ELECTRICAL CONDUCTIVITY AND DENSITY OF A METAL VAPOR

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Submitted to JETP editor February 19, 1965

J. Exptl. Theoret. Phys. (U.S.S.R.) **49**, 124-126 (July, 1965)

The results are reported of an investigation of the electrical conductivity and density of mercury vapor in a range of temperatures and pressures above the critical point of mercury. The dependence of the electrical conductivity of mercury on its density is reported.

IT is known that a metal vapor, which is a dielectric at low pressures, acquires metallic conduction on condensation, i.e., when the density increases by 2—3 orders of magnitude. This is obviously related to the reduction in the interatomic distances, which gives rise to an overlap of the wave functions of the outer electrons of the atoms.

One of the important problems in the physics of metals is the experimental establishment of the relationships between the metallic state of a substance, characterized by high electrical conductivity, and its thermodynamic state. The most direct method of solving this problem consists in the observation of the occurrence of the electrical conductivity in a metal vapor when its density is varied continuously. The experiments should be carried out above the critical temperature, where the density may be varied within wide limits by varying the external pressure without causing a phase transition. The experiments described in [1] were not carried out at sufficiently high temperatures and the density was not determined, so that the required results could not be obtained.

We describe below an investigation of the electrical conductivity of mercury in the trans-critical range of temperatures and pressures. The selection of mercury as the first object of such an investigation was dictated by its having the lowest boiling point among metals and consequently the lowest critical temperature. The experiments were carried out in a chamber in which pressures up to 4000 atm could be established by means of gaseous argon compressed with a thermal compressor.[2,3] The pressure was measured with a standard manometer, as well as using the change in the electrical resistance of a manganin probe placed inside the chamber.

The mercury filled a ceramic capillary made of beryllium oxide BeO, whose bore ranged from 0.6 to 1.5 mm, depending on the experiment. The outer diameter of the capillary was 7 mm. The middle part of the capillary, 50 mm long (the total length was 200 mm), was surrounded by an electric heater in the form of a graphite cylinder through which an electric current was passed. The heater made it possible to heat the middle part of the mercury-filled capillary to 2000°C (consuming 1.2—1.5 kW). The ends of the capillary were cooled by means of metal disks, which were in contact with the walls of the high-pressure chamber. The trans-critical conditions were thus established only in the middle part of the capillary. The temperature there was measured with a W—WRe thermocouple, whose junction was placed in a recess in the wall of the capillary. The electrical resistance of the mercury was found from the potential difference between nickel electrodes at the ends of the capillary, through which the measuring current (about 10 mA) was also supplied.

To determine its density, the mercury was first activated by neutron irradiation in a reactor. As a measure of the density, we used the γ-radiation from Hg^{203}, which passed through a collimating device in the middle part of the capillary and reached a scintillation counter with a photomultiplier. Corrections were made for the self-absorption of the γ-rays in the mercury, the absorption in the argon filling the high-pressure chamber, and the thermal expansion of the capillary.

The measured quantities (the current in the sample, the potential drop across it, the thermocouple emf, the potential drop across the manganin probe, and the total count of the scintillator photomultiplier) were recorded with a many-channel automatic recorder, which was switched on simultaneously with the current in the electric heater (at the beginning of experiment). Thus, a record was obtained on photographic film of all the curves necessary in the calculation of the total resistance of the sample R and its density ρ in the middle part of the capillary at a given pressure P (which was kept constant during each experiment)

