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ELECTRIC CONDUCTIVITY OF A HIGH-DENSITY XENON PLASMA

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by

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13. ABSTRACT

The temp. dependence of the sp. cond. of a xenon plasma was studied for high concns. of the charged particles when the notion for Debye screening was not applicable. For discharge tube diams. of 7.4-15.5 mm and under pressures of 200-600 T or R, similar dependences were found: with increasing temp. from 10,000 to 20,000°K, the sp. cond. rose from 60 to 190 omega-anion(1) cm-anion(1). An attempt was made to obtain theoretically the exptl. found dependence.
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By: S. I. Andreyev and V. Ye. Gavrilov

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О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

* ye initially, after vowels, and after ъ, ь; e elsewhere. When written as ё in Russian, transliterate as yё or ё. The use of diacritical marks is preferred, but such marks may be omitted when expediency dictates.

ELECTRIC CONDUCTIVITY OF A HIGH-DENSITY XENON PLASMA

S. I. Andreyev and V. Ye. Gavrilov

The purpose of this work is to experimentally investigate the dependence of specific electric conductivity (σ) of xenon plasma on temperature (T) under conditions of the high concentration of charged particles when the concept of Debye screening is not used.

The measurements were made in quartz tubes with a diameter of d = 7.5, 10.5, and 15.6 mm at a distance of l = 150 mm between electrodes. The temperature was determined from Planck's formula for the spectral density of the brightness of an absolutely black body $b_{\lambda p}(T, \lambda)$. Magnitude $b_{\lambda p}(T, \lambda)$ was determined from the transport equation

$$b_{\lambda p} = \frac{b_\lambda}{1 - e^{-\tau_\lambda}}, \tag{1}$$

where $e^{-\tau\lambda}$ is the transparency of the plasma which was measured by illuminating the plasma with an independent source, and b_λ is the spectral density of the plasma brightness which was measured by comparison with a standard EV-39 type source [1]. The temperature values thus obtained with a variation in b_λ and $e^{-\tau\lambda}$ at different wavelengths coincided for the same discharge mode within the limits not exceeding 300°K.

The resistance of the plasma column (R) was determined at the moment of the maximum current pulse (t_m) from the equation

$$R = \frac{U_0 - \frac{1}{c}\int_0^{t_m} i(t)\,dt}{i_m}, \tag{2}$$

where U_0 is the initial voltage to which capacitor C charges. Moment of time t_m was determined from the condition $\left(\frac{di}{dt}\right)_{t=t_m} = 0.$ The oscillographic notation of the current i(t) was integrated and differentiated graphically. To increase the accuracy of the graphic integration and differentiation, the current oscillogram was increased to dimensions determined by the thickness of the oscillograph beam. The accuracy of the oscillographic notation i(t) obtained by a special shunt was monitored by methods described in work [2].

The resistance of the entire discharge circuit without a discharge envelope was measured in like manner and was subtracted from the values of R obtained in the presence of the discharge. The voltage between the electrodes of the discharge tube at moment t_m amounted to a magnitude on the order of a kilovolt (or several kilovolts), so that the electrode voltage drops were negligibly low.

To connect the electric conductivity of the plasma in the center of the discharge column with the plasma temperature at the same point the radial temperature distribution whose results we described earlier [3] were investigated. In accordance with this investigation the radial temperature distribution of plasma under our conditions is described by the equation

$$T(r) = 1{,}18\ T_0 \left(0{,}5 - \frac{r}{d}\right)^{0{,}11}, \tag{3}$$

where T_0 is the temperature on the axis of the plasma column of diameter d, and $r > 0.25$ d.

Measuring R and T under different discharge-current densities, we established the function between the values of $\bar{\sigma}$ and $\bar{T}$, average in the cross section, in the first approximation. To calculate $\sigma(T)$ in the second approximation, distribution (3) in the expression[1]

$$R = \frac{l}{2\pi\int_0^{d/2} \sigma[T(r)]\, r dr}. \tag{4}$$

was calculated.

Hence there follows a subsequent connection between the experimentally measured values of R and σ_0 in the center of the plasma column:

$$\sigma_0 = 1{,}08 \frac{l}{R\frac{\pi d^2}{4}} + 0{,}08 f(T_0)\ (\Omega \cdot cm)^{-1}, \tag{5}$$

where $f(T_0)$ takes values of 2, 4, 8, 20, and 45 when T_0 is equal to 12, 14, 16, 18, and 20 thousand °K, respectively.

Since the experimental values under our conditions have an order of $10^2 (\Omega \cdot cm)^{-1}$, the second term in expression (5) amounts to no more than 5% of the measured magnitude. The first term of this expression differs by 8% from the electric-conductivity value average over the cross section with a radial distribution of T(r) in terms of (3).

