TEMPERATURE-INDUCED LOCAL MAGNETIC MOMENTS (TILMM)
IN MONOSILICIDES OF 3d TRANSITION METALS

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Features of the formation of temperature-induced local magnetic moments (TILMM) and their influence on the magnetic and thermophysical characteristics of iron, cobalt, and manganese monosilicides are investigated. The results obtained for magnetic susceptibility and specific heat measurements are discussed within the framework of spin-fluctuation theory. Temperature-concentration dependences are established for the TILMM absolute value for mutual solid solutions Fe_{1-x}Co_{x}Si and Fe_{1-y}Mn_{y}Si. It is shown that for a number of the alloys studied the saturation of the TILMM absolute value does not occur, while the anomalous behavior of the polytherm of their physical properties is associated with features of the band structure.

1. The theory of the magnetism of transition metals and their compounds treats their ground state within the framework of representations of the Stoner-Wolfahrt band model and starts from the assumption of the existence of temperature-induced local magnetic moments (TILMM) [1, 2] in describing the polytherm of the electron characteristics. However, experimentally the influence of the TILMM on the physical properties of the substances under consideration and their dependence on the features of the electron structure have clearly been studied inadequately, which predetermines the imperfection in modern representations about band magnetism.

In our opinion, the results of comparing the deductions of the theory of spin fluctuations (SF) in band magnets and the experimental data on magnetic susceptibility (\(\chi\)) and electronic specific heat (\(C_{e}\)) of the strong paramagnet FeSi, which is a semiconductor in the low-temperature domain while undergoing electronic transformation into the metallic state in the room-temperature range, might be an interesting illustration of the role of TILMM in the formation of features of the magnetic and thermophysical properties of the electron subsystems of certain transition metal compounds. The electron transition into the metal state is apparently associated with splitting of the electron states into fluctuating exchange fields resulting in "separation" in the energetic spectrum

\[ \varepsilon_{\sigma} = \varepsilon_{e} + a|m|, \]

where \(\sigma = \pm 1\), \(I\) is the exchange interaction parameter, and \(m\) is the rms spin magnetic moment. Moreover, its associated renormalization of the electron spectrum of FeSi by spin fluctuations results in abrupt growth of the appropriate spin-fluctuation contributions to the magnetic susceptibility and specific heat. Finally, for \(T > 800\) K the Curie-Weiss dependence \(\chi(T)\) is satisfied because of saturation of the TILMM modulus, and constancy of the specific heat coefficient also holds \(\gamma = (C_{\text{exp}} - C_{\text{phon}})/T\). All these features are not explained well within the framework of single-electron theory [4] and are described by the SF-theory developed in [3]. Other indications of the important role of TILMM in the formation of the electron characteristics follow from an analysis of the magnetic susceptibility polytherm of the band helimagnet MnSi [5], say, and a number of helimagnetic solid solutions Fe_{1-x}Co_{x}Si [6, 7] in which there are two sections, each of which is described approximately by the Curie-Weiss law with their own values of the constants and Curie temperatures. However, according to [5], such features can be associated also with the fine structure of the curve \(g_{0}(e)\) near the Fermi energy (\(e_{F}\)) whereupon the contributions of the single-electron Stoner excitations can predominate over the spin-fluctuations. Attempts to establish the role of both the mentioned mechanisms by magnetic neutron diffraction methods (see [8-10], e.g.) did not result in a unique deduction (see [11] also). At the same time, systematic

experimental data on the magnetic and thermophysical properties of Fe$_{1-x}$Mn$_y$Si and Fe$_{1-x}$Co$_x$Si solid solutions are lacking in a broad range of compositions $0 \leq x, y \leq 1$ and temperatures $4.2 \leq T \leq 1000$ K.

In this connection, experimental and theoretical investigations were undertaken of the magnetic susceptibility and specific heat of quasibinary MnSi and CoSi solid solutions in iron monosilicide that permit establishment of conditions for TILMM formation therein and their influence on the physical characteristics of the alloys studied.

2. The solid solutions Fe$_{1-x}$Mn$_y$Si and Fe$_{1-x}$Co$_x$Si used in the research were synthesized from pure components (99.99% Fe, 99.98% Co, 99.99% Mn, 99.997% Si) by melting their charges in an induction furnace. The ingots obtained were annealed in a vacuum at a 1200 K temperature for 100 hours and were cooled with the furnace. The homogeneity of the compounds obtained was confirmed by metallographic and x-ray diffraction methods.

The temperature dependences of the magnetic susceptibility were studied by the Faraday method in fields of intensity 13.5 kOe in the 77-1000 K temperature range. The error in its determination did not exceed 5%.

Polytherms of the specific heat ($C_p$) of the solid solutions were studied between 13 and 300 K by using an adiabatic calorimeter. The error in determining the specific heat was around 0.5% for temperatures above 25 K and around 2% for T < 25 K.

3. To establish the temperature dependence of the induced LMM of the solid solutions Fe$_{1-x}$Co$_x$Si and Fe$_{1-x}$Mn$_y$Si information about their electron configuration, borrowed from [12], must be compared with the temperature dependences of $y$ and $x$. Experimental investigations of the solid solutions with $x = 0.10, 0.30, 0.50$ and $y = 0.20, 0.85, 0.95$ were performed in the 12-300 K temperature range to find these dependences, as well as the susceptibility of alloys with $y = 0.10, 0.20, 0.25, 0.33, 0.40, 0.60, 0.80, 0.90, 0.95, 1.00$ for $77 \leq T \leq 1000$ K. The results of repeated investigation of the dependence $\chi(T)$ for Fe$_{1-x}$Co$_x$Si alloys with $x = 0.05, 0.10, 0.30, 0.40, 0.50, 0.70, 0.80, 1.00$ turned out to agree sufficiently well with that established in research performed earlier [7]. Some of the polytherms $\chi^2(T)$ and $y(T)$ obtained on the basis of these data are represented in Figs. 1 and 2.

The temperature dependences of $y$ are constructed on the basis of information obtained by subtracting values of the total specific heat for weakly diamagnetic CoSi whose specific heat is determined mainly by the phonon contribution from the total specific heat of the alloys studied. Identity of the phonon spectra of the isostructural solid Fe$_{1-x}$Co$_x$Si, Fe$_{1-y}$Mn$_y$Si, CiSi solutions was assumed here (an analogous procedure for extracting the electron contribution to the specific heat of FeSi was used earlier in [13]).

The formulas for the computation of the magnetic susceptibility and coefficient of specific heat polytherms found by differentiating the expression presented in [3] for the thermodynamic potential of the electron system with respect to the outer magnetic field and the temperature can be represented approximately in the form.