Developments, Problems, and Extensions of Electrodynamic

French-German WE-Heraeus-Seminar

29 – 23 August 2024

at the Physikzentrum Bad Honnef, Germany

WILHELM UND ELSE HERAEUS-STIFTUNG

Introduction

The Wilhelm und Else Heraeus-Stiftung is a private foundation that supports research and education in science with an emphasis on physics. It is recognized as Germany's most important private institution funding physics. Some of the activities of the foundation are carried out in close cooperation with the German Physical Society (Deutsche Physikalische Gesellschaft). For detailed information see https://www.we-heraeus-stiftung.de

Aims and scope of the French-German WE-Heraeus-Seminar:

Electromagnetic fields are the most important systems in physics. Without electromagnetic fields no observations could be made and no instrument would work. This holds for the classical as well as the quantum sector of physics. Though electromagnetism is the most intensely studied and used system in physics, and though we have it well under control in all technical applications, including quantum optics and the new quantum technologies, there are still aspects of the physics of the electromagnetic field to be investigated, and there are also open problems in the understanding and consistent description of all electromagnetic phenomena, like problems in the radiation reaction of charged partciies and divergence in the self energy. Some of these problems could be solved by, e.g., non-linear or non-local extensions of the Maxwell equations. Furthermore, a theory of quantum gravity also is expected to modifiy fundamental leas as the Maxwell equations. Accordingly, it is very reasonable to discuss general extension of the Maxwell equations in a systematic way. This is the topic of this French-German WE-Heraeus-seminar.

This French-German WE-Heraeus-seminar results from an existing cooperation between German and French scientists. With this seminar, we want to deepen and broaden this cooperation between German and French groups and will involve other colleagues, theorists as well as experimentalists, and from areas like quantum optics, relativistic astrophysics, and cosmology.

Scientific Organizer:

Prof. Claus Lämmerzahl	Universität Bremen, Germany E-mail: claus.laemmerzahl@zarm.uni-bremen.de
PD Dr. Volker Perlick	Universität Bremen, Germany E-mail: perlick@uni-bremen.de
Prof. Alessandro Spallicci	Université d'Orléans, France E-mail: alessandro.spallicci@cnrs-orleans.fr

Introduction

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Registration:

Elisabeth Nowotka (WE Heraeus Foundation)
at the Physikzentrum, reception office
Sunday (17:00 h – 21:00 h) and Monday morning

Program

Program

Sunday, 18 August 2024

17:00 – 20:00	Registration	
18:00	*BUFFET SUPPER and informal get-together*	

Monday, 19 August 2024

08:00	*BREAKFAST*	
08:45 – 09:00	Scientific organizers	**Welcome words**
09:00 – 10:00	Friedrich W. Hehl	**Birefringence and all that: Fresnel wave surface in optics, Kummer surfaces in electrodynamics and in gravitation**
10:00 – 11:00	Yakov Itin	**Anisotropic electromagnetism in premetric approach: dispersion relation and photon propagator**
11:00 – 11:30	*COFFEE BREAK*	
11:30 – 12:30	Michael Kiessling	**BLTP electrodynamics as initial value problem**
12:30	*LUNCH*	

Program

Monday, 19 August 2024

14:00 – 15:00	Nazim Djeghloul	**Alternative geometric formulation of classical electromagnetism and unification with gravitation**
15:00 – 16:00	Olaf Lechtenfeld	**From Yang-Mills in de Sitter space to Maxwell knots**
16:00 – 16:30	*COFFEE BREAK*	
16:30 – 17:00	Germann Hergert	**Ultra-nonlinear subcycle emission of few-electron states**
17:00 – 17:30	Gabriel Camacho De Pinho	**Quantum vacuum dispersion forces in Proca Electrodynamics**
17:30 – 18:30	**Discussion**	
18:30	*DINNER*	

Program

Tuesday, 20 August 2024

08:00	*BREAKFAST*	
09:00 – 10:00	Rainer Mandel	**Variational methods for nonlinear time-harmonic Maxwell equations in local and nonlocal media**
10:00 – 11:00	Jonathan Agil	**Vacuum magnetic birefringence: an optical test of non-linear electrodynamics**
11:00 – 11:30	*COFFEE BREAK*	
11:30 – 12:30	Claudio Paganini	**Gravitational spin hall effect of light**
12:30	*LUNCH*	
14:00 – 15:00	José Abdalla Helayël-Neto *(online)*	**Modified dispersion relations, massive photons and non-maxwellian extensions**
15:00 – 16:00	Eloy Ayón-Beato (*online*)	**On the electrodynamics of the first nonlinearly charged spinning black hole**
16:00 – 16:30	*COFFEE BREAK*	
16:30 – 17:00	Abedennour Dib	**Extended theories of electromagnetism: effective mass in non-linear theories**
17:00 – 17:30	**Poster flashes**	
17:30 – 18:30	**Posters**	
18:30	*DINNER*	

Program

Wednesday, 21 August 2024

08:00	*BREAKFAST*	
09:00 – 10:00	Alessandro Spallicci *(online)*	**Implications of Extended Theories of Electromagnetism (ETEM) on astrophysics and cosmology**
10:00 – 11:00	Claus Lämmerzahl	**The physics of active and passive charges**
11:00 – 11:30	*COFFEE BREAK*	
11:30 – 12:30	Philippe Bouyer	**Quantum sensors for testing fundamental limits**
12:30	*LUNCH*	
14:00 – 17:30	**Excursion**	
18:30	*HERAEUS DINNER (social event with cold & warm buffet with complimentary drinks)*	

