Projects on Quantum mechanics FYSN17/FMFN01 VT2016

Tineke van den Berg, Lund University, February 7, 2016

Within each project the students (in groups of three) shall elaborate on the respective topic. The idea is to come into contact with research articles and to learn to extract the main points from them. In this context it is generally necessary to look into further sources as well as the textbooks recommended for our course.

The material should be presented in our workshop (7 March, 9-16 in K262) within a 20 minutes talk with a subsequent discussion (30 minutes in total). It is mandatory for all participating students to attend at least one entire workshop.

The projects will be distributed according to the emails I receive with your suggestions until Wednesday, 10 February. This email shall contain:

- Suggestion of **three** topics from the list below. Suggestions for further topics, which are of particular interest to you, are very welcome.
- Names of those participating in the group

If several groups ask for the same topic, priority will be given to groups with three students and according to the number of exercises handed-in during the first three weeks.

1 Einstein-Podolsky-Rosen paradoxon

Describe the paradoxon and why it is mind-boggling. What does experiment tell us?

A. Einstein, B. Podolsky and N. Rosen, Physical Review **47**, 777 (1935)

A. Aspect, P. Grangier, and G. Roger, Phys. Rev. Lett. **49**, 91 (1982)

(You find an introduction to the topic in Sec. 3.10 of Sakurai or Chap. 17 of Bransden and Joachain as well.)

2 Wave-particle duality

Explain under which conditions particles exhibit interference, i.e. wave-like behavior. Which physical processes cause the loss of interference?

M. Arndt, O. Nairz, J. Vos-Andreae, C. Keller, G. van der Zouw, and A. Zeilinger: *Waveparticle duality of C_{60} molecules*, Nature **401**, 680 (1999)

3 Fock-Darwin states

Solve the eigenstates of a harmonic oscillator with an applied magnetic field in 2 dimensions. Show how these states interpolate between the oscillator states and Landau levels. How can these states be probed in a quantum dot?

Sec. 2.1 of Tapash Chakraborty *Quantum Dots* (Elsevier 1999)

R.C. Ashori: *electrons in artificial atoms*, Nature **379**, 413 (1996)

4 Aharonov Bohm effect

Discuss the Aharonov Bohm effect and its measurement in mesoscopic systems

S. Pedersen, A. E. Hansen, A. Kristensen, C. B. Sørensen, and P. E. Lindelof: *Observation of quantum asymmetry in an Aharonov-Bohm ring*, Phys. Rev. B **61**, 5457 (2000)
(You find an introduction to the topic in Sec. 2.7 of Sakurai or Sec. 12.2 of Bransden and Joachain as well.)

5 Quantum dot helium

Determine the eigenstates of a parabolic quantum dot confining two electrons. How does the spectrum differ from the single-particle case?

D. Pfannkuche, V. Gudmundsson and P.A. Maksym: *Comparison of a Hartree, a Hartree-Fock and an exact treatment of quantum dot helium*, Phys. Rev. **47**, 2244 (1993).

6 Shell structure in quantum dots

Describe the general concept of shell structure. Relate this to the structure of conductance peaks observed in circularly symmetric quantum dots by Tarucha et al. (1996).

S. Tarucha, D. G. Austing, T. Honda, R. J. van der Hage and L. P. Kouwenhoven, *Shell filling and spin effects in a few electron quantum dot*, Phys. Rev. Lett. 77, 3613 (1996) Sec. I of S.M. Reimann and M. Manninen: *Electronic structure of quantum dots*, Rev. Mod. Phys. **74**, 1283 (2002)

7 Casimir effect

Why do two metal plates attract each other? Discuss experimental realizations!

D. Kleppner, Physics Today **43**(10), 9 (1990)
S.L. Boersma, Am. J. Phys **64**, 539 (1996)

8 The spin Hall effect

Spin-orbit coupling in 2D layers gives rise to a perpendicular spin current, adding a new member to the Hall-effect family: the spin Hall effect. How does it work? Discuss experimental measurement and possible applications.

Universal Intrinsic Spin Hall Effect J. Sinova et al. Phys. Rev. Lett. **92** (2004).
Experimental Observation of the Spin-Hall Effect in a Two-Dimensional Spin-Orbit Coupled Semiconductor System J. Wnderlich et al. Phys. Rev. Lett. **94** (2005).

9 The Hanbury Brown-Twiss effect

Depending on the nature of the particles subjected to this intensity based interferometry there will be bunching or anti-bunching of particles.

Comparison of the Hanbury BrownTwiss effect for bosons and fermions. T. Jeltes et al. Nature **445** (2007).
Correlations between light of coherent beams of photons. Hanbury Brown and Twiss. Nature (1956).

10 Bose-Einstein condensation in a harmonic trap

What is a Bose-Einstein condensate? How did one observe this in experiment, and why is it so interesting?

W. Ketterle: *Nobel lecture: When atoms behave as waves: Bose-Einstein condensation and the atom laser*, Rev. Mod. Phys. **74**, 1131 (2002)
(You find an introduction to the topic in Sec. 14.8 of Bransden and Joachain as well.)

11 Quantum cascade laser

Describe the idea behind a quantum cascade laser. Show, how the gain is evaluated on the basis of Fermi's golden rule!

Quantum Cascade Laser J. Faist, Science **264** (1994).