<u>Semiconductors & Defects: Exercise 10 (17 Jan. '23)</u>

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

25. <u>Discussion only, no formulae, no details:</u> To calculate the recombination rate for a direct semiconductor, what is most important in the approach presented in the lecture regarding the underlying microscopic notions? What applies in general, and what specifically when considering majority and minority charge carriers?
(The idea behind this task is to catch the essence of the theory: What do you need to have understood well enough so that you are, at least in principle, able to derive the formulae yourself?)

26. <u>Discussion and formulae:</u> What is meant by the net recombination rate? What does the recombination theory finally give (under certain conditions) as an explicit result for the minority carrier lifetime in a direct semiconductor? What are those "certain conditions" for which this result for the lifetime is obtained? What is the main technologically adjustable factor that limits the minority carrier lifetime in a direct semiconductor?

27. <u>Discussion only, no formulae, no details:</u> To calculate the recombination rate for an indirect semiconductor, what is most important in the Shockley–Read–Hall (SRH) model regarding the underlying microscopic notions? What applies in general, and what specifically when considering majority and minority charge carriers?
(The idea behind this task is to catch the essence of the SRH model: What do you need to have understood well enough so that you are, at least in principle, able to derive the formulae yourself?)

28. <u>Discussion and formulae:</u> What does the SRH model finally give (under certain conditions) as an explicit result for the minority carrier lifetime in an indirect semiconductor? What are those "certain conditions" for which this result for the lifetime is obtained? What are the main technologically adjustable factors that limit the minority carrier lifetime in an indirect semiconductor? How does the energetic position of a defect state ("deep level") influence the lifetime in an indirect semiconductor, and what is the deeper reason that there is a particularly relevant energy range for its influence?

29. <u>Discussion (and maybe formulae):</u> Starting from a p–n junction in thermal equilibrium, by which basic considerations can its theoretical treatment be extended to stationary non-equilibrium, brought about by an external voltage applied in *forward* direction?

30. <u>Drawing, formulae, and discussion:</u> Consider a p–n junction in thermal equilibrium and draw the relevant distribution of the electrons and holes across the space charge region (SCR). Given that there is a constant acceptor (donor) density N_A (N_D) in the p-type (n-type) region, how is the hole (electron) density related to the local value of the electrostatic potential $V(x)$, and how can, in principle, the band bending (*i.e.*, the spatial variation of the band edge) in the SCR be calculated? Write down the relevant equations (only those to be solved, not their solution)! Compare the example shown graphically in the solution of "Exercise 2.3.5-1" (https://www.tf.uni-kiel.de/matwis/amat/semi_en/kap_2/exercise/s2_3_1.html) to the charge carrier distribution just drawn by you: What fundamental simplification has been made in the graphics shown in the solution of "Exercise 2.3.5-1"? (<u>Indirect hint:</u> It is correctly shown in this graphics that there is no band bending in the bulk regions outside the SCR – but why is this so?)

31. Discussion: Why and how does a p–n junction work as a diode (*i.e.*, as a rectifier)? What are the relevant charge carrier transport mechanisms? What is the physical reason for the current–voltage characteristic of a p–n junction being an exponential function?

32. Drawing and discussion: Draw the quasi-Fermi energies at a p–n junction under forward and reverse bias; describe the relevant physics.

33. Discussion: Have a look at the English Wikipedia entry explaining holes in semiconductors (https://en.wikipedia.org/wiki/Electron_hole) and comment on its scientific quality: What errors and problematic aspects do you notice in the very first paragraph?
Important: Do **not** try to fix it, just point out the problems. To do so, also think about possible consequences: What fundamental law of physics would be violated if the present version (as of 26 November 2022) of the explanation were correct?
(You might also have a look at the entries given in other languages about this topic – are they as bad, too?)

34. Drawing and discussion: What is the meaning of "Auger recombination"? Illustrate the Auger process in a schematic band structure. Why is this recombination mechanism so important in optoelectronic devices? What other recombination channels are there in a doped semiconductor?

35. Discussion: What are excitons in semiconductors? Give a remarkable example where excitons are relevant for the functioning of an optoelectronic device; discuss in some detail why it is so remarkable.

36. Calculation: Perform Exercise 5.1.2-1 from the hyperscript (https://www.tf.uni-kiel.de/matwis/amat/semi_en/kap_5/exercise/e5_1_1.html), *i.e.* calculate the injected carrier densities from the forward current of junctions. Proceed as follows: Consider the formula giving the current density for a symmetrically doped p–n junction under forward bias and neglect the generation term from the space charge region as well as the –1 term. Then, for silicon and gallium arsenide, (i) calculate the current density for some relevant values of N_{dop}, L and τ (follow the above link to the exercise to find a link to data from which these values can be obtained) in dependence on the diode forward voltage, and considering the carriers of this current to not recombine in the space-charge region (but just passing through), (ii) calculate the carrier density (per volume) by using the width of the space-charge region matching the given forward voltage.