Program

Thursday, 22 August 2024

08:00	*BREAKFAST*	
09:00 – 10:00	Jan-Willem van Holten	**Magnetic fields of compact astrophysical bodies**
10:00 – 11:00	Cherry Ng-Guiheneuf	**Fast radio bursts: A brief review**
11:00 – 11:30	*COFFEE BREAK*	
11:30 – 12:30	Guillaume Voisin	**Electrodynamics in neutron-star magnetospheres**
12:30	*LUNCH*	
14:00 – 15:00	Nick Mavromatos	**Aspects of non-linear electrodynamics and collider searches via light-by-light scattering**
15:00 – 16:00	Krzysztof Piotrzkowski	**High energy photon-photon interactions at colliders**
16:00 – 16:30	*COFFEE BRREAK*	
16:30 – 17:00	Detlef Hoyer	**Useful predictions from 5D vaccum equation**
17:00 – 18:30	**Discussion**	
18:30	*DINNER*	

Program

Friday, 23 August 2024

08:00	*BREAKFAST*	
09:00 – 10:00	Salvatore Capozziello	**Resonant graviton-photon transitions with cosmological stochastic magnetic field**
10:00 – 11:00	Volker Perlick	**Maxwell equations on Finsler spacetimes**
11:00 – 11:30	*COFFEE BREAK*	
11:30 – 12:30	Robertus Potting	**Standing waves in Born-Infeld theory**
12:30 – 12:45	Scientific organizers	**Closing words**
13:00	*LUNCH*	

End of the seminar

Departure of participants who announced their departure for Friday

NO DINNER for participants leaving on Saturday; however, a self-service breakfast will be provided on Saturday morning

Posters

Posters

Victor Alencar	**Schwinger effect in Weyl and Dirac materials: An application of the Euler-Heisenberg electrodynamics**
Bennet Grützner	**Time Transfer via Electromagnetic Signals**
Edgar Mabengo	**Optimization of Electromagnetic Communication and Navigation Systems for Modern Aviation**
Ryan McGuigan	**Coherent radiation of ultra-short bunches from linear acceleration**
Altin Shala	**Waves in BLTP generalized electrodynamics**

Abstracts of Talks

(in alphabetical order)

Vacuum Magnetic Birefringence: an Optical Test of Non-Linear Electrodynamics

J. Agil[2,3], **R. Battesti**[1], **C. Rizzo**[1]

[1] *Laboratoire National des Champs Magnétiques Intenses (UPR 3228, CNRS, UPS, UGA, INSA), F-31400 Toulouse Cedex, France*
[2] *Johannes Gutenberg-Universität Mainz, 55128 Mainz, Germany*
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The BMV (*Biréfringence Magnétique du Vide*) project is an ambitious experiment whose goal is to verify in the laboratory the vacuum energy predictions of quantum electrodynamics (QED). This theory predicts that vacuum, in the presence of a magnetic field, behaves like a birefringent medium. The BMV experiment mixes intense pulsed magnetic fields with a sensitive optical device, centred around a high finesse Fabry-Perot cavity, to measure the ellipticity acquired by a beam of light in vacuum. In the framework of QED, the birefringence of vacuum can be expressed as $\Delta n = k_{\mathrm{CM}} B^2$ with $k_{\mathrm{CM}} = 4 \times 10^{-24}\ \mathrm{T}^{-2}$. Thus, achieving this measurement would allow to directly test QED in the photonic sector, and more generally gives limits to coefficients of non-linear electrodynamics (NLED) which contains QED as a special case. In order to achieve the sensitivity necessary for this measurement, the BMV apparatus received several improvements, including a new generation of magnet. We present the new apparatus, the preliminary results obtained, as well as avenues to further increase the signal-to-noise ratio of the BMV experiment.

References

[1] M. Fouché, R. Battesti and C. Rizzo, *Phys. Rev. D* **93**, 093020 (2016).

[2] J. Béard, J. Agil, R. Battesti and C. Rizzo, *Rev. Sci. Instrum.* **92**, 104710 (2021).

[3] J. Agil, R. Battesti and C. Rizzo, *The Eur. Phys. Jour. D* **76**, 192 (2022).

On the electrodynamics of the first nonlinearly charged spinning black hole

Dr. Eloy Ayón-Beato

Cinvestav, CDMX, México

After many years of efforts, the first nonlinearly charged rotating black hole has been finally reported by Garcia. This is an important result that was pending in General Relativity, since nonlinear generalizations of the Kerr-Newman solution were not yet known. In the present talk we start by didactically reviewing the new approach devised by García allowing him to achieve such bold result. Unfortunately, the Lagrangian supporting this configuration cannot be expressible in terms of the standard invariants using elementary functions. Here, we show how to circumvent this problem by using the formulations of nonlinear electrodynamics in terms of mixed electromagnetic eigenvalues, introduced by Salazar, Garcia and Plebanski almost four decades ago. In doing so, we prove that the underlying theory becomes fully determined, and hence the new found nonlinearly charged stationary axisymmetric spacetimes correspond to exact solutions of a well-defined self-gravitating nonlinear electrodynamics whose fundamental structural functions are explicitly provided.

Quantum vacuum dispersion forces in Proca Electrodynamics

Gabriel Camacho de Pinho[1], Carlos Augusto Domingues Zarro[1], Carlos Farina de Souza[1], Reinaldo Faria de Melo e Souza[2], Maurício Hippert Teixeira[3].

