A 38: Interaction with VUV and X-ray light II

Time: Friday 11:00–13:15 Location: C/HSW

Invited Talk A 38.1 Fri 11:00 C/HSW

X-ray quantum optics: From Mössbauer to Fano — Kilian P. Heeg[1], Christian Ott[1], Daniel Schumacher[2], Hans-Christian Wille[2], Ralf Röhlsberger[2], Thomas Pfeifer[1], and •Jörg Evers[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg — [2]Deutsches Elektronen-Synchrotron DESY, Hamburg

Modern x-ray light sources promise access to structure and dynamics of matter in largely unexplored spectral regions. However, the desired information is encoded in the light intensity and phase, whereas detectors register only the intensity. This phase problem is ubiquitous in crystallography and imaging, and impedes the exploration of quantum effects at x-ray energies. Here, we demonstrate phase-sensitive measurements characterizing the quantum state of a nuclear two-level system at hard x-ray energies [1]. This system comprises a large ensemble of nuclei in a x-ray cavity. The nuclei are initially prepared in a superposition state via a short x-ray pulse. Subsequently, the relative phase of this superposition is interferometrically reconstructed from the emitted x-rays via the cavity. Next to phase-sensitive measurements, also control of spectroscopic line shapes at hard x-ray energies is enabled via the tunable Fano interference [2].

[1] K. P. Heeg et al., arXiv:1411.1545 [quant-ph]
[2] C. Ott et al., Science 340, 716 (2013)

A 38.2 Fri 11:30 C/HSW

Nonlinear effects with Mössbauer nuclei — •Kilian P. Heeg, Christoph H. Keitel, and Jörg Evers — Max-Planck-Institut für Kernphysik, Heidelberg, Germany

Probing Mössbauer nuclei in a cavity environment has recently facilitated the observation of many quantum optical effects in the hard x-ray regime [1-5]. However, due to the limitations of current 3rd generation synchrotron sources only the weak excitation regime could be accessed so far. In contrast, free electron laser sources enable the step to nonlinear quantum optics with Mössbauer nuclei. Based on our recent theoretical model [6] we explore this new parameter regime and give an overview of the arising effects and possible applications.

[1] R. Röhlsberger *et al.*, Science **328**, 1248–1251 (2010)
[2] R. Röhlsberger *et al.*, Nature **482**, 199–203 (2012)
[3] K. P. Heeg *et al.*, Phys. Rev. Lett. **111**, 073601 (2013)
[4] K. P. Heeg *et al.*, arXiv:1409.0365
[5] K. P. Heeg *et al.*, arXiv:1411.1545
[6] K. P. Heeg and J. Evers, Phys. Rev. A **88**, 043828 (2013)

A 38.3 Fri 11:45 C/HSW

X-ray polarization control using nuclear transitions — •Jonas Gunst, Adriana Pálffy, and Christoph H. Keitel — Max-Planck-Institut für Kernphysik, Heidelberg

Due to the recent progress of x-ray light sources, a number of quantum optical schemes could be transferred to the realm of nuclear physics [1]. In addition, the highly brilliant photon beams provided by x–ray free electron lasers (XFEL) are expected to render the resonant driving of nuclei embedded in solid–state targets efficient via direct or secondary electron-mediated processes [2]. For applications in the fields of photonics or quantum information, x-ray photon energies (10-100 keV) would drastically decrease the limitation on nanoscale photonic circuits determined by the diffraction limit (~ 1 μm for optical photons). Here, we investigate theoretically how to coherently control the polarization properties of x-rays in the course of nuclear forward scattering (NFS) on ensembles of Mössbauer ^{57}Fe nuclei. We show that it is possible to manipulate the polarization response of a nuclear 2-level system by employing NFS in external magnetic fields. Several control schemes are then applied to x-ray qubits in order to read, store and manipulate their polarization coding.

