# Q 51: Quantum Effects: QED I

Time: Thursday 11:00–13:00 Location: f442

Q 51.1 Thu 11:00 f442

**Prefactor in the dynamically assisted Sauter-Schwinger effect** — •Christian Schneider and Ralf Schützhold — Universität Duisburg-Essen

The dynamically assisted Sauter-Schwinger effect exhibits significant, qualitative differences between, for example, a Sauter pulse $1/\cosh(\omega t)^2$ and a Gaussian $\exp(-\omega^2 t^2)$ [1]. So far, only the exponent of the pair creation rate has been calculated, these results are now extended to include the subleading fluctuation prefactor.

Additionally, possible influences of spatial inhomogeneities are discussed. For example, a longitudinal spatial dependence modifies the exponent of the pair production probability [2], while a transversal dependence only affects the prefactor.

[1] M. F. Linder, C. Schneider, J. Sicking, N. Szpak, and R. Schützhold. *Phys. Rev. D* **92**, 85009 (2015).

[2] C. Schneider and R. Schützhold, arXiv:1407.3584 [hep-th]

Q 51.2 Thu 11:15 f442

**WKB-like approach to Sauter-Schwinger pair production in spacetime-dependent fields** — •Johannes Oertel and Ralf Schützhold — Universität Duisburg-Essen

A well-known method for calculating an approximation to the pair creation rate in the Sauter-Schwinger effect is based on approximating solutions of the Riccati equation. Although several interesting field configurations can be examined in this formalism (see e.g. [1]), its application is fundamentally restricted to the case of solely time-dependent electromagnetic fields. We propose a new WKB-like technique for approximating the pair creation rate in the presence of spacetime-dependent fields.

[1] M. F. Linder et al., Phys. Rev. D 92, 085009 (2015)

Q 51.3 Thu 11:30 f442

**Simulating the Dirac equation in spacetime-dependent electric fields in band insulators** — •Malte F. Linder and Ralf Schützhold — Fakultät für Physik, Universität Duisburg-Essen, Lotharstr. 1, 47057 Duisburg, Germany

The relativistic and quantum-theoretic description of electrons and positrons via the Dirac equation gives rise to many interesting phenomena. One prominent example is the Sauter–Schwinger effect, which is the nonperturbative pair creation in strong classical electric fields. However, this high-energy quantum effect is difficult to observe experimentally due to the largeness of the critical field strength $E_S \approx 10^{18}\,\mathrm{V/m}$. Analogs of the Dirac equation can be found in condensed matter physics such as in band and Mott insulators, for example. These systems are well accessible in the laboratory and typically exhibit critical field strengths for the Sauter–Schwinger effect (one mechanism of dielectric breakdown) much smaller than $E_S$. In this talk, we derive a 1+1-dimensional analog of the Dirac equation for conduction electrons in a band insulator from the underlying (nonrelativistic) physics. We especially point out in how far the (quantitative) analogy holds if the external electric field depends on time as well as on the space coordinate in a nontrivial way.

Q 51.4 Thu 11:45 f442

**The classical-quantum transition in the theory of free-electron lasers** — •Peter Kling[1,2], Enno Giese[2], Rainer Endrich[2], Roland Sauerbrey[1], and Wolfgang P. Schleich[2,3] — [1]Helmholtz-Zentrum Dresden-Rossendorf, D-01314 Dresden — [2]Universität Ulm, D-89069 Ulm — [3]Texas A & M University, College Station, Texas 77843, USA

The free-electron laser (FEL) is the best known example for a 'Classical Laser' [1]. However, there exists a regime where quantum mechanics is relevant and at some point even dominates the dynamics [2,3]. In this talk we pursue the goal to calculate the corrections to the classical FEL when quantum effects start to become perceivable.

Employing the formalism of the Wigner distribution function we find the quantum corrections to the gain of the FEL in the low-gain, small-signal regime. We demonstrate that these corrections scale with powers of the quantum mechanical recoil the electron experiences when it scatters off the photons of the wiggler and the laser field. Moreover, the width of the initial momentum distribution of the electron has to be small enough to ensure for quantum corrections to be visible.

[1] M. Borenstein and W. E. Lamb, Phys. Rev. A **5**, 1298–1311 (1972).

[2] R. Bonifacio , N. Piovella and G. R. M. Robb, Fortschr. Phys. **57**, 1041–1051 (2009).

[3] P. Kling, E. Giese, R. Endrich, P. Preiss, R. Sauerbrey and W. P. Schleich; accepted for New J. Phys. (Oct. 2015).

