

**INSTITUTE  
OF  
THEORETICAL PHYSICS**

**Faculty of Physics**

**Warsaw University**

**2000-2001**



**Warsaw 2003**

## INSTITUTE OF THEORETICAL PHYSICS

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**Chairman:** Jan Blinowski

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**Members:** all senior academic teachers (professors and *doctors habilitati* D.Sc.'s)  
and representatives of: other academic teachers, graduate and postgraduate  
students, technical, library and administrative personnel.

### Number of staff members (Dec. 31, 2001):

*Academic teachers:* 50

*Librarians:* 5

*Secretaries:* 2

*Technical personnel:* 5

*Operating personnel:* 1

## DIVISIONS

**FS** Field Theory and Statistical Physics

**RG** Theory of Relativity and Gravitation

**MP** Mathematical and Computer Physics

**NS** Nuclear Structure Theory

**QO** Quantum Optics and Atomic Physics

**EP** Theory of Particles and Elementary Interactions

**HL** Theory of Hadrons and Leptons

**SS** Solid State Theory

*Editor:* Paweł Klimczewski, IFT UW, 2003

*Cover picture:* Paweł Klimczewski & Krzysztof Pachucki, IFT UW, 2003

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## 1 FOREWORD

It became a tradition at the Faculty of Physics of Warsaw University that its two largest institutes, Institute of Experimental Physics and Institute of Theoretical Physics, organize at alternate years a symposium in which their main research topics and achievements are presented to the academic community. In December 2001 the Institute of Theoretical Physics organized its fourth Symposium “IFT UW-01”. This prompted us to publish the present report which contains information about the Institute and its activities and achievements in 2000–2001, i.e., in the period between our third and the fourth symposium.

## 2 PROFILE OF THE INSTITUTE

The Institute of Theoretical Physics is, after the Institute of Experimental Physics, the second largest among the five units within the Faculty of Physics at Warsaw University. It is the largest institution of theoretical physics in Poland. At the end of 2001 it employed 50 academic teachers whose duties are scientific research and/or teaching. 35 postgraduate students of the Faculty of Physics worked on their Ph.D. theses and assisted in teaching in our Institute. The administration, library, technical and operating personnel included 13 persons.

As a university unit the Institute combines the scientific activity with teaching. For this reason the research conducted at the Institute covers a comprehensive range of modern theoretical physics starting from the theory of elementary particles and interactions including gravitation, through the quantum theory of nuclei, atoms and condensed matter, statistical theory of macroscopic systems, up to the theoretical astrophysics. These investigations of physical systems are accompanied with studies on fundamental problems of quantum mechanics, mathematical problems of the classical and quantum field theory and nonlinear systems. So comprehensive scope of research requires division of the Institute into smaller research groups. There are 8 Divisions within the Institute at present. They carry on the research and also teaching for graduate (specialization in various domains of theoretical physics) and postgraduate students. More detailed information on particular subjects of research and achievements in 2000–2001 is presented below for each Division separately. According to the classification of the Polish State Committee for Scientific Research (KBN) in 2000–2001 the Institute, within the Faculty of Physics, was placed in the highest category I in physics together with 6 other institutions. An intense collaboration of members of the Institute with many international scientific institutions and foreign universities confirms on the one hand its high scientific standard and allows for keeping it on the other.

### 3 TEACHING ACTIVITIES OF THE INSTITUTE

Concerning teaching, the Institute provides lectures and courses on Calculus (Mathematics A for freshmen and sophomore), Mathematical Methods in Physics, Numerical Methods, and basic courses of theoretical physics (Classical and Quantum Mechanics, Classical Electrodynamics and Statistical Physics) for undergraduate students. The subjects are not assigned to particular lecturers or Divisions. The rule is that every lecturer can deliver by turns different lectures.

It is otherwise with specialized and monographic lectures on various topics in theoretical and mathematical physics for graduate and postgraduate students. These are delivered by specialists in that domain and assigned to particular Divisions. Only some of these lectures are in English, but we presume that the number of such lectures will increase in the future. The majority of specialized and monographic lectures are in Polish. They cover the whole of theoretical physics, like for instance mathematical methods in physics (soliton theory), geometry and the general theory of relativity, elementary particle physics and quantum field theories, theory of the nuclear structure, solid state and atomic physics, quantum optics, electrodynamics and statistical physics.