[1] F. Vagizov *et al.*, Nature **508**, 80 (2014)
[2] J. Gunst *et al.*, Phys. Rev. Lett. **112**, 082501 (2014)

A 38.4 Fri 12:00 C/HSW

Polaritons in a nuclear optical lattice — •Johann Haber[1], Kai Schlage[1], Kai Sven Schulze[2,3], Tatyana Guryeva[1], Robert Lötzsch[2,3], Lars Bocklage[1], Daniel Schumacher[1], Hans-Christian Wille[1], Ingo Uschmann[2,3], Rudolf Rüffer[4], and Ralf Röhlsberger[1] — [1]Deutsches Elektronen-Synchrotron DESY, Notkestraße 85, D-22607 Hamburg, Germany — [2]Institut für Optik und Quantenelektronik, Friedrich-Schiller-Universität Jena, Max-Wien-Platz 1, 07743 Jena, Germany — [3]Helmholtz-Institut Jena, Fröbelstieg 3, 07743 Jena, Germany — [4]European Synchrotron Radiation Facility, B.P. 220, 38043 Grenoble Cedex, France

We fabricate a nuclear optical lattice by sputtering alternating layers of nuclear resonant ^{57}Fe and non-resonant ^{56}Fe. The multilayer has no variation in the background refractive index, but the polaritonic interaction of x-ray radiation and the ^{57}Fe- nuclei leads to a variation of the index of refraction at the 14.41 keV resonance of ^{57}Fe. We perform reflectivity measurements and Mössbauer spectroscopy of the multilayer around the Bragg angle and explain our results in terms of the dispersion relation of the system which we derive by a transfer matrix algorithm as well as a simple quantum optical model.

A 38.5 Fri 12:15 C/HSW

Resonant scattering from single He nanodroplets in intense XUV laser pulses — •B. Langbehn[1], Y. Ovcharenko[1], D. Rupp[1], M. Coreno[2], R. Cucini[3], M. Devetta[4], P. Finetti[3], A. Garz[1], C. Grazioli[3], T. Mazza[5], O. Plekan[3], P. Piseri[4], K. C. Prince[2,6], S. Stranges[6,7], C. Callegari[3], F. Stienkemeier[8], and T. Möller[1] — [1]TU Berlin — [2]CNR Istituto di Metodologie Inorganiche e dei Plasmi, Monterotondo Scalo — [3]Elletra-Sincrotrone Trieste — [4]Università di Milano — [5]European XFEL, Hamburg — [6]CNR Istituto Officina dei Materiali, Trieste — [7]Università Sapienza, Roma — [8]Universität Freiburg

With the advent of tunable XUV light sources such as the free electron laser FERMI studying resonant light scattering by small particles has become possible. In particular, He nanodroplets can serve as model systems to investigate plasma formation as well as plasma dynamics by extracting the complex refractive index from scattering patterns obtained in a single-shot single-particle experiment.

Recently, such kind of experiment has been started at the FERMI free electron laser's low density matter beamline [1]. In order to measure single-cluster scattering patterns, a cluster source was set up using an Even-Lavie-valve to generate a stable pulsed He cluster beam. Scattering patterns of large He nanodroplets ($\langle N \rangle = 10^9$ atoms) have been recorded at photon energies ranging from 19 eV to 37 eV giving an insight into the droplets' optical properties.

[1] Lyamayev, V. et al., *J. Phys. B* **46** (2013)

A 38.6 Fri 12:30 C/HSW

Electron dynamics in He nanodroplets resonantly induced by intense XUV pulses — •Y. Ovcharenko[1], A. LaForge[2], M. Mudrich[2], P. O'Keeffe[3], A. Ciavardini[3], O. Plekan[4], P. Finetti[4], M. Devetta[5], P. Piseri[5], A. Mika[6], R. Richter[4], K.C. Prince[4,7], M. Drabbels[6], C. Callegari[4], F. Stienkemeier[2], and T. Möller[1] — [1]TU Berlin, Germany — [2]Universität Freiburg, Germany — [3]CNR Istituto di Metodologie Inorganiche e dei Plasmi, Monterotondo Scalo, Italy — [4]Elettra-Sincrotrone Trieste, Trieste, Italy — [5]Universita di Milano, Milano, Italy — [6]EPFL, Lausanne, Switzerland — [7]IOM-CNR TASC Laboratory, Trieste, Italy

