The effective coefficients of thermal conductivity, electrical conductivity, thermal emf, the effective Hall mobility, and the effective Hall coefficient are determined. The analytical dependences obtained are compared with experimental results for a Bi–Cd alloy.

Thermoelectrical Properties

The equations for the current density $\mathbf{j}_e$ and the heat flux density (energy) $\mathbf{j}_q$ in a homogeneous substance under the superposition of electrical and thermal conductivities have the form [1]

$$\mathbf{j}_e = \sigma \mathbf{E} - \alpha \nabla \mathbf{T},$$  

(1)

$$\mathbf{j}_q = \lambda \nabla \mathbf{T}.$$  

(2)

The thermal emf coefficient $\alpha$ is determined from (1) for $\mathbf{j}_e = 0$ and $\nabla \mathbf{T} \neq 0$, i.e.,

$$\sigma \mathbf{E} - \alpha \nabla \mathbf{T} = 0.$$  

(3)

The coefficient of electrical conductivity $\sigma$ is determined from (1) for $\nabla \mathbf{T} = 0$, and the coefficient of thermal conductivity $\lambda$ is determined from (2) for $\mathbf{j}_e = 0$.

Let us determine the coefficients $\alpha, \sigma, \lambda$ for a two-component layered system (Fig. 1a) when $\mathbf{j}_e$ and $\mathbf{j}_q$ are directed parallel to the layers along the $X$ axis. The equivalent circuit for this structure is shown in Fig. 1b.
Fig. 1. To calculate the properties of a layered system: a) model of the layered structure; b, c) equivalent circuit of the structure to determine the voltage drop of the electrical field parallel and perpendicular to the layers.

In this case the expression for the current density \( \langle j_e \rangle \) passing through the layer can be written in the form

\[
\langle j_e \rangle = m_1 \langle j_{e1} \rangle + m_2 \langle j_{e2} \rangle,
\]

where \( m_1 \) and \( m_2 \) are the volume concentrations of the first and second components, respectively. The angular brackets \( \langle \rangle \) denote the average over the volume. The subscripts 1 and 2 will refer, here and henceforth, to the first and second components, respectively, and \( \langle j_{ei} \rangle \) is the current density passing through the i-th component (i = 1, 2):

\[
\langle j_{ei} \rangle = \sigma_i \langle E \rangle - \alpha_i \sigma_i \langle \nabla T \rangle.
\]

Substituting (5) into (4), we obtain

\[
\vec{j}_e = (\sigma_1 m_1 + \sigma_2 m_2)\langle E \rangle - (\alpha_1 \sigma_1 m_1 + \alpha_2 \sigma_2 m_2)\langle \nabla T \rangle.
\]

Let us introduce the parameters \( \alpha_\parallel, \sigma_\parallel \), the effective coefficients of electrical conductivity and thermal emf of the layered system when the layers are parallel to the fluxes, and let us write for \( \langle j_e \rangle \)

\[
\langle j_e \rangle = \sigma_\parallel \langle E \rangle - \alpha_\parallel \sigma_\parallel \langle \nabla T \rangle.
\]

Taking account of (3), we determined \( \alpha_\parallel, \sigma_\parallel \) from (6) and (7)

\[
\alpha_\parallel = (\alpha_1 \sigma_1 m_1 + \alpha_2 \sigma_2 m_2)(\sigma_1 m_1 + \sigma_2 m_2)^{-1},
\]

\[
\sigma_\parallel = \sigma_1 m_1 + \sigma_2 m_2.
\]

It is seen from (4) that when the total current density \( \langle j_e \rangle \) equals zero the current in the components is not zero for \( \nabla T \neq 0 \), i.e., there exists a circulation current caused by the difference in the thermoelectrical properties of the components.

The electromotive force in the circulation current loop equals (see Fig. 1b)

\[
e = (\alpha_2 - \alpha_1) \Delta T,
\]

where \( \Delta T \) is the temperature difference between the isotherms bounding the layered system and perpendicular to the X axis.

According to the second Kirchhoff law

\[
e = I_1 R_1 + I_2 R_2,
\]

Here \( I_1 \) and \( I_2 \) are the total circulation currents flowing through the first and second components, respectively; \( R_1 = L/(\sigma_1 S_1) \) and \( R_2 = L/(\sigma_2 S_2) \) are the resistances of the first and second components to the electric current; \( S_1 = n_1 L_1, S_2 = n_2 L_2 \); \( n_1 \) is the number of