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V. A. Alekseev and A. A. Vedenov. Electric Conductivity of Dense Cesium Vapor

The question of the appearance of electric conductivity upon compression of metal vapors was considered in the literature many times.[1] The most interesting is the investigation of the electric conductivity of Cs, which has the lowest ionization potential, 3.9 eV, and critical parameters $p_c = 115$ atm, $T_c = 1775°C$, and $\rho_c = 0.445$ g/cm^3,[2] such that at $T \sim T_c$ rarefied cesium is an ideal weakly-ionized plasma with electric conductivity ~ mho/cm.

Measurements of the electric conductivity of Cs in the transcritical state have been carried out recently at the I. V. Kurchatov Institute of Atomic Energy[3] (analogous experiments were carried out also at the Karlsruhe University, West Germany[4]).

Success in the measurement of the electric conductivity of cesium in the transcritical state is due entirely to the choice of materials, since cesium has a rather high critical temperature and an increased reactivity. From among the insulators we have chosen pure beryllium oxide. The best metal is tungsten and for experiments of short durations it is possible to use niobium.

The experiment is based on the idea of the possibility of producing a liquid piston of the investigated metal, capable of transmitting the working-gas pressure to the zone of high-temperature measurements.

A measurement cell was constructed on the basis of this principle. The body of the cell was made of a tube of electronically-melted niobium 6.3 mm in diameter. A lower electrode of the same grade of niobium was welded to the lower part of the tube with an electron beam, and a capillary of beryllium oxide was tightly placed over the lower electrode. In the upper end of the capillary was inserted the upper electrode of niobium, of 2.5 mm diameter in such a way that the difference between the electrodes, where the cesium was located, was 2–3 mm. A thermocouple in a flat sleeve of beryllium oxide was fastened to the side of the cell. The junction of the thermocouple was placed opposite the gap between the electrodes, with accuracy ±0.2 mm.

To determine the temperature in the cell, the readings of the thermocouple at the housing of the cell were compared with the readings of a thermocouple placed in the zone in lieu of the cesium. The ends of the thermocouple were passed through conical inserts, and the second junction was placed in a dewar with melting ice. The cell length was chosen to accommodate the cesium expanding upon heating. The cell was heated with a tubular heater of molybdenum foil 10 cm long, to which 250 A alternating current was fed. A special mechanism has made it possible to regulate the position of the cell relative to the heater under pressure. The current lead was made in the form of a conical gasket on the lower obturator and served as the lower holder of the heater. The body of the heater was made of stainless-steel sheet and was spot welded along the perimeter of obturator. The thermal insulation of the heater was provided by magnesium-oxide powder filling the space between the heater and the housing. The cell with the heater were placed in a chamber for high-temperature measurements, which was filled with purified argon at the required pressure. Argon of "pure" grade was rid of oxygen, water, and carbon dioxide by passing it under pressure through briquettes made of fine chips of annealed red copper and liquid sodium at 400–450°C. After purification, the argon was fed to a thermal compressor, the action of which is based on liquefying the argon at liquid-nitrogen temperature followed by heating to the required pressures. The thermal compressor was a steel flask of 0.5 liter capacity. The pressure in the chamber was measured with standard manometers. The cesium resistance was determined from the potential difference produced between the niobium electrodes by the flow of direct current, and was recorded with an automatic potentiometer.

The results of the electric-conductivity measurements[3,4] are shown in Fig. 1.

The experimentally observed exponential dependence of the electric conductivity on the density may be due to the interaction of the "free" electrons with the neutral atoms.[5] Indeed, in the cesium density region $0 < n \lesssim n_c$ (where this exponential dependence is observed), the interaction between the electrons bound in different atoms is still not very large; at the same time, the average energy of the "free" electrons, owing to their large polarization interaction with the neutral atoms, decreases by an amount $U_1 = n\hbar^2\sqrt{\pi q}/m$, where q is the total cross section for elastic scattering of the slow electrons by the gas atom. The ion energy in the gas also drops, because of the polarization of the neighboring neutral atoms, by an amount $U_2 = 4n\pi e^2\alpha/r_0$.[6] A decrease of the ionization potential I by an amount $U_1 + U_2$ leads to an exponential growth of the electron concentration with increasing gas density

$$n_e \sim \exp(-I + U_1 + U_2)/2T$$

and (at constant mobility) to an exponential growth of the electric conductivity

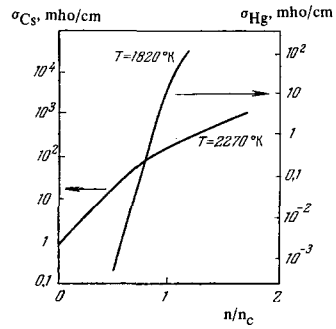

FIG. 1

$$\sigma \sim \exp(-I/2T) \div (n/n^*),$$
$$1/n^* \approx (2mT/\sqrt{\pi q}\,\hbar^2)^{-1} \div (Tr_0/2\pi e^2\alpha)^{-1}.$$

For q estimated from the optical-line shift ($q = 2 \times 10^{-13}$ cm^2), $r_0 = 2.6$ Å, and a polarizability $\alpha = 400$ at.un., we obtain a value of n* that agrees satisfactorily with the experiment $n^* = 1.7 \times 10^{20}$ cm^{-3}. We note that the analysis using individual charged trial particles becomes incorrect in the vicinity of the critical point because the plasma is non-ideal and degenerate.

Thus, when the density is increased, the electric conductivity of Cs does not increase jumpwise as a result of the dielectric-metal phase transition, but grows monotonically from a value corresponding to an ideal weakly-ionized plasma, ~1 mho/cm, to a value corresponding to liquid Cs, 5×10^4 mho/cm. In the density interval $0 < n \lesssim n_c$, the exponential growth of σ corresponds to a linear decrease of the ionization potential with increasing density, owing to the polarization interaction of the electrons and ions with the atoms.

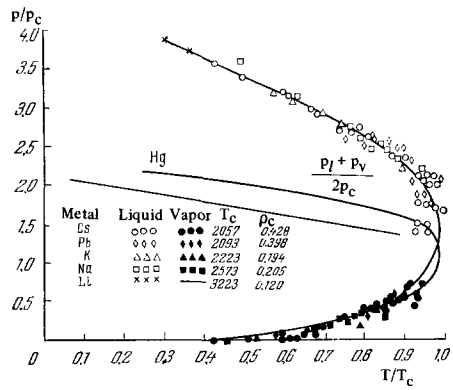

FIG. 2. r_l—density of the liquid, r_v—density of the vapor.

In conclusion we note that the difference between the equilibrium (ρ, T) diagrams[7] (Fig. 2) and the electric conductivity of Cs from the analogous results for Hg[8] (see Figs. 1 and 2) is due in the liquid phase to the larger compressibility of Cs, and in the gas phase (where the equilibrium curves practically coincide) to the much lower ionization potential of Cs, leading to an appreciable plasma conductivity.

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Translated by J. G. Adashko