[1]-*Institute of Physics- Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brazil*, [2]-*Institute of Physics- Universidade Federal Fluminense, Niterói, Brazil*, [3]-*Institute of Physics- Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil*

In Proca electrodynamics the photon is massive and electromagnetic waves travel in vacuum with a velocity smaller than c, including the possibility of a longitudinal polarization. This theory effectively describes different physical systems ranging from colloids to cavity quantum electrodynamics. In this work we study the interaction between two atoms in Proca electrodynamics. We demonstrate the convenience of employing an effective Hamiltonian proposed by P. Milonni in order to obtain the interaction energy for any distance in a first order perturbation calculation. We analyze two important regimes: the short distance one where the retardation of the electromagnetic field may be neglected and the long distance one where atomic dispersion can be neglected. We show that the presence of a photon mass adds a length scale which considerably changes the physical conditions determining each regime in comparison with the maxwellian case. Finally we study nonadditive effects considering a system (i) composed by three atoms - thus generalizing to the massive case the results originally obtained by Axilrod-Teller - and (ii) composed by two atoms near a conducting plate. Either of systems (i) and (ii) are supposed to be close enough so that retardation of electromagnetic field may be neglected. On both cases, the mass changes qualitatively the form of the interacting potential.

Resonant graviton-photon transitions with cosmological stochastic magnetic field

A. Addazi, S. Capozziello, Qingyu Gan

We investigate graviton-photon oscillations sourced by cosmological magnetic fields from Gertsenshtein effect. We adopt a robust perturbative approach and we find that the conversion probability from graviton to photon can be resonantly enhanced in monochromatic, multi-chromatic and scale invariant spectrum models of stochastic magnetic field fluctuations. In addition, the expansion of the Universe acts as a decoherence factor, which demands a natural discretization scheme along the line of sight. Including also decoherence from cosmic acceleration, we find that conversion probabilities for stochastic magnetic fields are completely different than results predicted from existing magnetic domain-like models in a wide range of magnetic strengths and coherence lengths. Resonances can be tested by radio telescopes as a probe of high frequency gravitational wave sources and primordial magnetogenesis mechanisms.

Phys.Lett.B 851 (2024) 138574

Extended theories of electromagnetism: effective mass in non-linear theories

Abedennour Dib[1,2,3], **José A. Helayel-Neto**[4], **Alessandro D.A.M. Spallicci**[1,2,3]

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Generalised theories of electromagnetism as a framework offer new insight on what is perceived as the best understood model in physics. While successful, Maxwell's theory remains fundamentally linear and rely on the sole free massless particle in the Standard-Model (SM), the photon. Previous work within extended theories of electromagnetism shows that they all exhibit non-conservations of the energy-momentum tensor when photons interact with an electromagnetic background, when the latter is non-constant. For (effective) mass theories as the de Broglie-Proca and the SM Extention based on Lorentz symmetry violation, non-conservative terms appear also when the background is constant. This behaviour hints towards violations of the translational symmetry, and to a larger extent Poincaré symmetry. The objective of this work is to show that within a generic generalised non-linear model it is possible to alter the action in a way to have a quadric term in potentials before studying the Hamiltonian picture and constraint algebra of the model. We then demonstrate the propagation of a third degree of freedom linked to a non-constant mass term. We conclude by discussing the implications and possible mechanisms behind a spatially variable mass.

Alternative geometric formulation of classical electromagnetism and unification with gravitation

Nazim Djeghloul

Oran 1 University, Faculty of Exact and Applied Sciences, Department of Physics, Laboratoire de Physique Théorique d'Oran.

Starting from a geometric analysis of electrostatics, an alternative formulation of classical electromagnetism is presented. It is then shown that the latter allows a unified scheme for gravitation and electromagnetism in four-dimensional spacetime. It is, in particular, the introduction of a rank two antisymmetric tensor within the spacetime contortion [1], which allows constructing a single Hilbert-type action synthetically describing both phenomena.

References

[1] N. Djeghloul and M. A. Kellou, *Gen. Relativ. Gravit.* **56**, 19 (2024).

Birefringence and all that: Fresnel wave surface in optics, Kummer surfaces in electrodynamics and in gravitation

Friedrich W. Hehl
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Guided by results in the premetric electrodynamics of local and linear media, we introduce on 4-dimensional spacetime the new abstract notion of a Kummer tensor density of rank four, $\mathcal{K}^{ijkl}$. This tensor density is, by definition, a cubic algebraic functional of a tensor density of rank four $\mathcal{T}^{ijkl}$, which is antisymmetric in its first two and its last two indices: $\mathcal{T}^{ijkl} = -\mathcal{T}^{jikl} = -\mathcal{T}^{ijlk}$. Thus, $\mathcal{K} \sim \mathcal{T}^3$. (i) If $\mathcal{T}$ is identified with the electromagnetic response tensor of local and linear media, the Kummer tensor density encompasses the generalized *Fresnel wave surfaces* for propagating light. In the reversible case, the wave surfaces turn out to be *Kummer surfaces* as defined in algebraic geometry. (ii) If $\mathcal{T}$ is identified with the *curvature* tensor R^{ijkl} of a Riemann–Cartan spacetime, then $\mathcal{K} \sim R^3$ and, in the special case of general relativity, $\mathcal{K}$ reduces to the Kummer tensor of Zund (1969). This $\mathcal{K}$ is related to the *principal null directions* of the curvature. We discuss the properties of the general Kummer tensor density. In particular, we decompose $\mathcal{K}$ irreducibly under the 4-dimensional linear group $GL(4, R)$ and, subsequently, under the Lorentz group $SO(1, 3)$.

