

Electrostatic Potential of Dust Particle in thermodynamically equilibrium dusty plasma

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I. Electrostatic potential of phase boundary in Coulomb systems

The basic feature of thermodynamic equilibrium in Coulomb system is the existence of stationary potential drop at any mean-phase interface in such systems [1] [9] [4] (so-called Galvani-potential). The discussed interface potential drop is a *thermodynamic* quantity. The point is that in contrast to other zero-temperature electrophysical parameters such as work function or the value of the so-called surface dipole at metal-vacuum surface at $T = 0$ (calculated via DFT [12]) the value of potential drop is well-defined quantity at any temperature. It depends on the bulk properties (chemical potentials) of coexisting phases only and does not depend on surface properties of phase interface, $\Delta\varphi = \Delta\varphi(T)$ [6].

$$\Delta\varphi(T) \equiv \varphi'(r \rightarrow -\infty) - \varphi''(r \rightarrow +\infty) = e^{-1}[\mu_e'(T)\mu_e(T)] = (Ze)^{-1}[\mu_i(T)\mu_i'(T)]. \quad (1)$$

As thermodynamic quantity the discussed interface potential forms separate phase diagram (electrophysical phase "portrait" of Coulomb system) additional to well-known caloric and thermal phase diagrams [10] (see figures 1,2). For example, such "portrait" has been calculated for classical and quantum melting of Wigner crystal in the ordinary one-component ionic model on rigid background (notation OCP) [5]. Definitely such electrostatic phase diagram is meaningful for all the phase transitions in dusty plasmas. Existence of such phase diagram is still not well-recognized and its properties are not known.

Galvani-potential of mean phase interface $\Delta\varphi(T)$ has two remarkable features in low- and high-temperature limits. It evidently tends to zero at critical point of gas-liquid phase coexistence. A special critical exponent ϕ can be introduced to describe this behavior [4] [5]. This exponent ϕ completes the set of standard critical exponents.

$$\Delta\varphi(T) \sim |T - T_C|^\phi \rightarrow 0 \quad \Delta\rho(T) \sim |T - T_C|^\beta \rightarrow 0 \quad (T \rightarrow T_C) \quad (2)$$

New exponent ϕ coincides with the density exponent β if the chemical potential of both components, ions and electrons, are analytic functions of temperature and densities at critical point. This is the case for example in simplified Coulomb models like modified one-component plasma of point-like ions on *uniformly compressible* electronic background (notation OCP()) and "double" OCP models (notation DOCP) - superposition of two OCP() (positive and negative) [2]. In both the models $\phi = \beta = 1/2$ [4]. Equality of both exponents ($\phi = \beta$) in general case is still an open question.

The zero-temperature limit of this potential $\Delta\varphi(T)$ at $T \rightarrow 0$ (along the phase boundary) is an individual substance coefficient, which completes the standard set of substance coefficients like sublimation energy, ionization potential etc. Simplified thermodynamics of phase coexistence in this limit makes it possible to connect the value $\Delta\varphi(T \rightarrow 0)$ with sublimation energy $\Delta_S H^0$ ionization potential I and zero-temperature value of electron chemical potential $\mu_e(T = 0)$ [3] [6].

$$e\Delta\varphi(T = 0) = (1/2)[\Delta_S H^0 + I] + \mu_e(T = 0) \quad (T \rightarrow 0) \quad (3)$$

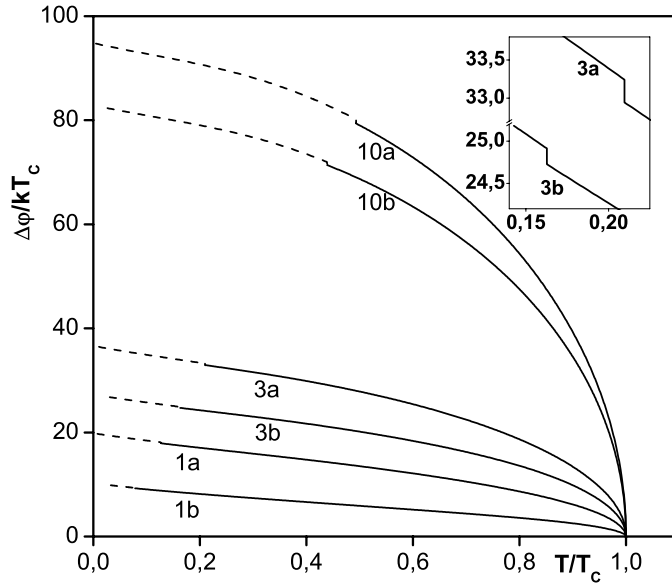


FIG. 1: Temperature dependence of interface (Galvani) potential in OCP () (a) and DOCP (b) models (left) with different values of ionic charges ($Z = 1, 3, 10$); S - sublimation (*dashed*) and L - boiling (*solid*) boundaries. Small gaps of potential in melting point could be distinguished between S and L branches (on insertion).

