THE CONDUCTIVITY OF DENSE CAESIUM PLASMA NEAR THE SATURATION LINE

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Institute of High Temperatures, U.S.S.R. Academy of Sciences, Moscow, U.S.S.R.

The measurements of electrical conductivity of saturated caesium plasma/1/have demonstrated the extremely large values, exceeding the results of the usual gas-kinetic consideration by 5-6 orders of magnitude.The mesurements of conductivity at 20 atm./2/have shown abrupt decreasing in narrow temperature interval near saturation line and then according to the growth of temperature,relatively smooth increasing(Fig.).The anomalious behaviour of conductivity will be explained here with the formation of higher-order ionic clusters.The minimum at isobar arises due to concurrence of two processes: the ionic clusters dissociation and thermal ionization of neutral atoms.

The influence of heavy ions on conductivity for the first time was discussed by Leckenby and Robins/3/.They showed that the presence of the quadramer sodium cluster would increase the conductivity of sodium vapour by an order of magnitude over that expected for the monomer.The atom of caesium has polarization constant which is larger than one for sodium.That is why the caesium vapour at high pressure has to contain more heavy ions.The structure of such ions is investigated very badly,there are no data on their role in ionization equilibrium of plasma.The semiconductors theory/4/helps overcome the difficulty.Let us consider the expression for free-energy caesium vapuor with ions in a centre of it.We will suppose that the concentration of particles $N(\vec{r})$ depends on co-ordinates.Such dependence is due to the strong polarization attraction of caesium atoms to the ion.In order to take into account the expression for the free energy is used which corresponds to the Van-der-Waals equation. Thus,the expression for the free energy follows

$$\beta F = \int_{\Omega_1} d\vec{r}\left[N(\vec{r}) \ln\left(\frac{N(\vec{r})}{1-bN(\vec{r})}\right) - N^2(\vec{r})a\beta + \beta\frac{U(\vec{r})}{\varepsilon}\right] + (\Omega-\Omega_1)\left[N_1 \ln\left(\frac{N_1}{1-N_1 b}\right) - N_1^2 a\beta\right] \qquad (1)$$

where β is reciprocal temperature in energetical units, Ω the total volume, Ω_1 is the volume with characteristic scale of atom-ion interaction, a and b are the Van der-Waals parameters.The value N_1 is the average concentration of particles in the volume $\Omega-\Omega_1$, $N_1 = \dfrac{N\Omega - \int_{\Omega_1} N(\vec{r})\, d\vec{r}}{\Omega - \Omega_1}$

N is the average concentration, $U(\vec{r})$ is the potential of ion-atom interaction from calculation/6/, ε is dielectric permeability taking into account the decrease of potential due to dipols interaction. According to/5/ $\varepsilon = 1 + \frac{8}{3}\pi N(\vec{r})\alpha$ where α is the polarization constant.For

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C_S the value of α is 430 a_0^3.Let us suppose the concentration $N(\vec{r})$ is changed very strongly in the volume Ω_1 and in the volume Ω the fluctuation $c(\vec{r}) = \frac{N(\vec{r}) - N}{N} << 1$. We will find such distribution of concentration in the total volume Ω,which corresponds to the minimum of free energy.For this purpose let us find the change of free energy,due to ionic cluster formation

$$\beta \Delta F_i \{c\} = N \int d\vec{r} \{ (c(\vec{r})+1) \ln \left[\frac{(c(\vec{r})+1) C_0}{C_0 - c} \right] - \frac{c(\vec{r})}{N b C_0} - \beta N c^2(\vec{r}) a + \beta U(\vec{r}) (c(\vec{r})+1)/\varepsilon \} \qquad (2)$$

The optimum fluctuation is found from the condition $\delta \Delta F_i / \delta c = 0$.It satisfies the following equation

$$\tilde{c}(r) = (\exp(-\beta \tilde{U}(r)) - 1)/(1 + \exp(-\beta \tilde{U}(r))/C_0) \qquad (3)$$

where $\beta \tilde{U}(r) = \frac{\beta U(r)}{\varepsilon^2} + \frac{C_0 + 1}{C_0 - \tilde{c}(r)} - \frac{1}{N b C_0} - 2 N a \beta \tilde{c}(r)$

$C_0 = 1/Nb - 1$

At small temperatures the equation(3)can have three roots.The smallest and the largest ones are realized,that corresponds to the phase transition from gas to liquid state inside the cluster.At high temperatures equation(3)has one root and there is no transition inside cluster.By means of free energy minimization we get the equation for concentration of negatively and positively charged particles.We suppose that electron-neutral atom and ion-neutral atom interaction is dominant,while electron,electron-electron,ion-electron interactions are negligible.So we have

$$\frac{N^+ N^-}{N} = \left(\frac{mT}{2\pi \hbar^2} \right)^{3/2} (1 - Nb)^{-1} \exp\left[-\beta (I - \Delta I^- - \Delta I^+ + 2Na) - \frac{Nb}{1 - Nb} \right]$$

where

$$\beta \Delta I^+ = -N \int d\vec{r} \{ (\tilde{c}+1) \ln \left[\frac{(\tilde{c}+1) C_0}{C_0 - \tilde{c}} \right] - N \tilde{c}^2 a \beta - \frac{\tilde{c}(r)}{N b C_0} + \frac{\beta U (\tilde{c}+1)}{\varepsilon} \}$$

The quantity ΔI^+ can be written analogically.The calculations show that the concentration of negatively charged particles has a deep minimum at isobar.This minimum corresponds to the minimum of conductivity in Fig.The same methods as in /7,8/ were used for the calculation of electrical conductivity of a dence caesium plasma.The reults are shown in Fig.

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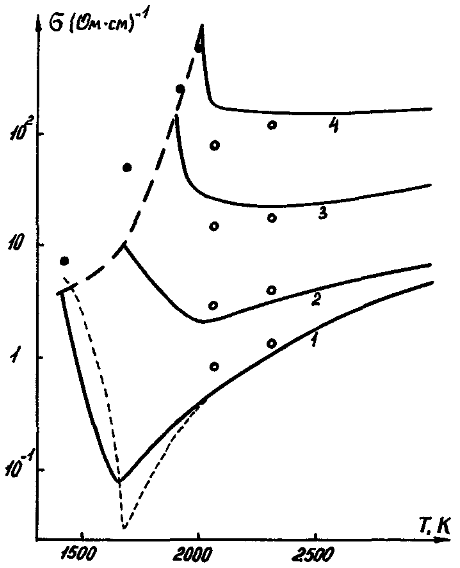

• -experiment/1/at saturation line, ---- -experiment/2/,performed at isobar p=20 atm, o -experiment/1/at 2073K and 2273K, 1-results of present work at p=20atm,2,3, 4-results at =0.22,0.43,0.75ρ_c respectively, ρ_c -critical density,— —results at saturation line.