short-wave edge of the line corresponds to smaller R (larger energy of Coulomb interaction in the final state). As R increases towards the long-wave edge of the luminescence line, ρ increases. A change of ρ induced by uniaxial compression was also observed.

An investigation of the exciton orientation in a weak field H has shown that ρ of the annihilation radiation of exciton is several times smaller than that of recombination radiation with participation of oriented acceptors, other conditions being the same.

We note, in conclusion, that simple methods of measuring circular polarization make it possible to "sense" magnetic-sublevel energy shifts on the order of 10^{-5} - 10^{-6} eV.

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OBSERVATION OF THE DRAWING OUT OF NEEDLES BY ELECTRIC FIELDS

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It has been observed that when tungsten needles are heated to 2300 - 2700°K in an electric field (3 - 6) × 10^7 V/cm, the needles become sharper and elongated in directions normal to the close-packed faces, in contrast to earlier observations. The experiments were performed by field-emission electron microscopy with needles having radii 0.1 - 1.5 μ.

When a metallic needle is heated it becomes blunter - its length is decreased and the radius of curvature of the tip is increased [1, 2]. By applying an electric field it is possible to decrease the rate of blunting, and to stop it at a certain field value E_0 [3]. Herring's classical macroscopic theory [4], simplified by assuming an isotropic needle material [3], predicts for the motion of the tip of the needle a field dependence that agrees well with the one obtained experimentally for tungsten [3]. According to this theory, the needle should become drawn out by the field at $E > E_0$ (its length should increase and the radius of curvature decrease). Experiments, however, have never revealed such a growth of the needle in an electric field (see, e.g., [5]). This was attributed either to the difficulty of growing new atomic layers on the smooth close-packed faces [3] or to the absence of appreciable

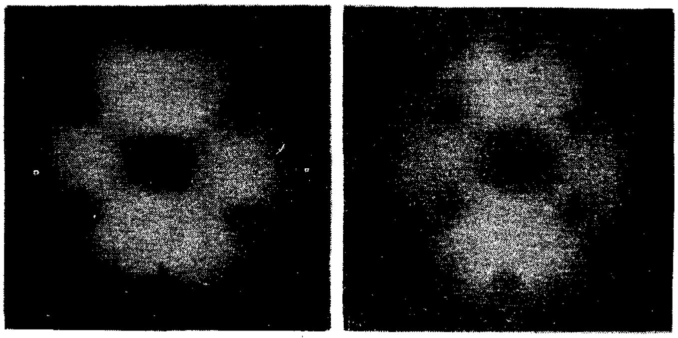

Fig. 1. Field-emission electron micrograms of needles: a) initial, b) elongated by the field ("sharpened") and annealed.

diffusion of the atom towards the tip of the needle [5]. Instead of an elongation, all that could be observed so far at $E > E_0$ was a "restructuring" of the tip into a multifaceted shape and, with further increase of E, also the appearance on the surface of random "piling on of atoms" or steps, the heights of which were limited by field evaporation [5, 6].

Our experiments were performed with a field-emission microscope with residual-gas pressure $<10^{-9}$ Torr, on tungsten needles oriented parallel to <011>. The needles were annealed before hand at 3000°K (Fig. 1a). The shape of the needle was assessed from the observed field-emission microgram and from the Fowler-Nordheim characteristics. The latter were used also to determine the electric-field intensity at the tip of the needle, assuming a work function 4.4 eV for tungsten.

The needle was lengthened when heated at T = 2300 - 2700°K in the presence of a positive electric field $E = (3 - 6) \times 10^7$ V/cm (the field was determined for the annealed needle) for time intervals ranging from several minutes to several hours. In addition, the needle surface was modified and the aforementioned "piling-on of the atoms" was observed. The needles were therefore annealed in the absence of the field, until the annealed shape was reached, before the Fowler-Nordheim characteristics were plotted.

Figure 2 shows typical Fowler-Nordheim plots for the annealed needle before and after heating in the field as described above. The slope of the characteristic decreases (to less than one-half in our example), thus indicating an increase of the field factor, and consequently a lengthening of the needle and a decrease of its radius of curvature.