Apart from lectures two student's seminars in theoretical physics for undergraduate and graduate students are conducted, where participants are supposed to prepare a lecture under the supervision of a senior physicist of the Institute, and present it in front of other students attending these seminars. In this way young people actively take part in the educational process, what fosters an early engagement in scientific researches, and in some cases results in publishing their work in international scientific journals prior to receiving M.Sc. degrees. The employees of the Institute supervise other forms of educational activities. For instance some of our colleagues organize Workshops for pupils of grammar schools from different parts of Poland and supervise the activity of the Student Group of Nonlinear Physics, that is even publishing its own Bulletin with student's original scientific papers.

Due to a substantial increase of the number of students studying physics in the Faculty of Physics at Warsaw University the teaching load of employees and Ph.D. students of the Institute has recently jumped up significantly. In the last two academic years, 1999/2000 and 2000/2001, 20 students got their M.Sc. degrees, 8 post graduate students defended their Ph.D. theses, and 1 scientist received the D.Sc. (*habilitation*) degree. At present employees of the Institute supervise the scientific work of 35 postgraduate (Ph.D.) students, which got stipends from the University.

### 4 SEMINARS

The important part of the Institute activity which combines research with teaching are regular specialized seminars organized in the Institute. These seminars cover all branches of theoretical physics practiced in the Institute. During the academic years 1999/2000 and 2000/2001 the following seminars were organized (or coorganized together with colleagues from other units):

- Seminar on Chaos and Nonlinearity
- Seminar on Condensed Matter Physics
- Seminar on High Energy Physics
- Seminar on Geometry of Space-time
- Seminar on Geometry and Nonlinearity
- Seminar on Computer News
- Seminar on Elementary Interactions
- Seminar on Nuclear Spectroscopy
- Seminar on Astrophysics
- Seminar on Optics
- Seminar on Statistical Physics
- Seminar on Theory of Atomic Nuclei
- Seminar on Theory of Relativity

## 5 LEOPOLD INFELD SEMINAR

A special role among the seminars is played by the Leopold Infeld Seminar (*konwersatorium*). It was established by Professor Leopold Infeld, the founder and the first director of the Institute, and has the tradition of almost 50 years. It is the seminar for the entire community of Warsaw's theoretical physicists where general, actual and hot problems of theoretical physics are discussed. The language of the seminar is English or Polish but English is chosen when people who do not understand Polish are in the audience.

At present time it is coorganized by the Institute of Theoretical Physics at Warsaw University, the Center of Theoretical Physics of the Polish Academy of Sciences and the Department of Nuclear Theory of the Andrzej Sołtan Institute for Nuclear Studies (since 1999). Traditionally, it is chaired by the heads of the above institutions (i.e., by Stanisław G. Rohoziński, Kazimierz Rzążewski and Grzegorz Wilk)

**LECTURES GIVEN ON THE LEOPOLD INFELD SEMINAR IN 1999/2000 AND 2000/2001**

- 7.10.1999** Stanisław Bazański, IFT UW  
*PRINCIPLE OF INERTIA. A HISTORICAL REVIEW.*
- 18.10.1999** Kacper Zalewski, Krakow  
*INTENSITY INTERFERENCE: SIZES OF STARS AND SIZES OF PARTICLES.*
- 4.11.1999** Marek Demiański, Ernest A. Bartnik, Krzysztof Meissner  
*TOTAL ECLIPSE OF SUN - 11<sup>TH</sup> AUGUST 1999.*
- 18.11.1999** Hans Werner Diehl, Uniwersytet w Essen  
*WHEN THE BOUNDARY BECOMES INFINITELY THICK – CRITICAL BEHAVIOR AT INTERFACES.*
- 2.12.1999** Kazimierz Rzażewski, CFT PAN  
*BOSE-EINSTEIN CONDENSATION.*
- 6.01.2000** Iwo Białynicki-Birula  
*FROM FEYNMAN'S MISTAKE TO NOBEL PRIZE '99.*
- 20.01.2000** Jerzy Kijowski, CFT PAN  
*HEAD OR TAIL: THE DILEMMA OF ELECTRODYNAMICS.*
- 02.03.2000** Zbigniew Jaworowski, Centralne Laboratorium Ochrony Radiologicznej  
*HAZARD OF RADIATION AND ETHICS.*
- 16.03.2000** Jan Bartelski, IFT UW  
*ABC OF PROTON'S SPIN.*
- 30.03.2000** Danuta Kielczewska, IFD UW  
*OBSERVATIONS OF NEUTRINOS OSCILLATIONS.*
- 13.04.2000** Herbert Wagner, Ludwig Maximilians Universität, Munich  
*SURFACE MELTING.*
- 27.04.2000** Tomasz Dietl, IF PAN  
*FERROMAGNETIC SEMICONDUCTORS AND SPINTRONICS.*
- 11.05.2000** Andrzej Białas, Uniwersytet Jagielloński  
*FLUCTUATIONS IN MULTIPLE PRODUCTION.*
- 25.05.2000** Aleksander Filippow, Nikołaj Płakida, Dubna, Rosja  
*BASIC DIRECTIONS OF SCIENTIFIC RESEARCH AND INTERNATIONAL COLLABORATION OF THE N.N. BOGOLUBOW THEORETICAL PHYSICS LABORATORY OF JOINT INSTITUTE FOR NUCLEAR RESEARCH IN DUBNA.*