This lecture is based on joint work with *Peter Baekler* (Cologne), *Jens Boos* (KIT, Karlsruhe), *Alberto Favaro* (faculty.ai, London), *Yakov Itin* (Hebrew University and Jerusalem College of Technology), *Yuri Obukhov* (Russian Academy of Sciences, Moscow)

1. F.W.Hehl, Yu.N.Obukhov, Found.Class.Electrodyn., Boston, MA (2003)
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3. Y.Itin, J.Phys.A42, 475402 (2009)
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5. A.Favaro, Electromagnetic wave propagation in metamaterials: a visual guide to Fresnel-Kummer surfaces..., arXiv:1603.00063 (2016)
6. J.Boos, A.Favaro, Kerr principal null directions from Bel–Robinson and Kummer surfaces, arXiv:1703.10791 (2017)
7. A.B.Balakin, A.E.Zayats, Class.Quant.Grav.35, 065006 (2018)
8. E.Goulart, J.E.Ottoni, Remarks on the algebraic structure of (2, 2) double forms, arXiv:2311.14879 (2023)

“Modified Dispersion Relations, Massive Photons and Non-Maxwellian Extensions of Electrodynamics”

J. A. Helayël-Neto

Brazilian Centre for Research in Physics (CBPF, Rio de Janeiro)

This contribution sets out to present and discuss non-Maxwellian extensions of Electrodynamics, encompassing different categories of models: non-linear scenarios in presence of electromagnetic backgrounds and extensions that account for effects from Physics Beyond Standard-Model. Supersymmetry, Loop Quantum Gravity, Lorentz-Symmetry Violation, Extra Dimensions and Axion Physics are cases that shall be contemplated, and a number of QED-vacuum material properties are investigated which carry imprints from the mentioned classes of new physics.

Ultra-Nonlinear Subcycle Emission of Few-Electron States

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Recent demonstrations of the photoemission of Coulomb-correlated few-electron number states [1, 2] from metal nanotips open up interesting perspectives for enhancing the nonlinearity of multiphoton electron emission by increasing the electron number. Here, we explore this route in experimental studies of multiphoton emission from sharp metal tips using few-cycle near-infrared pulses at 2 µm. We demonstrate subcycle-driven multiphoton emission with up to 20th order and single peak autocorrelation traces with sub-fs peak width. The central results of our work are summarized in Figure 1.

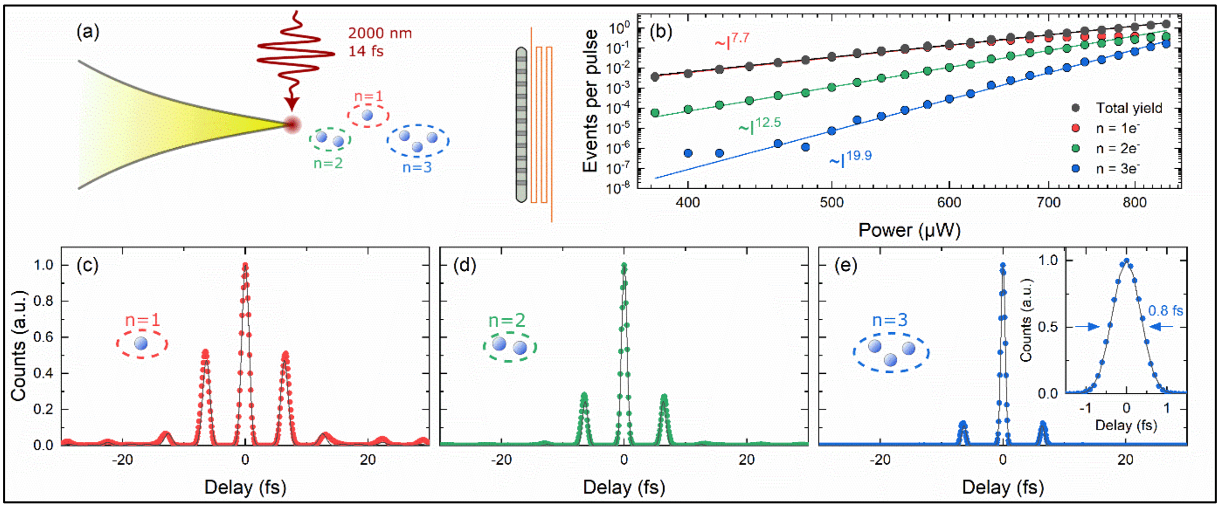

Fig. 1. (a) Extremely nonlinear multiphoton emission of ultrashort few-electron wavepacktes from a sharp gold taper. (b) Total electron yield as a function of laser power I (black dots) following a power law of $\sim I^{7.6}$. The total electron yield is sorted into one-, two- and three-electron wavepackets by post-selection (red, green, and blue dots), with nonlinearities of 7.7 ($n = 1$), 12.2 ($n = 2$) and 19.0 ($n = 3$), respectively. (c-e) Ultrafast interferometric autocorrelations of multi-electron events. Electron emission is highly confined to delays around $\tau = 0$ fs. For the three-electron events, the emission mainly occurs within the central peak with a width of 0.8 fs (see inset).

In essence, our experiments show that multiphoton emission of electron number states from sharp metal tips driven by few-cycle near-infrared pulses creates an interesting source of subcycle low-energy electron pulses with immediate applications in ultrafast point-projection electron microscopy [3]. The pulse profile can be altered to an isolated subcycle electron beam by controlling the tip bias. By combining highly nonlinear photoemission and one-electron state selection to reduce Coulomb-broadenings, this may improve the temporal resolution of low energy electron microscopy to the subcycle regime.