In some cases (in fields $E > 5 \times 10^7$ V/cm) field-emission micrograms similar to those shown in Fig. 3 were observed during the course of annealing. It is seen from the picture that several stubs have grown in various directions on the original needle surface. Heating the needle until the usual annealed shape is reached (Fig. 1a) was accompanied in such cases by a considerable blunting of the needle.

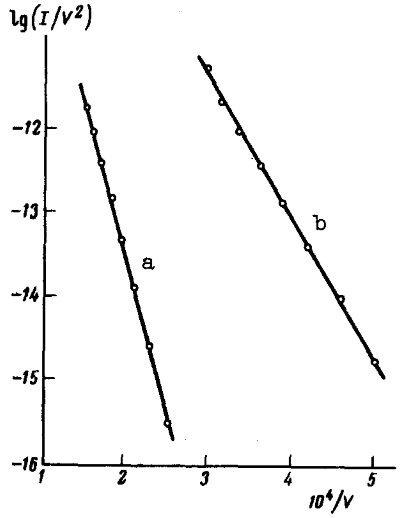

Fig. 2. Fowler-Nordheim characteristics of needles: a) initial, b) drawn out by the field and annealed.

Using the macroscopic approach, the phenomena occurring when a crystalline needle is heated in an electric field can be attributed to competition between the pressure (p_γ) due to surface tension and the pressure ($p_E = -E^2/8\pi$) of the electric field.

If $E > E_0$ and $|p_E| > |p_\gamma|$, then the change of the needle shape can proceed with a decrease of the local curvature radius of the surface, and consequently the local fields E and the pressures $|p_E|$ and $|p_\gamma|$ increase. Two cases are possible: 1) $|p_E|$ increases more slowly than $|p_\gamma|$ (in practice this means that E increases more slowly than the reciprocal square root of the smallest curvature radius). The needle can acquire an equilibrium shape. This case is apparently realized in the case of "restructuring." 2) $|p_E|$ increases more rapidly than $|p_\gamma|$. Then no equilibrium state can be achieved, the crystal surface is unstable and "swells out," and stubs similar to those shown in Fig. 3 grow from it. If this condition is satisfied on the very tip of the needle, then the needle grows in length.

From the microscopic point of view, the growth of the needle can be explained in the following manner. In sufficiently strong field, the migration of the atoms over the surface towards the sections of maximum field causes sufficient supersaturation of the "two-dimensional gas" to initiate and grow new atomic layers. If sufficient supersaturation takes place on several sections of the surface, then several stubs grow simultaneously (see Fig. 3). If the supersaturation is reached only on the tip of the needle, then growth of the needle takes place. The growth of the needle stops when the rates of field evaporation and inflow of material to the maximum-field sections becomes equalized. The crystal surface, like Drechsler steps, then assumes a quasistationary state.

Fig. 3

Thus, at sufficiently high temperatures and fields, conditions are realized for a relatively rapid growth of the needle in directions perependicular to the close-packed faces, including the face located on the tip of the needle.

This process can be used, in particular, to sharpen electron and ion field emitters without breaking the vacuum in the instrument. This greatly extends the possibilities of studying crystals well purified in vacuum by methods of field-emission microscopy.

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CONTAINMENT OF A PLASMA FILAMENT IN A TOKAMAK TO-1 BY AN AUTOMATIC-CONTROL SYSTEM

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The main discharge characteristics were investigated experimentally in a TO-1 Tokamak without a jacket, in which the plasma filament was kept in equilibrium by an automatic-control system. Three stages of discharge were observed: macroscopically unstable, "free" motion, and contact with the diaphragm. The discharge duration and the energy content of the plasma increase with increasing equivalent time constant of the control winding.

The plasma filament in the TO-1 Tokamak is maintained in equilibrium along the major radius by an impedance-type automatic control system [1]. This system, as well as the main characteristics of the apparatus and preliminary results of the experiments, were described in a paper delivered at the Fourth International Conference on Nuclear Fusion [2].