- 5.10.2000** Karol Życzkowski, CFT PAN  
*FRactal SOLUTIONS OF THE SCHRÖDINGER EQUATION.*
- 19.10.2000** Robert Smolańczuk, IPJ  
*SYNTHESIS OF ACTINIDES.*
- 2.11.2000** Stanisław L. Woronowicz, KMMF  
*QUANTUM SPACES.*
- 16.11.2000** Witold Bardyszewski, IFT UW  
*INFORMATICS AND TELECOMMUNICATION – PHYSICS OR TECHNOLOGY?  
NOBEL PRIZE IN PHYSICS 2000.*
- 14.12.2000** Jacek Dobaczewski, IFT UW  
*THE AMERICAN RARE ISOTOPE ACCELERATOR PROJECT.*
- 4.01.2001** Jacek Leliwa-Kopystyński, IG UW  
*SATELLITES OF HUGE PLANETS.*
- 18.01.2001** Iwo Białynicki-Birula, IFT UW  
*ON THE DYNAMICS OF VORTEX LINES IN QUANTUM MECHANICS.*
- 22.02.2001** Marek Zrałek, IF UŚ  
*CURRENT AND FUTURE ROLE OF NEUTRINOS.*
- 8.03.2001** Jerzy Lukierski, Uniwersytet Wrocławski  
*NON-ABELIAN GEOMETRIES IN THE THEORY OF FUNDAMENTAL INTER-  
ACTIONS.*
- 22.03.2001** Bogdan Lesyng, Uniwersytet Warszawski  
*MICROSCOPIC AND MESOSCOPIC DESCRIPTIONS OF BIOMOLECULAR  
PROCESSES.*
- 9.04.2001** Andrzej Staruszkiewicz, Uniwersytet Jagielloński  
*PHILOSOPHY OF TEORETICAL PHYSICS OF EINSTEIN AND DIRAC.*
- 19.04.2001** Krzysztof Haman, IG UW  
*WHAT IS GOING ON WITH THE CLIMATE?*
- 10.05.2001** Jasper Knoester, University of Groningen  
*COLLECTIVE NONLINEAR OPTICAL RESPONSE OF MOLECULAR ASSEM-  
BLIES: FROM PHOTOGRAPHY TO PHOTOSYNTHESIS.*
- 24.05.2001** Roman Micnas, Uniwersytet w Poznaniu  
*THEORETICAL ASPECTS OF HIGH TEMPERATURE SUPERCONDUCTIVITY.  
FROM BCS THEORY TO LOCAL PAIRS.*

## 6 SYMPOSIUM IFT UW-01

Symposium IFT UW-01 has been organized in the Institute on December 14–15, 2001. In the 9 lectures topics related to main research subjects and achievements in 2000–2001 of the Institute have been presented in a popular way to nonspecialists and students. The 3 additional talks presented topics of research carried out in two smaller units of the Faculty, the Institute of Geophysics, the Astronomical Observatory and the Chair of Mathematical Methods in Physics.

### PROGRAM OF THE SYMPOSIUM

#### Friday, December 14

##### Morning session

Chairperson: Andrzej Szymacha

- Bohdan Grządkowski, *Discrete Symmetries*
- Aleksy Bartnik, *Bound States in QCD*
- Adam Falkowski, *Extra Dimensions — XL size*
- Piotr Sołtan, *Multiplicative unitary operators in quantum group theory*

##### Afternoon session

Chairperson: Marek Napiórkowski

- Agnieszka Jaroń, *High-Harmonic Generation*
- Krzysztof Rejmer, *Adsorption on the corrugated substrate*
- Jerzy Krupski, *Electron mobility in semiconductor quantum wells*
- Konrad Bajer, *Dynamics of vortices and magnetic fields*

#### Saturday, December 15

##### Morning session

Chairperson: Wojciech Satuła

- Przemysław Olbratowski, *Spontaneous chiral symmetry breaking in rotational nuclei bands*
- Antoni Sym, Robert Prus, *Conformal geometry in pictures*