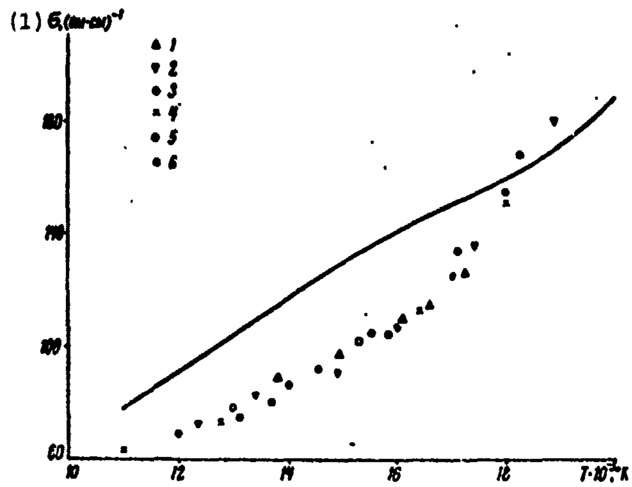
The experimental results $\sigma_0(T_0)$ obtained on different-diameter tubes under various discharge modes but with the same temperature T_0 proved to coincide within the limits of ±5%. These results are shown in the figure. It also shows the results of calculating from

[1]It turned out that we can limit ourselves to the second approximation, since the third approximation differs from the second approximation within the accuracy limits of approximation (3).

the formula stemming from the approximation of paired collisions with the cutoff of the radius of motion of the Coulomb forces by the Debye radius [4]:

$$\sigma = 2{,}62 \cdot 10^{-4}\, T^{\frac{3}{2}} \frac{n_e}{\dfrac{n_1 \ln \Lambda_1}{\gamma_1} + \dfrac{4n_2 \ln \Lambda_2}{\gamma_2}}, \tag{6}$$

where $\Lambda_{(1,2)} = \dfrac{3kT}{Z_{(1,2)}\, e^2} D$, $D = \left(6{,}9 \dfrac{T}{n_e + n_1 + 4n_2}\right)^{\frac{1}{2}}$ is the Debye radius, n_e is the electron concentration, n_1 are the one-time ionized atoms, n_2 are twice ionized atoms, and γ_1 = 0.582 and γ_2 = 0.683 are factors which consider the interelectrode impact.



Temperature function of the specific electrical conductivity of xenon plasma: 1 – points relate to the case of a discharge in a tube with an internal diameter of d = 15.5 mm filled with xenon when p_0 = 400 mm Hg; 2 – d = 10.5 mm, p_0 = = 200 mm Hg; 3 – d = 10.5 mm, p_0 = 400 mm Hg; 4 – d = 10.5 mm, p_0 = 600 mm Hg; 5 – d = 7.4 mm, p_0 = 400 mm Hg; 6 – d = = 10.5 mm, p_0 = 400 mm Hg. The discharge mode: points 1-5 – C = 415 μF; L = 25 μH; 6 – C = 4.8 μF; L = 1 μH. The discharge-column length in all cases amounted to 150 mm. KEY: (1) $\sigma(\Omega \cdot cm)^{-1}$.

It should be noted that the qualitatively excellent function $\sigma(T)$ calculated from (6) is observed. The numerical agreement of the calculation results from (6) with the experiment is obviously random, since the concept of Debye screening, based on a statistical averaging of a large number of particles in the Debye sphere, has no physical sense.

Actually, as the data shown in the table indicates, the number of particles in the sphere of the Debye radius (N) proves to be less than unity under the conditions of our experiment. The magnitude of the Debye radius (D) is less than the average distance between particles ($n_e^{-1/3}$). The average energy of the Coulomb interaction $e^2(n_e+n_1)^{-\frac{1}{3}}$ is approximately 5 times less than the thermal value of (kT). The consideration of the role of the twice-ionized atoms leads to a reduction in the calculation values of σ in the region of 18-20 thousand °K. In calculating the ionized composition of plasma the radial temperature distribution and the reduction in the ionized potential according to work [5] were considered. Let us note that if we assume the digital factor in the expression for Λ_z to be equal to 2 [6], and not 3 [4], the calculation value of σ is approximately twice as high as the experimental value in the region of 12-14 thousand °K.

Table. Data for calculative σ(T).

$T\cdot 10^{-3}$, °K	$n_e\cdot 10^{-16}$, $см^{-3}$	$D\cdot 10^{7}$, см	$n_e^{-\frac{1}{3}}\cdot 10^{7}$, см	$N=\frac{4}{3}\pi D^3 n_e$	$\frac{(n_e+n_1)^{\frac{1}{3}}e^2}{kT}$	$\ln\Lambda_z$
12	1,6	4,3	7,9	0,5	0,22	2,21
14	2,9	3,4	7,0	0,5	0,21	2,15
16	4,0	3,1	6,3	0,5	0,21	2,18
18	4,7	3,0	6,0	0,5	0,20	2,27
20	5,8	2,9	5,6	0,6	0,18	2,26

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