Semiconductors & Defects: Exercise 4 (22 Nov. ’22)

General remark: Always try to come up with a short answer that catches the essence.

5. Calculation: Show that the width of the “soft zone” of the Fermi–Dirac distribution $f(E)$ is approximately $4k_BT$. [Hint: Use the tangent to $f(E)$ at $E = E_F$.]

6. Formulae and discussion: Using the relevant formula, explain how the carrier density in an energy interval depends on the density of states (DOS) and on the Fermi–Dirac distribution function. What is the difference between the true DOS function, $D(E)$, and the effective density of states, N_{eff}? For which condition is the latter a good approximation to the former? Mathematically speaking, in which way does N_{eff} simplify the equations needed to describe a semiconductor (SC)? In physics terms, how does the usage of N_{eff} simplify the thinking about the electronic transitions taking place in a SC?

8. Discussion: Lift the seeming contradiction between the images shown on the second page by explaining how this geometric paradox “works.”

   (Remarks: This is an off-topic task, deliberately introduced here just for to train both your ability to catch the essence as well as your logical argumentation skills. The key word in this task is “explaining” – think about what makes a statement an essence-catching explanation.)

9. Discussion, drawing, and formula: What is meant by an “extrinsic semiconductor”? Draw the schematic band diagram of an extrinsic SC having conduction band, valence band, donor level, and acceptor level. Specify the charge neutrality condition in an extrinsic SC, and explain why the various charges are counted this way. Which important quantity can be obtained from this condition (for a given temperature)?

11. Discussion: What are semiconductors (SCs) in general, and by which “condition” are only some of them (in principle; there are a few exceptions) of technological relevance? Explain the main differences between metals, semiconductors and insulators. Give examples for different kinds of SCs that can be formed by elements of the periodic table.

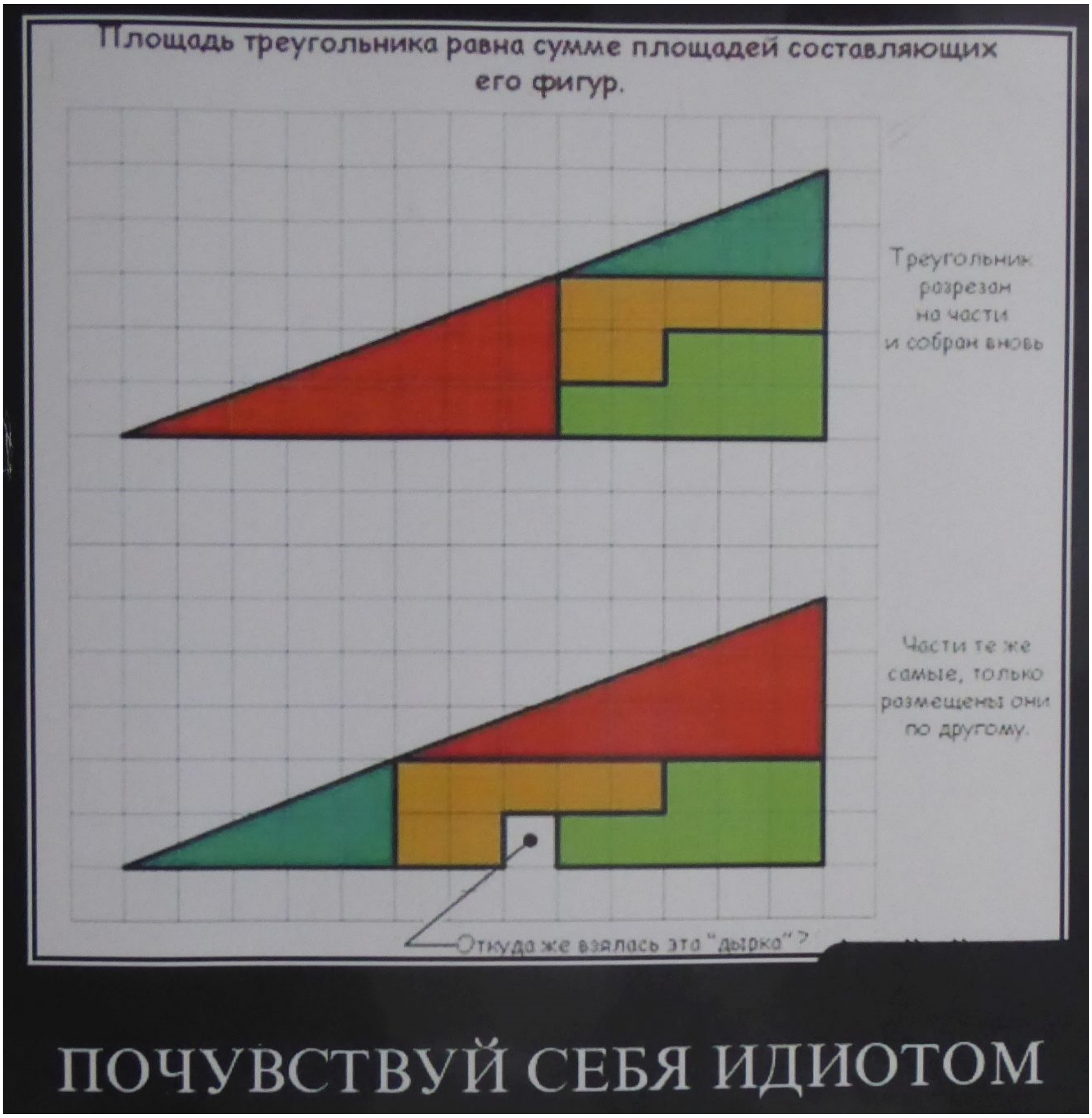
12. Formulae and discussion: Explain the quantity “mobility”: How is it defined, and how can it be written in the simple scattering time approximation – and why so? What are the main factors affecting the mobility of charge carriers, and in which way? How can these effects be understood on the basis of the model of nearly free electrons? How do these effects depend on temperature – and why so?

13. Schematic drawing and discussion: Which pieces of fundamental information do we get about a semiconductor from its band structure? Name only those properties that we have touched in the lecture so far, and try to mention as many as possible. (Hint: A real-world semiconductor is a 3D object; how does that show up in the band structure?)

14. Calculation and discussion: Derive the mass action law for an extrinsic semiconductor in a stationary equilibrium situation, starting from the Fermi distribution for calculating the carrier densities in the bands. Justify the approximations used.

15. Calculation and discussion: Describe, in your own words, why in thermal equilibrium the Fermi energy is the same everywhere.

16. <u>Discussion, drawing, and formula:</u> Demonstrate the band-bending and the formation of a space charge region at the surface of a **p-type** semiconductor. Why is it called "space charge region" (SCR)? What charges are there, and why? Why is the surface charged at all; could there be a situation where the surface is not charged? Show the direction of the electric field lines. In the SCR, why are the bands not flat anymore?



By the way, the Cyrillic text is Russian, the line below meaning "feel like an idiot", while the headline tells "The area of a triangle is equal to the sum of the areas of the figures that make up the triangle." On the right it says "The triangle has been cut into pieces and reassembled again" and "The parts are the same, only they are placed differently". Finally, there is the question "Where did the hole come from?"