[1] S. Meier *et al*., Nat. Phys. **19**, 1402-1409 (2023)
[2] R. Haindl *et al*., Nat. Phys. **19**, 1410-1417 (2023)
[3] G. Hergert *et al*., ACS Photonics **8**, 2573-2580 (2021)

Useful Predictions from 5D Vacuum Equation

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Abstract. Since the work of Kaluza it has been known that Maxwell's equations are mathematically a subset of the Ricci curvature tensor in five dimensions. In the present paper a complete set of equations for the 5D Ricci curvature tensor is described that reproduces both the 4D Einstein gravitational equations and the equations of electromagnetism. The fifth row and column of 5x5 matrices of the Ricci tensor result in new parameters capable of generating 4D stress-energy-momentum tensors. We recall that using 5D vacuum equation no additional 5D stress-energy-momentum tensor is required. Solutions of the 5D vacuum equation $\boldsymbol{R}_{ij} = 0$ have been given the term 'induced matter theory.' A special feature of this theory is the occurrence of a scalar force field which is capable of generating mass [1]. Three important exact solutions are addressed: the solution of the 5D vacuum equation for a charged mass, solutions without charges and electromagnetism but with gravity and the scalar field, and a static two mass solution also known as the '1-body metric.' Results are discussed and further work on differences between the use of 4D and 5D formulations under electromagnetic influence is outlined.

[1] Y. Balytskyi, D. Hoyer, A. O. Pinchuk, L. L. Williams,
"*New physical parameterizations of monopole solutions in five-dimensional general relativity and the role of negative scalar field energy in vacuum solutions*",
Journal of Physics Communications,
IOPScience 2021

Anisotropic electromagnetism in premetric approach: dispersion relation and photon propagator

Yakov Itin
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July 6, 2024

Abstract

The work addresses the premetric description of electromagnetism in anisotropic media. The medium is defined by the general anisotropic electric permittivity and magnetic permeability tensors. Using the pure algebraic formulation of the first and second adjoint tensors, we obtain the premetric equations for the dispersion relation and photon propagator in anisotropic media. When temporal gauge constraints are used, the explicit computations of the photon propagator become significantly simpler. We derive the propagator's general form and specialize it to the situations involving isotropic, biaxial, and uniaxial media. The last case reinstates the expressions that are well-known from the literature.

References

[1] F.W. Hehl and Yu.N. Obukhov, *Foundations of Classical Electrodynamics: Charge, Flux, and Metric* (Birkhäuser: Boston, MA, 2003).

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[6] Y. Itin, "Photon propagator for axion electrodynamics," Phys. Rev. D **76**, 087505 (2007)

[7] Y. Itin, "Photon propagator in skewon electrodynamics," Phys. Rev. D **93**, no.2, 025023 (2016)

BLTP electrodynamics as initial value problem

Michael K. – H. Kiessling and A. Shadi Tahvildar-Zadeh

Rutgers University, Department of Mathematics
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This talk presents the proof of local well-posedness of the joint initial value problem for the evolution of classical electromagnetic fields and the motion of their point charge sources, in a theory sanctioned "Bopp–Landé–Thomas–Podolsky (BLTP) electrodynamics."

The physics of active and passive charges

Claus Lämmerzahl

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Here we report on a modification of Maxwell's theory which is very fundamental in that it is directly related to the definition of charge and, thus, deeply connected to the metrology of electromagnetism. An active charge is a charge which *creates* an electric field, and a passive charge *reacts* on an electric field. A difference of active and passive charge violates fundamental conservation laws. In this presentation the theoretical and experimental consequences of a difference of active and passive charges will be derived. With spectroscopy of differently charged nuclei one can derive constraints to a violation of the equality of active and passice charges. This also extends to modern metrology where all the physical units are derived from the definition of fundamental constants, one of which is the charge. We also generalize this concept to the notion of active and passive magnetic moment and also derive for this case consequences and possible tests. We also make remarks on the notions of active and passive mass. Part of this talk is based on [1], see also [2].

References

[1] Claus Lämmerzahl, Alfredo Macias, and Holger Müller: Limits to differences in active and passive charges, Phys. Rev. **A 75**, 052104 (2007)

[2] Vishwa Vijay Singh, Jürgen Müller, Liliane Biskupek, Eva Hackmann, and Claus Lämmerzahl: Equivalence of active and passive gravitational mass tested with Lunar Laser Ranging, Phys. Rev. Lett. **131**, 021401 (2023).

From Yang-Mills in de Sitter space to Maxwell knots

Olaf Lechtenfeld

Institut für Theoretische Physik, Leibniz Universität Hannover
Appelstrasse 2, 30167 Hannover, Germany

Abstract
I will review analytic SU(2) Yang-Mills solutions with finite action on de Sitter space from a new perspective. As a byproduct, all abelian solutions are classified and related with rational electromagnetic knots in Minkowski space. In the Yang-Mills case, the gravitational backreaction is easily taken into account as well.

Variational methods for nonlinear time-harmonic Maxwell equations in local and nonlocal media

Rainer Mandel

[1]*KIT, Karlsruhe, Germany*

In this talk we want to discuss mathematical models involving nonlinear time-harmonic Maxwell equations in local and nonlocal media. We will concentrate on criteria ensuring the (non-)existence of nontrivial localized solutions using modern tools from the Calculus of Variations. The so-called “ground states” having least energy among all nontrivial solutions are at the center of our considerations. We shall elaborate that important properties of the propagation medium have a rather direct impact on the solution theory of the associated mathematical model. This fact even may even allow to theoretically adjust model parameters based on experimental data.

