Lecture series I (3x2 hours+discussion session):
Pair production in strong and strongly varying electromagnetic pulses

Lecturer: Reinhard Alkofer (U. Graz)

<u>1st lecture:</u> Overview, objectives and current research topics

The theoretical treatment of electron-positron pair production in ultra-strong electric fields has a long history. According to the pioneers one speaks about the Sauter-Schwinger effect. After some short derivation and discussion of Schwinger's formula the scales and the nature of the process will be discussed. Introducing for time-dependent oscillatory electric fields the Keldysh parameter one can discriminate the Sauter-Schwinger from the multi-photon regime. In addition, it will be analyzed under which circumstances the Sauter-Schwinger effect is (non-)perturbative.

Some elementary considerations about electromagnetic fields in crossed laser beams will be supplemented by a discussion of parameters to be achieved in some planned laser facilities like the European XFEL at DESY or in the Extreme Light Infrastructure (ELI) project.

The underlying idea of the Dynamically Assisted Schwinger Pair Production will be explained in some detail. In addition, the crossover from Sauter-Schwinger to multiphoton production ("nonperturbative threshold regime") will be analyzed with respect to a possible experimental verification of effects in strong-field QED.

<u>2nd lecture:</u> Selected theoretical and numerical approaches

The Dirac-Heisenberg-Wigner (DHW) formalism will be introduced in order to treat the Sauter-Schwinger effect in phase space. As a second formalism the Quantum Kinetic Theory (QKT) will be presented. It will be demonstrated how for homogeneous electric fields the DHW equations reduce to QKT ones. Available analytical solutions will be discussed. An inclusion of back-reaction in QKT requires renormalization for a time-dependent process, and the corresponding derivations will be given.

Numerical difficulties and successful strategies to solve the QKT and the DHW equations are a further but essential topic.

<u>3rd lecture:</u> Selected numerical results and outlook

Numerical results for the following cases will be presented and discussed: (NB: This is admittedly a subjective choice.)

- Sub-cycle structure
- Dynamically Assisted Schwinger Pair Production
- Application of Optimal Control Theory
- Effective mass effects in the nonperturbative threshold regime
- Particle self-bunching in inhomogeneous fields

The lecture series will conclude with an extended outlook on some "hot topics" as e.g. the inclusion of magnetic fields in the DHW formalism, quantum radiation in strong fields, and quantum cascades. Last but not least, applications of related different formalisms to QCD, and hereby especially to quark-antiquark and gluon creation in the early phase of heavy-ion collisions, will be critically assessed in view of our current understanding of strong-field QED.

Lecture series II (2x2 hours+discussion session)
QCD phase transition in strong magnetic field

Lecturer: Gergely Endrődi (Univ. Regensburg)

The interplay between the strong and the electromagnetic interactions is an important aspect for the description of physical systems where the quark-gluon plasma is exposed to background electromagnetic fields. Prominent examples of such systems are non-central heavy-ion collisions in contemporary experiments at RHIC or at the LHC.

In these lectures, an overview of the effects of magnetic fields on strongly interacting matter will be given. These effects include the magnetic catalysis of chiral symmetry breaking, the paramagnetic nature of the thermal QCD vacuum and the chiral magnetic effect. Most of these effects can only be studied via non-perturbative lattice simulations. On the other hand, one can gain insight into several aspects of the problem via the analysis of free charged fermions in a magnetic field, which can be treated analytically. In particular, the free theory can be used to understand the general structure and the renormalization properties of the thermodynamic potential in the presence of the magnetic field. After discussing these, a couple of numerical results obtained in recent lattice simulations will be presented.

Lecture series III (2x2 hours+discussion session)
The Casimir effect

Lecturer: Gábor Takács (Budapest Technical University)

1. Casimir effect between ideal metal plates, basic approaches.
2. Dependence on material properties and temperature. Thermodynamic effects.
2. Geometry dependence, lateral Casimir effect.
3. The Casimir effect, the quantum vacuum and the van der Waals force.
4. Casimir self-energy. Gravitational aspects.
5. Dynamical Casimir effect.
6. Vacuum birefringence.

Lecture series IV (3x2 hours+discussion session)
Strong-field-driven electron dynamics in solids

Lecturer: Vladislav S. Yakovlev (Max-Planck-Institut für Quantenoptik, Garching)

How do electrons in a solid respond to a laser pulse at field strengths where the conventional nonlinear optics is inapplicable? Recent developments in attosecond science promise new insights into such strong-field driven dynamics of charge carriers in condensed matter, while a precise control over optical waveforms enables steering the motion of electrons with attosecond accuracy. These lectures will give a general overview of the relevant physical processes and report on the current stage of the experimental and theoretical research.