Q 51.5 Thu 12:00 f442

**stopping x-ray pulses in a thin-film cavity** — •xiangjin kong and adriana pálffy — Max Planck Institute for Nuclear Physics, Saupfercheckweg 1, D-69117 Heidelberg, Germany

Recent years have witnessed the commissioning of coherent x-ray sources opening the new field of x-ray quantum optics [1]. While not yet as advanced as its optical counterpart, x-ray quantum optics may enable coherent control of x-rays, with potential applications for the fields of metrology, material science, quantum information, biology and chemistry. The desirable properties of x-rays are deeper penetration, better focus, no longer limited by an inconvenient diffraction limit as for optical photons, correspondingly spatial resolution, robustness, and the large momentum transfer they may produce. A promising platform for x-ray control are thin-film planar x-ray cavities [2] with embedded layers containing nuclei with a transition resonant to the x-ray pulse.

Here, we demonstrate from the theory side that a spectrally narrow x-ray pulse can be mapped and stored as nuclear coherence through a mechanism reminding of electromagnetically induced transparency in a thin film planar x-ray cavity. The storage time can reach approximate hundred nanoseconds [3]. We anticipate this setup can become a versatile tool for control of spectrally narrow x-ray pulses.

[1] B. W. Adams, et al., Journal of Modern Optics 60.2 (2013)

[2] R. Röhlsberger et al., Nature 482, 199 (2012)

[3] X. Kong, and A. Pálffy, arXiv:1508.06762 (2015)

Q 51.6 Thu 12:15 f442

**Design and control of quantum optical schemes at x-ray energies** — Paolo Longo, Kilian P. Heeg, Christoph H. Keitel, and •Jörg Evers — Max Planck Institute for Nuclear Physics, Heidelberg

Modern synchrotron light sources and x-ray free electron lasers strive to continue the success story of optical lasers at hard x-ray energies. However, in contrast to the broad capabilities available in labs operating at optical frequencies, the implementation of laser-coupled quantum systems in the x-ray domain remains a challenge due to basic experimental limitations. In recent years, first steps to circumvent these limitations were taken by few experiments which demonstrated basic quantum optical effects at x-ray energies. However, systematic approaches to implement advanced quantum optical level schemes at x-ray energies are currently lacking, impeding further progress in the field.

Here, we present our progress towards such a systematic approach. Our basic idea is to tailor cooperative effects in large ensembles of nuclei in such a way that effectively, a single artificial quantum system is simulated with the desired properties. To achieve this goal, we consider nuclear ensembles embedded in an x-ray cavity as our model system.

Q 51.7 Thu 12:30 f442

**Optimisation of energy transfer processes to increase upconversion luminescence in multi-layered photonic structures** — •Fabian Spallek, Andreas Buchleitner, and Thomas Wellens — Institute of Physics, University of Freiburg, Germany

Upconversion materials, which convert two low-energy photons into one photon with higher energy, in combination with photonic structures give promising possibilities to improve the efficiency of silicon solar cells by utilising the full range of the solar spectrum [1]. We analyse the influence of photonic structures on energy transfer processes between active charged centers within the upconverter material. Using the framework of macroscopic quantum electrodynamics, the dependence of energy transfer rates can be derived in the presence of arbitrarily shaped dispersing and absorbing material bodies [2]. We calculate the relevant energy transfer rates for multi-layered photonic structures with the goal to optimise the energy transfer properties for the upconversion process.

[1] B. Herter, S. Wolf, S. Fischer, J. Gutmann, B. Blasi, and J.C.

Goldschmidt, *Increased upconversion quantum yield in photonic structures due to local field enhancement and modification of the local density of states - a simulation-based analysis*, Opt. Express **21**, A883 (2013)

[2] H.T. Dung, L. Knöll, and D.-G. Welsch, *Intermolecular energy transfer in the presence of dispersing and absorbing media*, Phys. Rev. A **65**, 043813 (2002)

Q 51.8 Thu 12:45 f442

**Exploring quantum interference at x-ray nuclear interfaces** — •Jonas Gunst and Adriana Pálffy — Max-Planck-Institut für Kernphysik, Heidelberg

The concept of interference lies at the heart of quantum physics. Already in its beginnings, a number of gedankenexperiments have been proposed to better understand the origin and controllability of interference phenomena. Along with the great success of quantum optics, it has been shown that coherent control schemes can be employed to gain and subsequently remove again the which-way information in a double-slit scenario, known as the "quantum eraser" [1].

Here, we propose a quantum eraser setup with x-ray quanta, potentially extending time-energy complementarity tests into the so far unexplored parameter regime of x-ray energies. In the course of nuclear forward scattering (NFS) with synchrotron radiation on ensembles of Mössbauer $^{57}$Fe nuclei generally more than one hyperfine transition can be driven at once. Since the scattering paths remain unresolved, the interference leads to the so called quantum beat characteristic for the time spectrum of NFS in an external magnetic field [2]. We show that it is possible to mark the individual paths by orthogonal polarizations such that the quantum beat pattern disappears in the time spectrum. Moreover, we put forward how to recover the interference by erasing the which-way information stored in the x-ray polarization.

[1] M. O. Scully *et al.*, Nature **351**, 111 (1991).

[2] J. Hannon and G. Trammell, Hyperfine Interact. **123-124**, 127 (1999).