References

[1] R. Mandel, Partial Diff. Equ. Appl. **3**, 22 (2022).

[2] A. Fernandez, L. Jeanjean, R. Mandel, M. Maris, Journal of Differential Equations **330** (2022), 1-65.

N.E. Mavromatos (Nat. Tech. Univ. Athens and King's College London)

Aspects of non-linear electrodynamics and collider searches via light-by-light scattering

Non-linear electrodynamics (NED) (Euler-Heisenberg with quartic interactions or a resummed version of it by Born and Infeld) appears as an effective low energy theory which may come from more fundamental theories such as strings. In this talk I discuss several aspects of it. First, as a motivation, I describe briefly some theoretical features of NED, including finite energy magnetic monopole solutions, as well as self-gravitating magnetically charged black hole systems. Then, I proceed to the main topics of the talk, namely an up-to-date status of searches for NED at colliders, via the most recent results on light-by-light scattering (LLS) from LHC, and a description of some LLS-based feasilbility studies at future colliders (in particular Future Circular Collider).

Fast Radio Bursts: A Brief Review

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Fast Radio Burst (FRB) is a recently identified phenomenon involving bright bursts in radio waves that have travelled from extragalactic distances [1]. In the last few years, the FRB field has made tremendous progress [see, e.g. 2 and references therein]. The total number of published FRBs is approaching 800 of which at least 45 have been localised to a host galaxy, with examples from both younger and older stellar populations. Several dozen FRBs have been seen to repeatedly burst, and chromatic periodic activity cycles have been identified in a few sources. FRBs have been detected by at least 12 radio telescopes, where emission has been seen from as low as 110 MHz to as high as 8 GHz. While the nature of FRBs is still an open question, interesting constraints are emerging from these observational clues which opens the possibility of using FRBs as a cosmological probe. In this talk, I will review the progress made in FRB observations in the last decade and summarize what we have learnt so far regarding the provenance of FRBs.

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Gravitational spin Hall effect of light

C. F. Paganini
joint work with
M. A. Oancea, J. Joudioux, I.Y. Dodin, D.E. Ruiz, L. Andersson

The propagation of electromagnetic waves in vacuum is often described within the geometrical optics approximation, which predicts that wave rays follow null geodesics. However, this model is valid only in the limit of infinitely high frequencies. At large but finite frequencies, diffraction can still be negligible, but the ray dynamics becomes affected by the evolution of the wave polarization. Hence, rays can deviate from null geodesics, which is known as the gravitational spin Hall effect of light. By considering the WKB approximation for Maxwell's equations, I will briefly present the main steps towards a covariant derivation of the polarization-dependent ray equations describing the gravitational spin Hall effect of light.

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Maxwell equations on Finsler spacetimes

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Finsler spacetime models are characterized by a metric that is not a function on the base manifold but on the tangent bundle. This generalization of the spacetime setting of general relativity can be motivated by a modified version of the Ehlers-Pirani-Schild axiomatic approach to spacetime theory. Moreover, among all theories that replace the pseudo-Riemannian metric of general relativity with a more general geometric object, apart from Weyl geometry Finsler geometry is the only one that admits an unambiguous notion of standard clocks (i.e., of proper time).

In this talk I will discuss two possibilities of how to generalize Maxwell's equations into a Finsler setting. The first possibility is to allow the electromagnetic field tensor to be a function on the tangent bundle of the spacetime manifold, the second possibility is to make Maxwell's equations into pseudo-differential equations. I will give several arguments in favour of the second possibility. Among other things, I will demonstrate that the pseudo-differential version of Maxwell's equations admits a satisfactory transition to ray optics, I will discuss a Finsler-modified Coulomb potential and the correspondingly changed spectrum of the hydrogen atom, and I will outline possible tests of Finsler spacetime theory in the Solar system and in cosmology.

The talk is partly based on joint papers with Claus Laemmerzahl (University of Bremen), Wolfgang Hasse (TU Berlin) and Yakov Itin (Hebrew University Jerusalem).

High energy photon-photon interactions at colliders

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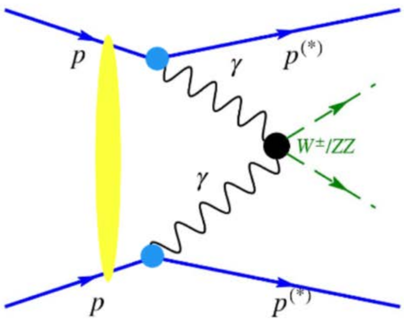
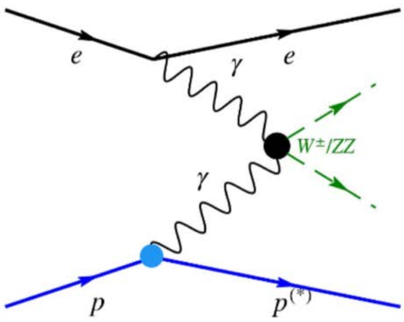
An introduction will be given to the studies of photon-photon interactions at high energy colliders. First, measurements of high energy photon-photon fusion at the LHC will be extensively discussed, including very specific detector and data analysis techniques associated with them. Then, the prospects of such studies at future colliders will be considered, in particular at the proposed Large Hadron Electron Collider (LHeC), which is to operate at a center-of-mass energy of 1.2 TeV and is anticipated to provide an integrated electron-proton luminosity of about 1 ab^{-1}. The unique scientific potential of studying such photon-photon interactions at the LHeC (and other proposed colliders) will be analyzed for various processes, including for example the exclusive production of pairs of W and Z bosons, of lepton pairs and Higgs bosons as well as pairs of charged supersymmetric particles.





