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The Applicability of the Relation of Detailed Balance for a Cluster of Ions of Stationary Composition

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IN a recently published work of Korsunskii, Leviant, and Pivovar[1] on the basis for the treatment of the experimental data presented in another work of these authors[2], a confirmation is made of the fact that to processes of charge exchange between ions of a cluster and molecules of a substance, occurring upon passage of the ionic cluster through the substance, one can apply the relation

$$\sigma_{ik} / \sigma_{ki} = N_k / N_i, \tag{1}$$

where σ_{ik} and σ_{ki} are effective cross sections for an ionic transition from the charge-state i to the charge-state k and vice versa; N_k/N_i is the ratio of the number of ions with charge k to the number of ions with charge i in a cluster of stationary composition. The composition of a cluster passing through a layer of material is determined by the differential equations

$$dN_k / dn = \sum_{i=1}^{m} \sigma_{ik} N_i - N_k \sum_{i=1}^{m} \sigma_{kl}, \tag{2}$$

where n is the thickness of the layer of material in atoms per cm^2, and 1, 2, ... m are the charge-states of the ions of the cluster. The cluster attains a stationary state for the condition $dN_k/dn = 0$. The relation (1) is obtained from this condition for the charge-states fulfilling the condition $|i - k| = 1$, if for $|i - k| > 1$ all $\sigma_{ik} = \sigma_{ki} = 0$ (processes of exchange of more than one electron do not occur). Since the conditions indicated in Ref. 2 are not satisfied, its fulfillment in this work proves to be purely by chance, inasmuch as the relation (1) is not derived from any sort of general considerations.

The applicability of Eq. (1) can be subjected to a direct check in processes of capture and loss of two electrons in single collisions of protons and negatively charged hydrogen ions with molecules of hydrogen. For these processes, according to Eq. (1), the equality

$$\sigma_{1-1} / \sigma_{-11} = N^- / N^+. \tag{3}$$

must hold. The effective cross-sections σ_{1-1} for capture of two electrons by protons upon collision with hydrogen molecules, and the ratios N^-/N^+ in a hydrogen cluster of stationary composition, formed in the passage of protons through hydrogen, were determined in the work of Fogel' and Mitin[3]. On the other hand, we determined the effective cross sections of σ_{-11} for the loss of two electrons in collisions of negative hydrogen ions with molecules of hydrogen[4]. In the Table, values of the quantities $\sigma_{1-1}/\sigma_{-11}$ and N^-/N^+ are presented for various energies of the ions of the cluster. The

Energy of Ions, kev.	$\sigma_{1-1} \cdot 10^{18}$ cm^2	$\sigma_{-11} \cdot 10^{17}$ cm^2	$\frac{\sigma_{1-1}}{\sigma_{-11}} \cdot 10^2$	$\frac{N^-}{N^+} \cdot 10^2$	$\frac{\sigma_{1-1}/\sigma_{-11}}{N^-/N^+}$
10,3	7,2	3,8	18,7	17,5	1,1
15,2	11,4	4,1	28,1	13,1	2,1
20,7	12,3	3,8	32,3	9,1	3,6
24,9	8,9	3,9	25,7	6,3	4,1
29,6	7,2	3,7	19,5	4,3	4,5
31,8	4,2	3,1	13,1	3,5	3,7

errors in measurement of the quantities in the table are as follows: for $\sigma_{1\text{-}1}$, ±30%; for N^-/N^+, +18%; and for $\sigma_{\text{-}11}$, ±15%. As is seen from this Table, the equality (3) is not satisfied in a significant part of the energy interval investigated.

Thus the relation (1) cannot be of universal applicability to processes of energy exchange between an ionic cluster and a material.

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On the Possibility of Observing the Variation of the Chemical Potential of Electrons of a Metal in a Magnetic Field

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1. AS is known, the quantization of the energy levels of electrons in a magnetic field leads to a number of phenomena (diamagnetism of the electron gas, De Haas-van Alfen effect, Shubnikov-de Hass effect, *et el.*) As a rule, the variation of the chemical potential of the electron gas in the magnetic field is insignificant in all these phenomena.

The dependence of the chemical potential ζ on the magnetic field can be detected directly by measuring the contact potential difference $\delta\varphi$ between two samples of the same metal, if one of these samples is placed in a strong magnetic field.

The contact potential difference which arises is determined by the difference of the chemical potentials

$$e\,\delta\varphi = \zeta(H) - \zeta_0; \qquad \zeta_0 = \zeta(0).$$

to the accuracy of a constant component related to the different states of the sample surfaces.

According to Ref. 1, this difference is:

$$e\,\delta\varphi = \frac{2\sqrt{2\pi}}{dU/d\zeta}\left(\frac{e\hbar H}{c}\right)^{3/2}\frac{G(\zeta_0, H)}{|\partial^2 S(\zeta_0, p_z)/\partial p_z^2|^{1/2}}, \quad (1)$$

where

$$G(\zeta_0, H) = \sum_{k=1}^{\infty}\frac{1}{k^{3/2}}\Psi(k\lambda)\sin\left[\frac{kc}{ehH}S_m(\zeta_0) \mp \frac{\pi}{4} - 2\pi k\gamma\right] \times \cos\left[\frac{k}{2m_0}\frac{dS_m}{d\zeta}\right];$$

$$\Psi(z) = z/\sinh z; \quad \lambda = (\pi c\theta/e\hbar H)\, dS_m/d\zeta$$

(the notation is the same as in Ref. 1). If the expression for the oscillating part of the magnetic moment $\mathbf{M}_{\text{osc}}$ [Ref. 1, Eq. (3.2)] is used, then there can be obtained:

$$e\,\delta\varphi = -\frac{\alpha\,\mathbf{MH}_{\text{osc}}}{N}, \quad \alpha = U\frac{dS_m}{d\zeta}\Big/ S_m\frac{dU}{d\zeta}; \quad (2)$$

α is a nondimensional function of the angles between the field and the crystallographic directions; $\alpha = \frac{2}{3}$ in case of an isotropic quadratic dependence; N is the number of electrons.

We took into account only that variation of the chemical potential in (1), which is related to the oscillating component of the thermodynamic potential since that variation of the chemical potential which is caused by the presence of monotonic components (diamagnetic and paramagnetic) is proportional to

$$\delta\zeta \sim \mu H(\mu H/\zeta),$$

and, as we will see below, is considerably less than the oscillatory part (certainly, for low temperatures).

In order to estimate the order of magnitude of the effect expected, it can be considered that

$$|\partial^2 S(\zeta_0, p_z)/\partial p_z^2|_m^{-1/2} G(\zeta_0, H) \sim 1,$$
$$e\,\delta\varphi \sim (\mu H/\zeta_0)^{1/2}; \quad \mu = e\hbar/m^* c.$$

For

$$H \sim 10^4 \text{G}, \qquad \zeta_0 \sim 10^{-12}\ \text{эрг}, \quad \mu \sim 10^{-20}; \quad \delta\varphi \sim 10^{-6}\ \text{V}.$$

This estimate is lowered considerably since it is not taken into account that the effective mass of the majority of metals for which the De Haas-van