Experimental proof of Anderson localization in liquid selenium

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We measured the electric conductivity of selenium at high temperatures (~ 2000°C) and at pressures (up to 1000 atm) greatly exceeding the critical values. An abrupt decrease of the electric conductivity of selenium with decreasing density was observed after saturation was reached at the level $\sim 2\times 10^2 \Omega^{-1}$ cm^{-1}, which corresponds according to Mott's known criterion to the minimal value of the metallic electric conductivity. This behavior of the electric conductivity is a consequence of the Anderson localization of the electrons, a fact confirmed by calculations. A method is proposed for verifying the formulas for the electric conductivity near the mobility threshold and for determining the critical exponent.

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The electric conductivity of liquid selenium σ_{Se} at high temperatures reaches, with increasing temperature, values $\sim (1-2)\times 10^2 \Omega^{-1}$cm^{-1}.[1] The semiconductor-type temperature dependence of σ gives way in this case to a near-metallic dependence. According to the known Mott criterion, this corresponds to the minimal value of the metallic electric conductivity.[2] So low a value of the metallic electric conductivity makes it possible to observe the Anderson effect of electron localization with decreasing density of the sele-

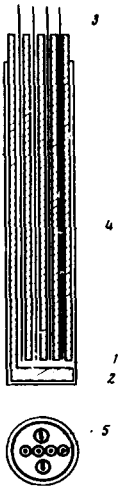

FIG. 1. Beryllium oxide chamber for the measurement of the conductivity of selenium at high temperature; 1—round channel drilled in a core of BeO and containing the liquid selenium, 2—BeO core, 3—two current and two potential graphite electrodes, 4—BeO vessel, 5—two channels for VR5—VR-20 Thermocouples for temperature measurements.

nium. This effect does not manifest itself explicitly in metals. The possible reason is that in the metal—nonmetal transition region σ_{Se} begins to decrease with decreasing density, from values that exceed their minimal metallic value by more than two orders of magnitude.

This may turn out to be the decisive factor in inhomogeneous systems, the conductivity of which is determined by the amount of interconnected regions of high metallic electric conductivity.[3] Owing to the presence of such conducting regions, the effect due to the Anderson localization becomes shunted by these regions.

The electron-localization effect should manifest itself in a sharp decrease of the electric conductivity with rising temperature. To exclude the jumps produced in σ by the boiling of the selenium, the experiments were performed at pressures and temperatures exceeding the critical values ($T_{cr}=1766$ °K, $P_{cr}=268$ atm[4]). To measure the electric conductivity of selenium at high temperatures we constructed a cell of beryllium oxide with four graphite electrodes (Fig. 1). The cell consisted of two parts, a core (2) and a vessel (4). Inside the core were six vertical channels, four for the electrodes (3) and two for the thermocouples (5). A horizontal measurement channel (1) was drilled perpendicular to the four electrode channels and contained the selenium. The assembled core was placed in the vessel, which served as an expander for each selenium sample in the course of heating. The cell was heated with a graphite oven placed in a high-pressure chamber. The pressure-transmitting medium was argon. The setup was described in detail earlier.[5]

The temperature dependence of the electric conductivity was measured at constant pressure. Figure 2 shows four isobars; two are lower than the critical pressure (165 and 103 atm). On these isobars the boiling sets in before the metallization level is attained. The two other isobars (500 and 100 atm) exceed the critical pressure, so that the observed abrupt decrease of the electric conductivity cannot be connected with boiling. This abrupt decrease of the electric conductivity, from a level on the order of the minimal metallic value,

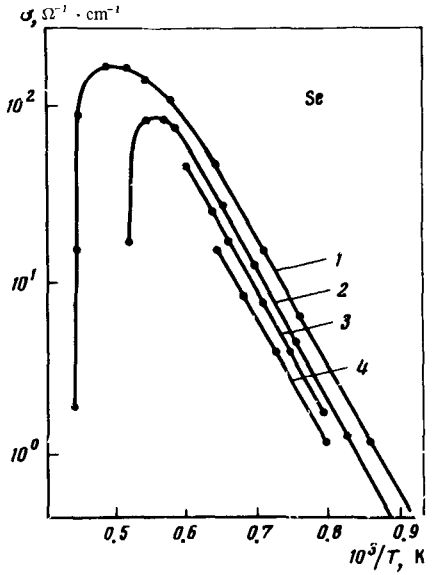

FIG. 2. Dependence of the electric of liquid selenium on the temperature at different pressures (atm): 1—1000, 2—500, 3—165, 4—103.

where shunting hardly comes into play, allows us to interpret the observed transition to the dielectric state as an Anderson transition due to complete localization of the electrons.[2,6]

Total localization takes place when the ratio W/V, where W is the amplitude of the scatter of the energy levels of the electrons at the atoms and V is the amplitude of the transition of the electron from atom to atom, reaches the critical value $(W/V)_c$.[6] This ratio seems to increase with heating (expansion) of the system.

We determine the temperature at which the Anderson transition takes place from the condition

$$\frac{W(T_c)}{V(T_c)} = \left(\frac{W}{V}\right)_c . \tag{1}$$

In a transcritical metal there are grounds for assuming the ratio W/V to be a non-analytic function of the temperature, so that near T_c we have

$$\frac{W(T)}{V(T)} \approx \left(\frac{W}{V}\right)_c + B\frac{T - T_c}{T_c} . \tag{2}$$

Near the transition ($T \lesssim T_c$) (on the "plateau") the conductivity is a slow function of the temperature. Under the conditions of the described experiment, the temperature corresponding to the plateau is estimated at $\rho \approx 5 \times 10^{22}$ cm^{-3}. At $T = T_c$ the system goes over jumpowise (the jump is smeared out under the experimental conditions by the finite-temperature effects) [2] from the metallic to the hopping mechanism of the conductivity $\sigma \ll \sigma_{min}$. No change to the hopping conductivity regime was observed in this experiment. The hopping conductivity near the mobility threshold is given by [2]

$$\sigma = \sigma_h \exp\left\{-\frac{a^3}{R_{loc}^3}\frac{W}{T}\right\}, \tag{3}$$

where R_{loc} is the localization radius of the electron wave functions:

$$R_{loc} \approx a\left|\frac{W - W_c}{W_c}\right|^{-\nu}, \tag{4}$$

and ν is a critical exponent determined only by the dimensionality of the space[7] and equal to the exponent of the correlation length of a second-order phase transition with a zero-component order parameter.[8] In three-dimensional space we have $\nu \approx 0.6$,[6,7] so that at $T \gtrsim T_c$ we obtain from (2), (3), and (4)

$$\ln\frac{\sigma}{\sigma_h} \sim -\left(\frac{T - T_c}{T_c}\right)^{3\nu}. \tag{5}$$

Observation of the transition of the conductivity of selenium to the hopping regime is of great interest because it affords a possibility of checking on a relation of type (5) and determining the exponent ν from experiment.

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