Standing waves in Born-Infeld theory

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We review recent work by the authors on standing-wave solutions in Born-Infeld theory [1]. In particular, we focus on the case in which the vector potential describing the electromagnetic field has only one nonzero component depending on time and on the coordinate perpendicular to the plates, reducing the problem to the the scalar Born-Infeld equation. We employ two alternative methods to obtain the solutions: an iterative method, and a “minimal surface” method. The results thus obtained can provide a theoretical background for experimental tests of Born-Infeld theory.

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Implications of Extended Theories of Electromagnetism (ETEM) on astrophysics and cosmology

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The ad-hoc dark Universe is compatible with General Relativity (GR) but it faces the lack of experimental evidence and of identified candidate particles in the Standard Model (SM). In alternative to the dark universe, options to GR are not observationally needed. We observe that despite neutrinos, cosmic rays and now gravitational waves, photons remain by large the main messengers of the cosmos. Thus, we analyse whether Extended Theories of Electromagnetism (ETEM) induce a reinterpretation of light signals impacting astrophysics and cosmology, beyond our concern focused on fundamental physics. The SM Extension (SME) induces a mass to a photon [1,2], the only SM free massless particle, compatible to the upper limits by Fast Radio Bursts [3-5] and solar wind [6,7]. In this conference Non-Linear theories will be also shown to manifest a mass induced by the background. Further, all photons either SME or massive of the de Broglie-Proca type or non-linear of the Born-Infeld, Heisenberg-Euler type and even Maxwellian undergo a frequency shift in presence of an electromagnetic and/or Lorenz Symmetry Violation backgrounds [8,9]. This shift, added to expansion redshift determines new cosmological scenarios, e.g., without recurring to dark energy [10-12] and possibly to dark matter. Finally, we have applied the Heisenberg principle to cosmological scales. The minimal mass is drawn from the energy-time relation for the age of the universe. We read the Hubble constant as quantum measurement and reinterprete the tension accordingly [13,14].

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Magnetic fields of compact astrophysical bodies

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Magnetic fields of compact astrophysical bodies like neutron stars and black holes are modeled by the solutions of the Maxwell equations in the background of the exterior static Schwarzschild and slowly rotating Kerr space-times, with the boundary condition that the electromagnetic fields are to vanish at infinity. These solutions allow us to study the motion of charged test particles in the combined gravitational and electromagnetic fields. Bound circular orbits exist in odd-multipole magnetic fields; a discrete set of orbits with particular radii are found also in combinations of two or more even-multipole magnetic fields. A perturbative approach for the construction of non-circular orbits is used to study stability of the parent circular orbits.

Ref.

R. Kerner, G. Koekoek, J.A. Schuring and J.W. van Holten
Polar magnetic fields in black-hole space-times,
preprint NIKHEF 2024-009; arXiv:2407.04975;

Electrodynamics in neutron-star magnetospheres

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Neutron star magnetospheres are the siege of extreme conditions where electrodynamics reigns barely unchallenged by gravity. This is explained by extreme magnetic fields, ranging from 10^4 to 10^12 Teslas close to the surface. In a struggle to keep corotating with the rapidly rotating star (from 1ms to ~20s), the electron-positron pair plasma opens up 10^12V potential gaps that accelerate leptons to energies only limited by radiation reaction, up to Lorentz factors of about 10^7. Radiation reaction is mostly the result of synchrocurvature radiation, that is the radiation emitted by particles spiraling around a curved magnetic field line with large Lorentz factors. The magnetosphere copiously produces pairs mainly through gamma rays interacting with the magnetic field, but also through photon-photon interactions, in a way that is sufficient to keep the magnetosphere filled with plasma. As a result the magnetosphere forms a complex system that can hardly be reduced to any local approximation. In this talk we will review the main electrodynamical processes at play, before focusing more particularly on the quantum theory of synchrocurvature radiation as an informative example of physical process within these extreme environments.

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Abstracts of Posters

(in alphabetical order)

Schwinger Effect in Weyl and Dirac Materials: An Application of the Euler-Heisenberg Electrodynamics

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In the last two decades, Weyl [1], Dirac [2], and even the exotic Rarita-Schwinger-Weyl [3] fermions have appeared in models for semimetals, superconductors, topological insulators, and other states of matter, often presenting non-trivial topological properties. The advent of relativistic spinors in condensed matter has led to novel techniques to describe phase transitions and topologically protected states. This fruitful bridge between two realms of physics not only employs similar mathematical machinery but also reveals new shared phenomena. One notable example is the Schwinger effect—the creation of hole-antihole pairs by strong electromagnetic fields. This effect has been observed in analogs within graphene [4] and predicted for BCS superconductors [5], and Dirac semimetals.

In this work, we develop a method to compute the Schwinger effect analog in condensed matter by deriving an effective theory based on the Euler-Heisenberg formalism [6]. The Euler-Heisenberg theory, originally developed to describe the nonlinear behaviour of vacuum in quantum electrodynamics, provides a powerful framework for understanding strong-field phenomena in materials. We derive effective electromagnetic theories by integrating out the electrons using the momentum-shell renormalization group. In this framework, the electromagnetic self-interaction terms depend on the physical properties of the material, such as the Fermi velocity. Beyond the Schwinger effect analog, these effective theories may also be useful in nonlinear optics, as they allow us to study harmonic generation and birefringence.