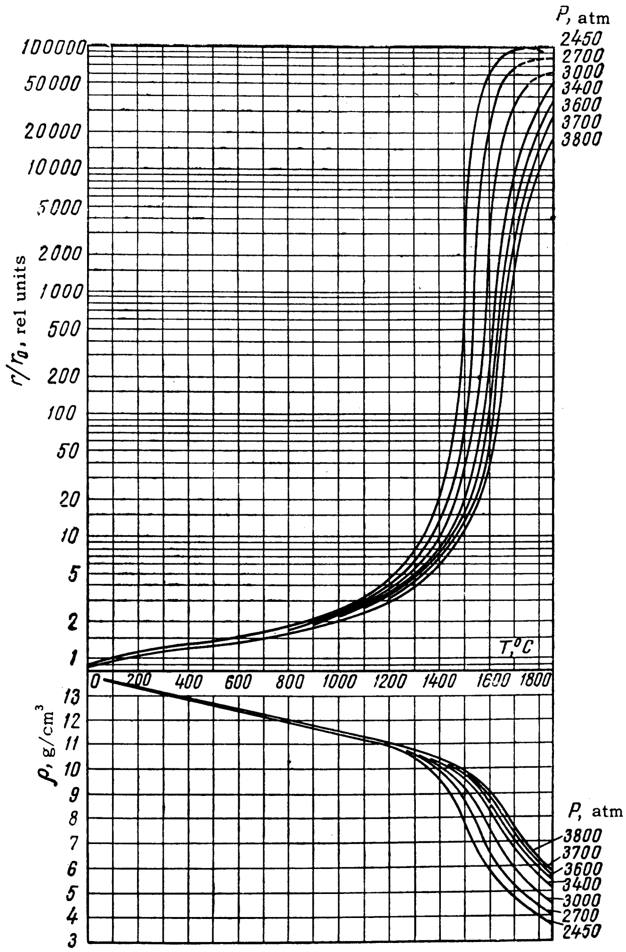

FIG. 1

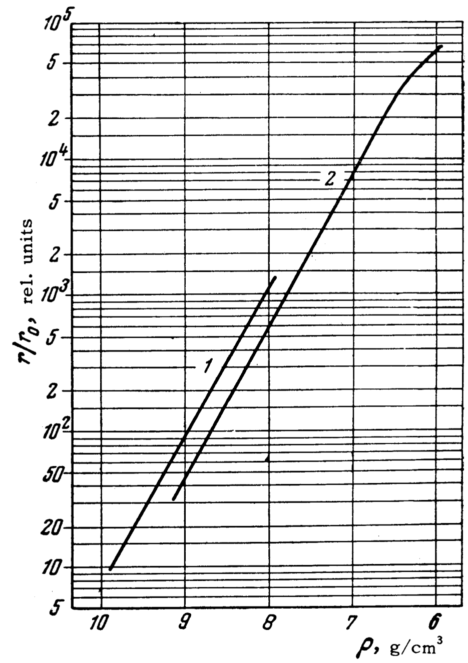

FIG. 2

over the whole range of temperatures T from room temperature to 2000° C. The family of curves, obtained at different pressures, made it possible to determine the "electrical equation of state" $r = f(\rho, T)$ together with the thermodynamic equation for the density $\rho = \varphi(P, T)$. The critical temperature of mercury was found to be 1450 ± 50°C.

Figure 1 shows families of the curves representing the temperature dependences of the density of mercury ρ and of its electrical resistivity. The resistivity is given (in relative units) relative to the resistivity of liquid mercury under normal conditions, r_0. It must be mentioned that in the experiments described the accuracy of the measurement of the resistivity of mercury was not very high because in calculating the resistivity it was necessary to take into account the temperature distribution along the capillary. This temperature distribution was found in a separate experiment. The error in the value of the relative resistivity r was estimated to be not more than 3—5% in the range of values $r \leq 10^2$ and 10% in the range $10^2 \leq r \leq 10^4$. The data obtained at higher values of the relative resistivity were not very accurate because of the possible influence of the conductivity of the capillary material (BeO) itself.

From these data, we could obtain resistivity—density isotherms at any temperature. Figure 2 shows two such isotherms at 1500°C (curve 1) and 1600°C (curve 2). It is evident from Fig. 2 that, as expected, the conductivity of mercury increases very rapidly as the density increases.

The accuracy of our experiments was not sufficiently high to determine the temperature coefficient of the resistivity at constant density but it was established qualitatively that the temperature coefficient was negative at densities below 7—8 g/cm^3 but at higher densities it was close to zero. This is in agreement with the data reported by Gubar and Kikoin.[4]

A more detailed description of the experiments and the results obtained will be published elsewhere.

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Translated by A. Tybulewicz
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