Exam "Foundations of Quantum Mechanics", 30 January 2014, 9.00-12.00 a.m.

Please write your name and registration number on every sheet!

1. According to standard (Copenhagen-like) presentations, the role of measurement in quantum mechanics is different from its role in classical physics. Explain what this difference is and how it shows itself in the formalism.
   Compare the Copenhagen interpretation with two other interpretations on this point. How do these other interpretations deal with measurement and how do they compare to classical physics?
2. Hidden variable theories attempt to solve interpretational problems of quantum mechanics. Explain exactly what problem they try to solve, and how they attempt to do this.
   In the 1930's von Neumann published an impossibility proof: hidden variables theories for QM cannot exist. Explain the central idea of this proof, and also explain why this proof is no longer taken seriously.
3. Bell showed in the 1960's that local deterministic hidden variables theories for QM cannot exist. Explain in more detail what his premises were.
   If these premises are sufficiently relaxed the contradiction with QM will disappear. Suppose we abandon determinism (like QM itself does). Is this sufficient to restore compatibility with QM? Explain the situation in detail.
4. Consider three spin ½ particles, at large distances from each other. It is given that the spin part of their total quantum state is given by
   $1/2\sqrt{2}$ $\{|\uparrow\uparrow\uparrow\rangle - |\downarrow\downarrow\downarrow\rangle\}$, in which $|\uparrow\uparrow\uparrow\rangle$ stands for the three-fold tensor product of spin up states in the z-direction, etc.
   Construct a variation of the EPR argument to argue that the three particles in this state must each possess a well-defined spin value in the z direction, independent of measurement.
   It turns out that the above three-particle spin state predicts the certain value +1 for the product of the results of an x-spin measurement on any one of the particles and y-spin measurements on the others. Adapt the EPR-like argument to argue that the three particles must have definite spin values in all three directions x, y and z.
   Finally, it turns out that the above state predicts with certainty that the product of the results of three x-spin measurements will be -1.
   Show that this prediction cannot be reproduced by a hidden variables theory à la EPR.
5. A fair coin is tossed in a very long series of experiments (an infinite series, say). Depending on whether the outcome is Heads or Tails a spin ½ particle is prepared in either $|\uparrow\rangle$ or $|\downarrow\rangle$. An experimenter performs measurements on this beam of spin particles. What is the spin state that he/she will determine from the measurements?
   Discuss the interpretation of this state. Explain, in your discussion, the difference between mixed states and pure states.
   Finally, consider the question of how the same state of a beam of spin ½ particles could be produced without making use of coin tossing or some other random mechanism.