A technique is presented, by which the magnetic susceptibility $\chi^G$ of the ion core of an anisotropic semiconductor $\text{Bi}_2\text{Te}_3$–$\text{Sb}_2\text{Te}_3$ crystal is determined from experimental data on the magnetic susceptibility $\chi_{||}$ and $\chi_{\perp}$ obtained with allowance for the orientation of the magnetic field vector $\mathbf{H}$ with respect to the trigonal $C_3$ axis of the crystal in accordance with the expression $\chi = \chi_{||} + \chi_{\perp}$. In this expression, the value of the magnetic susceptibility of free charge carriers $\chi^\text{eh}_{||}$ and $\chi^\text{eh}_{\perp}$ depending on their effective masses $m^*_{||}$ and $m^*_{\perp}$ known from the experiment is calculated within the framework of the Pauli and Landau-Peierls approaches. The found value of $\chi^G$ for $\text{Bi}_2\text{Te}_3$–$\text{Sb}_2\text{Te}_3$ crystals is in good agreement with experimental data, as well as with the estimates obtained in the framework of the Larmor approach explaining, in particular, a linear dependence of the molar magnetic susceptibility on the number of electrons in the molecule observed for a large number of compounds. The proposed technique can be extended to other anisotropic semiconductors.

**Keywords**: magnetism, semiconductors, magnetic susceptibility.

**INTRODUCTION**

A review of studies of magnetic properties of diamagnetic semiconductors shows that interpretation of experimental results is connected with the need to separate the contributions from the susceptibilities of the ion core $\chi^G_{||}$ and free charge carriers $\chi^\text{eh}_{||}$ to the total magnetic susceptibility $\chi_{||}$ [1–3]. Of greatest interest is the magnetic susceptibility of free charge carriers that depends on their concentration, effective mass, type of the energy spectrum, and a variety of other factors, such as the presence of the Van Hove singular points in the energy spectrum, and, therefore, contains information on the parameters of electronic system of the material. Important is also that the magnetic susceptibility, as the equilibrium thermodynamic parameter, is weakly dependent on the intensity of relaxation processes, which play an important role when considering transport phenomena and mask information about the electronic system. Thus, separation of contributions to the crystal magnetic susceptibility is an urgent task of semiconductor physics, the solution of which would allow to more accurately interpret the data obtained in studying the kinetic phenomena, as well as to determine the parameters of the electronic system using the data on the magnetic susceptibility. This work is aimed at the development of a technique that would allow to approach the solution of this
problem. First, we note that, in some cases, using the concentration and temperature dependences of the magnetic susceptibility, it can be concluded about the presence in the material under study of, for example, paramagnetic impurities or to which extent, the observed dependences correspond to theoretical concepts. In other cases, it is more difficult to make such conclusions due to the insufficient amount of information on the energy spectrum and other characteristics of the material. In this regard, studying the behavior of the magnetic susceptibility of Bi$_2$Te$_3$–Sb$_2$Te$_3$ solid solutions seems to be attractive due to the fact that they are thermoelectric materials and are investigated for decades. Therefore, considerable information has been accumulated [4-6], which can be used, in particular, to interpret the results of experimental studies of magnetic properties of these crystals.

EXPERIMENTAL

We investigated single crystals of Bi$_2$Te$_3$–Sb$_2$Te$_3$ solid solutions containing 10, 25, and 50 mol% of Sb$_2$Te$_3$ grown by Czochralski method at the A. A. Baikov Institute of Metallurgy and Materials Science. As initial materials, Te, Sb, and Bi containing 99.9999 wt.% of the main substance were used. Chemical composition of grown single crystals was determined by the atomic absorption spectrometry. Quality of single crystals was monitored by the X-ray diffraction topography.

The Bi$_2$Te$_3$ crystal has a rhombohedral structure with the space group D$_{3d}^5$ ($R3m$) and its structure can be represented as a set of layers perpendicular to the trigonal axis of symmetry C$_3$. Single crystals under study had a thickness of 15-20 mm and weight of 200-300 g. Samples for the magnetic measurements were cut out from the ingot by means of spark cutting and then purified by etching. Typical dimensions of the samples for the magnetic measurements were $2 \times 2 \times 4$ mm. The magnetic susceptibility was measured in the temperature range from 2 to 400 K with a step of 3 K in magnetic fields up to 30 kOe with a Josephson superconducting quantum interferometer (SQUID-magnetometer) at two orientations of the magnetic field $H$ with respect to $C_3$ ($H \parallel C_3$ and $H \perp C_3$). Below everywhere, the subscripts at $\chi_{\parallel}$ and $\chi_{\perp}$ characterize the mutual orientation of the magnetic field strength $H$ and $C_3$. The relative measurement error does not exceed 2%.

ANALYSIS OF EXPERIMENTAL RESULTS

The results of studying the magnetic susceptibility of the samples No. 1 – Bi$_{1.8}$Sb$_{0.2}$Te$_3$, No.2 – Bi$_{1.5}$Sb$_{0.5}$Te$_3$, and No. 3 – BiSbTe$_3$ in the temperature range from 2 to 400 K are shown in Fig. 1. It can be seen that the magnetic susceptibility $\chi_{\parallel}$ and $\chi_{\perp}$ of all the examined samples possesses diamagnetic response, and, in general, the obtained values of $\chi_{\parallel}$ and $\chi_{\perp}$ are consistent with the data presented in [7-9]. As can be seen from Fig. 1, for all the samples under study, a slight decrease of the diamagnetism is observed with decreasing temperature from 25 to 2 K. Similar temperature behavior of the magnetic susceptibility in the range from 15 to 2 K found in [10] in the course of studying Cu$_x$TiSe ($0.1 \leq x \leq 0.8$) was explained by influence of paramagnetic impurities. Let us analyze the possibility of the effect of the paramagnetic contribution from the impurity atoms, which can be described by the expression

$$\chi^{CG} = \frac{\mu_B^2 n_{pr}}{3k_0T},$$  \hspace{1cm} (1)

where $\mu_B = 9.27 \cdot 10^{-21}$ erg/Gs is the Bohr magneton, $n_{pr}$ is the concentration of impurity atoms, $k_0 = 0.138 \cdot 10^{-15}$ erg/K is the Boltzmann constant, and $T$ is the absolute temperature. We estimate the possible concentration of impurity atoms in a single crystal. Since the content of the main substance in the solid solution is 99.9999%, the amount of impurity atoms is 0.0001%. In 1 cm$^3$, the minimum number of the main material atoms is $\sim 10^{21}$, therefore, the number of impurity atoms can be $\sim 0.0001 \cdot 10^{21} = 1 \cdot 10^{17}$. Experimental data suggest that the change in the magnetic susceptibility in the temperature range from 2 to 25 K is $|\Delta \chi| = 0.013 \cdot 10^{-6}$ cm$^3$/g. According to Eq. (1),