Since the first seeded Free Electron Laser FERMI became available for users, it offers unique possibility to perform detailed investigations in complex atomic and molecular systems due to the narrow bandwidth, fine energy tunability and high intensity in XUV energy range. By using this new source the ionization dynamics in He nanodroplets has been explored with electron spectroscopy in a wide energy range above first ionization potential (IP) as well as below it, going through the surface as well as bulk excitations. In addition to the conventional sequential multi-step ionization (MSI) with a photon energy well above IP a novel collective ionization process [1] following resonant bulk excitation is observed. It is due to autoionization of two or more electronically excited cluster atoms as predicted recently. The process is very efficient and can exceed the rate of direct photoionization above IP.

[1] Y. Ovcharenko et al., Phys. Rev. Lett. 112, 073401 (2014)

A 38.7 Fri 12:45 C/HSW

Excitation energy resolved photon-induced fluorescence spectrum of hydrogen molecules in the regime of singly excited molecular states — •Philipp Schmidt[1], Christian Ozga[1], Philipp Reiss[1], Andreas Hans[1], Ltaief Ben Ltaief[1], André

Knie[1], Arno Ehresmann[1], Kouichi Hosaka[2], Masashi Kitajima[2], and Noriyuki Kouchi[2] — [1]Institut für Physik and Center for Interdisciplinary Nanostructure Science and Technology, Universität Kassel, Heinrich-Plett-Straße 40, 34132 Kassel, Germany — [2]Department of Chemistry, Tokyo Institute of Technology, Meguro-ku, Tokyo 152, Japan

The potential energy landscape of molecules is a fundamental concept to explain and characterize a multitude of molecular processes. The hydrogen molecule is the most abundant molecule in the universe and has been a prototype for calculations of such energy landscapes for a long time. Here we present results for the photon-induced fluorescence spectrum of hydrogen molecules in the far ultraviolet regime after photoexcitation with synchrotron radiation in the energy range between 10 eV and 18 eV. The high resolution of both the excitation source and the fluorescence spectrum in this experiment allows the direct probing of the potential energy diagram. These regimes for the hydrogen molecule in particular cover the excitation into the B and C electronic states as well as the dissociation into neutral and excited hydrogen atoms leading to molecular and atomic fluorescence features showcasing various effects and processes that are not visible in common potential energy calculations.

A 38.8 Fri 13:00 C/HSW

Excitation energy transfer processes in Ar dimers below the Interatomic Coulombic decay (ICD) threshold probed with XUV-pump IR-probe experiments — •Tomoya Mizuno, Philipp Cörlin, Andreas Fischer, Michael Schönwald, Thomas Pfeifer, and Robert Moshammer — Max-Planck-Institut für Kernphsik, Heidelberg, Germany

We investigated the mechanism of transferring excitation energy to a neighbouring atom in Ar dimers below the ICD threshold by using XUV-pump IR-probe experiments. The first XUV pulse, which is generated from 10 fs IR laser pulse via HHG in Ar gas, creates two different types of excited states in one of two Ar atoms, such as a $3s$ inner-shell vacancy and $3d$ excitation state (Ar $3p^{-2}(3P)3d\ ^2P$ and ^2D) following $3p$ valence ionization by shake-up process. And then, the delayed IR probe pulse further ionizes into a repulsive Ar+$(3p^{-1})$ and $Ar^+(3p^{-1})$ state after a variable time delay. Finally, all charged reaction products emerging from the Ar dimer were detected by a reaction microscope. The apparatus enables us to record the kinetic energy release (KER) of a $Ar^+ + Ar^+$ ion-pair as a function of the pump-probe delay, in order to discuss the internuclear distance R at a given time. We found that the delay-dependent KER spectra exhibit clearly two dissociation pathways, corresponding to decay of 3s inner-shell ionization channel and shake-up channel, respectively. Moreover it was also found that the excitation energy is transferred to a neighbouring atom at the crossing points due to nonadiabatic transition.