to $g = 2.00$. Neither the position of the line, nor its width depends on the orientation of the crystal. For $CoCO_3$ down to 20°K no paramagnetic resonance was found.

The derivative of the absorption line obtained for $MnCO_3$ in the antiferromagnetic state (T=4.2°K) is shown on Fig. 1. The h.f. and static magnetic field are mutually normal and in this case are in the basal plane

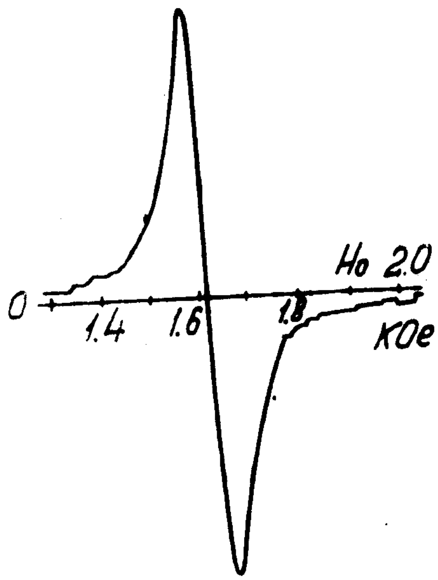

Fig 1

of the crystal. The same result was obtained when the h.f. field was along the trigonal axis of the crystal. It must be stressed that in contrast to the result obtained in [8] the line is very narrow (~60 Oe). Apparently the line-width in [8] is caused by defects in the crystal. The same situation seems to hold in the paramagnetic state. When the crystal was rotated in the basal plane the position of the line did not change within the accuracy of our measurements (~20 Oe). Thus we used relation (1) to calculate the value of H_D= 5.35 kOe. The value of H_D obtained from static measurements (H_D= 4.38 kOe) [2] is by 20% smaller. This may be connected with the fact that beside the anisotropy in the basal plane there is an additional cause for the gap in the energy spectrum.

Resonance absorption in $CoCO_3$ in the antiferromagnetic state was obtained in very small fields (H_0= 100 Oe). If both the h.f. and static fields lie in the basal plane a very assymmetrical line (see Fig. 2) is obtained. When the h.f. field is directed along the trigonal axis, the intensity of absorption falls by a factor of about 100. At the

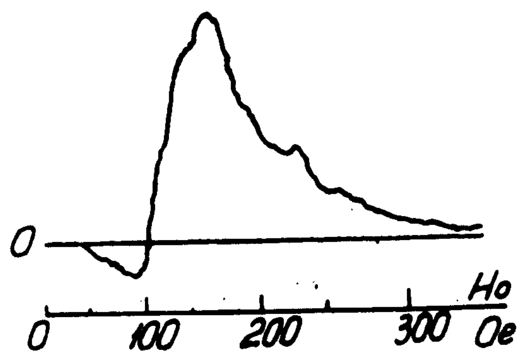

Fig.2

same time the line becomes more symmetric. Quantitative analysis of the data for $CoCO_3$ is for the time being impossible since the value of the g-factor is not known. We must underline the fact that resonance in $CoCO_3$ is observed for fields much below the saturation value.

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317. "NEUTRON DIFFRACTION INVESTIGATION OF ORDER-DISORDER IN THE ALLOYS FERRUM-NICKEL AND FERRUM-COBALT"

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1. The strong asymmetry of the concentration region of existing of the superlattice Ni_3Fe about the stoicheometric composition was obtained. This is the cause of the asymmetry of the known diagram "composition-variation of the properties of the binary alloys Ni-Fe differently heat treated". For the alloy 70%Ni-30%Fe the highest value of parameter σ in comparision with the parameter σ of the alloy Ni_3Fe was obtained. This testifies that the investigated alloy states are not balanced and that the ordering energy in these alloys is apparently different. These facts confirm the hypothesis of Smoluchowski about the essential investment of 3d-interaction of the ordering energy in the Ni-Fe alloys and the close connection of the composition dependency of ferromagnetic Curie point with the shape of the alloy equilibrium diagram in the ordering region / 1 /.

2. In the equiatomic alloy NiFe the laminated ferromagnetic superlattice of the CuAu or CuPt types was not obtained. The known influence of the alloy heat treatment on his physical constants and properties could be explained by the ordering processes of the positive or negative short rang ordering types.

3. The superlatice in the Mo-permalloy and supermalloy was not obtained also. In the 75%-permalloy with the Cu-addition the long rang order degree is small.However in the 74%-permalloy with the Cr-addition the superlattice was found clearly developed. As the magnetic induction of these alloys decrease abruptly by the addition of Cr it can be expected that the Cr atoms have antiferromagnetic connections whis their own heighbours and take active part in the creation of the triple superstructure $Ni_3(Fe,Cr)$ in distinction from Cu atoms.

4. The shape of the temperature dependency σ ,the large expansion of the superlattice line and the presence of the hysteresis of the order-disorder transformation in the alloy Ni_3Fe show that the atomic ordering in this alloy must be attributed to the phase transformation of the first kind.This corresponds with the results of the Landau-Lifshits's theory of the f.c.c. structures. With some simplifications the coefficient of the surface strain on the boundary of two phases (ordering and disordering) are equal approximately to 10^{-1} erg/cm^2.

5. For the superstructure CsCl type that realises itself in α-solid solution Fe-Co Landau-Lifshits's veto on the phase transition order-disorder of the second kind is annuled. The shape of the temperature dependency σ for the equiatomic alloy and also the absence of visible expansion of the superlattice lines in all the

investigated alloys testify actually about the embryonless transformation mechanism in this system. By cooling of the alloy FeCo below 500°C considerable decrease of parameter σ is observed. This decrease does not coincide with the extrapolated regular dependency $\sigma = \sigma(T)$. This fact conform with the results / 2 / about the existence of some transformation at 500°C.

6. The abnormal large region of the superstructure FeCo existence (relatively with the other investigated systems) was obtained at a relatively rapid cooling of the allos from the high temperatures. The boundaries of this region are near the low limit of the solution concentration $\frac{100}{Z}$ % where the idea of the long atomic order loses already the sense by itself. The shape of this region is somewhat asymmetrical relatively to the composition 50:50 that conforms with the extrapolated on the γ-region concentration dependency of the ferromagnetic Curie point / 3 /.

7. The summary of the obtained results and the analysis of some other dates permit attribute the superstructures Ni_3Fe and FeCo to the fairly ample specific class of the superstructures of the magnetic solid solutions / 4 /.

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