Behavior of Galvani potential $\Delta\varphi(T)$ along any phase coexistence curve can be calculated with the use of equality (1) in frames of so-called quasi-chemical representation ("chemical picture", see for example [?]) when this approach is used for calculation of thermodynamic functions and equilibrium composition in both coexisting phases. For example it is exposed at figure 2 for metallic uranium [11] and its important compound, uranium dioxide, standard fuel of presently exploited nuclear reactors [7] [8].

II. Dusty plasmas

The existence of the temperature-dependent mean-phase potential drop, $\Delta\varphi(T)$ has an influence upon ionization properties of low-temperature plasmas with condensed dispersed particles (CDP-plasmas). Ionization equilibrium in such plasmas strongly depends on emission properties of CDP-particles as well as on their density n_p (and ionization ability of gas environment). It's well-known [13] that expansion of CDP-plasma and mutual separation of CD-particles in the case of gas-particle equilibrium on electron exchange only leads to an infinite growth of CD-particle charge and potential. In contrast to that one meet perfectly different behavior in the case of total gas-particle equilibrium via electron as well as heavy particles exchange. For example, this is the case for equilibrium of microscopic metallic drops with its own vapors [3]. Mutual separation of CD-particles in this case leads to the well-defined restricted values of CD-particle charge Z^* and potential φ^* . In general it depends on temperature T , size L , and form of solitary CD-particle (notation $\{\diamond\}$) being the solid dust particle or liquid drop.

$$|\varphi * \{T, n_p, |L, \diamond, \}\}| \leq |\varphi * \{T, 0, |L, \diamond, L\}|. \quad (4)$$

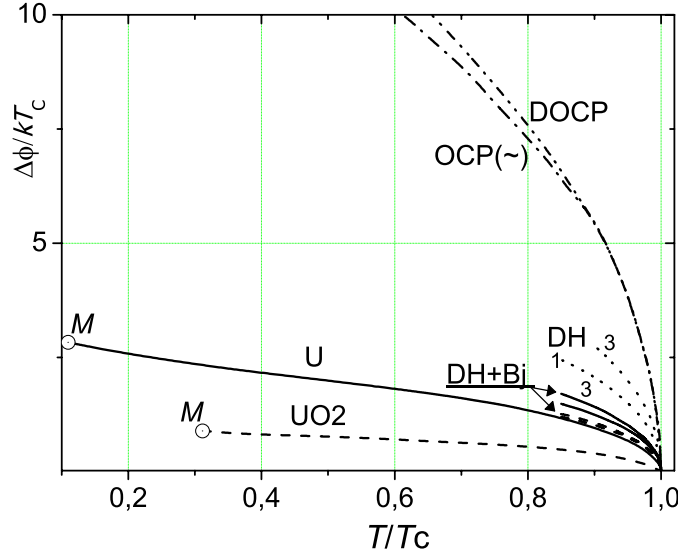


FIG. 2: Reduced potential of gas-liquid interface (Galvani potential) in real substances and simplified plasma models. Calculations for uranium (U) and uranium dioxide (UO_2) via SAHA-code [11] [8]. *Models*: OCP(·), DOCP - modified one-component plasma; CHS - charged hard spheres [14]. DH - ordinary Debye-Huckel approximation in charge-asymmetric CHS with $Z^+/Z^- = 3$ and 2; DH - Bj - the same in Debye-Huckel-Bjerrum approximation (with bound clusters); M - melting point.

For a great-size solitary CD-particle the limiting value of its electrostatic potential φ^* tends (at absolute value) to its upper bound, φ^{**} , which depends on temperature only and corresponds to the mentioned above equilibrium potential drop of flat gas-liquid interface, $\varphi^{**} \rightarrow \Delta\varphi(T)$ (see fig. 2).

III. Applications

Dependence of Galvani-potential φ^* of dust particles (liquid micro-drops) on their size, shape and thermodynamic parameters can be calculated successfully in frames of so-called Density Functional Theory (DFT). Knowledge of this dependence may be useful for (i) diagnostics of dust plasmas, and (ii) for active influence on properties of such plasmas. When the magnitude of φ^* being measured one can obtain useful information on particle number, their size and dispersion in thermally equilibrium dust plasmas. It is also interesting to reveal connection of equilibrium charge of liquid micro-drop with its mechanic oscillations. Fundamental (resonance) frequencies of these oscillations may be calculated as mechanical property of the drop depending on density and compressibility of its material, as well as its size and surface tension. It seems to be interesting to measure electromagnetic field, which accompanied mechanical oscillations of the drop. An opposite process is also interesting - increasing of micro-drop oscillations under external resonance irradiation. This could be effective tool for controlled increase of dispersion in such "misty" plasmas because of resonance amplification of liquid micro-drop oscillations and their subsequent destruction. It could be useful for example, for creation of highly-dispersive screen of liquid metallic

clouds in the earth atmosphere *etc.*

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