Our approach not only provides a deeper understanding of the Schwinger effect analog in various condensed matter systems but also highlights the significance of Euler-Heisenberg electrodynamics as a versatile tool for exploring other nonlinear electromagnetic phenomena.

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Time Transfer via Electromagnetic Signals

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Abstract To properly synchronize an extended clock network we need to transfer time signals between clocks, which is done with electromagnetic signals. These signals are influenced by the geometry of spacetime as described with the gravitational metric, giving rise to several phenomina, like gravitational redshift, Sagnac effect or the Shapiro delay. Calculating and measuring these effects is of increasing importance, as the accuracy of clocks steadily increases. Additional effects would be expected in electrodynamics beyond Maxwell.

Optimization of Electromagnetic Communication and Navigation Systems for Modern Aviation

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Electromagnetic fields are critical for the communication and navigation systems that ensure the safety and efficiency of modern aviation. Although significant progress has been made in reducing electromagnetic interference, challenges remain, particularly in high-density environments like airports and urban areas.
This research aims to address these challenges by exploring innovative solutions to optimize these systems, focusing on three main areas: the impact of electromagnetic fields on onboard instruments, the development of new communication technologies based on non-linear or non-local electromagnetic fields and the applications of electromagnetic fields in obstacle detection and avoidance systems.
In-depth analysis is crucial to understanding how electromagnetic fields influence navigation and communication instruments under various conditions. Exploring advanced theories, such as non-linear and non-local extensions, can lead to the development of more robust and efficient communication technologies.
Thus, the research will explore new materials and configurations for avionics to mitigate interference and ultimately enhance the safety and efficiency of modern aviation.

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Coherent Radiation Of Ultra-Short Bunches from Linear Acceleration

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The radiation and self-field of accelerated charge are thought to be intimately linked, regulating the balance of energy in an electromagnetic field according to Poynting's theorem [1]. Radiation into the far-field constitutes a loss of energy for the emitting charge, the magnitude of which is particularly great when the radiation is coherent, varying quadratically with the number of charges N [2]. We present a detailed analysis of coherent radiation from ultrashort compact bunches, an extension of the classic textbook [3] problem of radiation emitted by charge that is linearly accelerated for a finite duration. Contrary to usual expectations of immeasurably small and negligible emission [4], we show that for ultrashort compact bunches at the boundaries of current experiments, a significant and measurable radiation pulse is produced. The underlying mechanism for this significant radiation is a coherence in the emission from bunches with $N \sim O(10^8)$ electrons (corresponding to $Q \sim 100$ pC). We derived analytic descriptions of the emission spectrum and energy for acceleration fields and bunch conditions encountered in RF-driven particle accelerators, and in the extreme high-gradient conditions of plasma-driven acceleration.

In extremely compact bunches, albeit not yet realizable in the laboratory, the radiation losses approach the Lamour radiation for a massively-charged particle ($Q \sim 10^9 e$). In such conditions the energy of the longitudinal acceleration radiation may approach the energy available from the electric field driving the acceleration, raising questions of a connection to mechanisms of field depletion and radiation reaction in the near-field.

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Laser optogalvanic spectroscopy of lead lines − Isotope shifts and hyperfine structure studies

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Lead manifests as a mixture of four distinct stable isotopes with masses of 204, 206, 207, and 208 in its natural state. Its lines exhibit considerable isotope shifts (IS), making it an optimal candidate for in-depth IS studies. Further, spectroscopic calculations of Lead are crucial to accurately predicting the stellar Pb abundances [1]. Following the importance of lead spectroscopic data and the lack of results on hyperfine (hfs) and isotopic studies, in this study, six atomic lines of Pb I within the wavelength range 569–612 nm and two lines of Pb II in the wavelength span 560–608 nm were investigated using optogalvanic spectroscopy. Further, we performed theoretical calculations to support our measurements using the multiconfigurational Dirac–Hartree–Fock (MCDHF) theory implemented in the GRASP2018 package [2]. The corrections arising from quantum electrodynamic effects, viz., vacuum polarization and self-energy, as well as nuclear corrections, including specific and normal mass shifts and the Breit interaction in the low-frequency limit, are incorporated in the relativistic configuration interaction calculations.

Our comparative analysis between theoretical results and experimental findings demonstrates good agreement. For Pb I, the theoretical results exhibit a mean relative deviation of 1.9 % with the present measurements of hfs constant A. In the case of Pb II, the hfs measurement is conducted for the $6s^2 7p\ ^2P_{3/2}$ level, and it aligns well with the current calculation, showing a relative deviation of only 0.5 %. Similarly, our IS results demonstrate a comparable agreement between theory and observations, with Pb II showing particularly good agreement. The experimental data we have obtained supplement or refine previous data; in several cases, the results are the first available data. Additionally, our theoretical calculations include isotope shifts for certain lines in both Pb I and Pb II that have not been detected in current or prior experiments.

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Waves in BLTP generalized electrodynamics

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We investigate the extent in which BLTP waves can be distinguished from waves coming from ordinary Maxwell electrodynamics. As a first step we compute standing wave solutions. These solutions and its propagation are analysed in the context of energy requirement. Feasibility of ordinary experiments is discussed. Furthermore we motivate an alternative approach based on a standard fluid model from plasma-physics where we modified the field equations in order to find differences in dispersion relations for a collision-less electron plasma. We then discuss how we can handle the experimentally restrictive energy conditions in order to obtain a propagating mode of BLTP that can be measured.