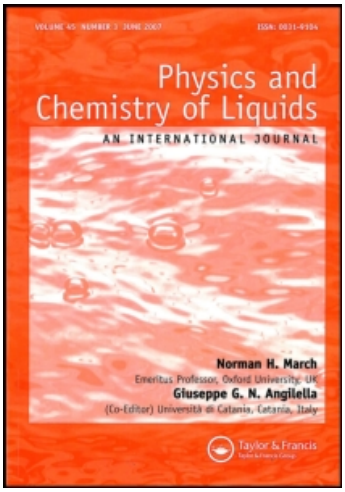

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LETTER

Scaling of Electrical Conductivity in Strongly Coupled Plasmas, with Reference to Expanded Liquid Alkali Metals

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Using the Nernst-Einstein relation, a metallic plasma of ions of valency Z has an electrical conductivity $\sigma = 3\Gamma D/(4\pi Z a^2)$ where a is the near-neighbour distance while Γ is the ionic plasma coupling parameter $(Ze)^2/ak_B T$. For Cu plasma, and for $\Gamma > 10$, experiment reveals that $\sigma \propto \Gamma$, which implies that D/a^2, with D the electronic diffusion coefficient, is independent of thermodynamic state in this strong coupling regime. Possible relevance to expanded liquid metal Cs is briefly discussed.

KEY WORDS: Plasma coupling parameter, electronic diffusion coefficient.

The purpose of this Letter is to interpret experimental data on the electrical conductivity σ of Cu plasma, as a function of the plasma coupling parameter Γ for the ions. For valency Z, this parameter is defined by

$$\Gamma = (Ze)^2/ak_B T \tag{1}$$

where a is the interionic separation, related to ionic density n_i by

$$n_i = 3/4\pi a^3. \tag{2}$$

The motivation for the present work resides in recent experiments on Cu plasma[1] in which the conductivity σ has been measured for numerous thermodynamic states. This work has been compared and contrasted with H plasma by one of us[2] elsewhere. When σ is then plotted as a function of Γ, a family of curves for $\Gamma < 10$ collapses onto an 'almost universal curve' in a range $10 < \Gamma < 100$. Examining the slope of the log-log plot in Ref. 1, one finds the empirical result

$$\sigma = \sigma_0 \Gamma \quad (10 < \Gamma < 100). \tag{3}$$

This result (3) has prompted us to utilize the Nernst-Einstein relation between electronic diffusion coefficient D, mobility μ and thermal energy $k_B T$, namely

$$D/k_B T = \mu. \tag{4}$$

Now the current density j is given by $j = n_e ev = n_e e\mu E$ or

$$\sigma = n_e e^2 \mu = n_e e^2 D/k_B T. \tag{5}$$

Introducing into Eqn. (5) the plasma parameter Γ defined in Eqn. (1), and using the relation $n_e = Zn_i$ between electronic and ionic number densities we find

$$\sigma = \frac{Zn_i e^2 D\Gamma a}{(Ze)^2} = \frac{3}{4\pi Z}\Gamma \frac{D}{a^2}. \tag{6}$$

Thus we reach our main conclusion by combining Eqns. (6) and (3), for the case of strongly coupled Cu plasma

$$D/a^2 = \text{constant}, \tag{7}$$

where the meaning of constancy in Eqn. (7) is that, for a particular species of plasma, say Cu, D/a^2 is independent of thermodynamic state.

Evidently, on dimensional grounds D/a^2 has the meaning of the inverse of a characteristic time. This, since it is independent of thermodynamic state over a wide range of coupling parameter Γ, we shall term a 'chemical' rate, which could be related to the number of 'closed orbits' an electron makes round, say, a pair of Cu nuclei before leaving such a 'bond' by hopping on to another 'chemical complex' in the plasma. We naturally expect that D/a^2 will change as we vary the plasma species.

In the light of the above discussion of Cu, it seems of interest to briefly comment also on the possible relevance to further electrical conductivity data on other species of strongly coupled plasma. Such systems are afforded by the heavy liquid alkali metals Rb and Cs, taken up the liquid-vapour coexistence curve from just above their normal freezing points towards the critical point. One has here important information also on the liquid structure factor $S(k)$ determined by the neutron scattering experiments of Hensel and coworkers[3]. These experiments reveal a remarkably constant near-neighbour distance, say R_c, and show that the lowering of the mass density required as the critical point is approached is due to a lowering of the coordination number z. The 'chemical complex', or building block, of the structure in this case is related therefore to a Cs (or Rb) 'bond'. However, as argued by Poshusta and Klein[4] for hydrogen, and later by Malrieu *et al.*,[5] for sodium and other alkalis, a Heisenberg Hamiltonian appears to be an appropriate tool to give a quantitative description (though Malrieu *et al.*, were, in fact, concerned with crystalline Na). The characterization of such a Hamiltonian appears to require potential energy curves for both singlet and triplet states.

Nevertheless, because experiment makes clear the role of a 'chemical complex' in Cs (and Rb) as the thermodynamic state is changed, it seems plausible in these cases that D/a^2 will be related to the time an electron spends in the neighbourhood of such a complex, before 'hopping' to a neighbouring complex in the fluctuating environment of ions in the strongly coupled plasma.

In summary, scrutiny of the experimental data on Cu plasma for $\sigma(\Gamma)$ shows that, in the strong coupling regime $\Gamma > 10$, Eqn. (3) represents the results with σ_0 independent of the thermodynamic state. The Nernst-Einstein relation then leads to the simple conclusion that in this regime of coupling parameter the ratio D/a^2 is a

constant, independent of thermodynamic state, D being the electronic diffusion coefficient and a the near-neighbour distance. Finally, the possible relevance to the expanded heavy alkali liquid metals is discussed.

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