##### Afternoon session

Chairperson: Andrzej Trautman

- Jacek Tafel, *Gravitational Radiation*
- Michał Jaroszyński, *Gravitational Lenses*

### ABSTRACTS OF THE LECTURES

- **Bohdan Grzadkowski**, *Discrete Symmetries*

Time reversal (T), charge conjugation (C) and spatial reflection (P) were reviewed in the context of the theory of fundamental interactions. P and T were introduced at the classical level and C was defined through the invariance of the Dirac equation. Experimental evidence for violation of CP was discussed and the model of CP non-conservation embedded into the Standard Model of electroweak interactions was presented. The important role played by the top quark in searches for physics beyond the Standard Model was discussed focusing on the non-conservation of CP in top-quark interactions. Grand Unified Theories and the observed baryon asymmetry were considered in the context of non-conservation of CP.

- **Aleksy Bartnik**, *Bound States in QCD*

**Introduction:** QCD provides a standard description of hadron interactions. In situations where perturbative treatment is justified (high energies, large momentum transfer) it gives us very accurate predictions. However at low energies the running coupling constant becomes large precluding perturbative treatment. herefore the hadron spectrum is usually accounted for by phenomenological quark models and the only basic approach - lattice Monte Carlo simulations - gives relatively limited information. I propose a new method for computing *ab initio* bound states in QCD.

**The method:** For bound states calculations in gauge theories it is not only judicious to chose an appropriate reference system (CMS), but there exists a preferred gauge - the temporal gauge  $A^0 = 0$ . In this gauge one calculates easily the Hamiltonian density, which is given in terms od vector potentials only:

$$\mathcal{H} = \frac{\vec{E}^a \cdot \vec{E}^a}{2} + \frac{\vec{B}^a \cdot \vec{B}^a}{2} - \vec{j}_a \cdot \vec{A}^a,$$

Physical solutions have to fulfill the (non abelian) Gauss law

$$\vec{\nabla} \cdot \vec{E}^a + g f^{abc} \vec{A}^b \cdot \vec{E}^c = -4\pi \rho^a$$

The basic idea is to split gluon momenta into high momenta, where one can treat the theory perturbatively - one obtains the usual one gluon exchange potential, which is however applicable for high momentum transfer only. This is the usual Coulomb potential with modified long range behaviour. Low momenta are expanded in Fourier series. In position space this corresponds to an expansion in terms of sinc functions

$$\text{sinc}_n(x) = \sqrt{\frac{\Lambda}{\pi}} \frac{\sin(x - n\pi/\Lambda)}{x - n\pi/\Lambda}$$

which preserves locality in x-space. Sinc functions are localized and with a suitable choice of cutoff only one sinc function is appreciable in the region of the hadron.

Therefore only 24 (localized) gluons interact with quarks composing the hadron. As a first approximation we have then quarks interacting with 24 gluonic degrees of freedom, the gluons having additionally quartic interactions. Thus in the lowest order the problem can be solved numerically. This method has additionally a remarkable property - already in the lowest order the quarks are confined. Preliminary calculations are very encouraging.

- **Adam Falkowski**, *Extra Dimensions — XL size*

Everyday's experience suggests that our world has three spatial and one time-like dimensions. Einstein's theory of General Relativity treats all these dimensions as one geometrical object — the four-dimensional space-time. But already at the beginning of the 20th century T. Kaluza and O. Klein speculated that the space-time can have more than four dimensions. The fact, that the extra dimensions had not been observed was explained by compactification — extra dimensions were assumed to shrink to a very small size, of order  $10^{-33}$  cm, thus being unobservable to experiment. The idea of Kaluza and Klein has become popular with the birth of String Theories, which can be consistently formulated only in a ten-dimensional space-time. In recent years the interest has grown even more. It has been observed, that all experiments performed up-to-date do not exclude the possibility of quite large extra dimensions — even up to 1 millimeter length. The existence of large extra dimensions could also explain one of the puzzles of theoretical physics, namely, why gravity is so much weaker than the other three fundamental forces of nature (the so called hierarchy problem). If the idea of large extra dimensions is correct, we will discover them in the year 2007, when the LHC accelerator in CERN begins to operate.

- **Piotr Soltan**, *Multiplicative unitary operators in quantum group theory*

Following a short introduction to noncommutative geometry and quantum groups the definition of a multiplicative unitary operator is given. As the main example we consider the Kac-Takesaki operator of a locally compact group. Then we describe the class of manageable multiplicative unitary operators and present the main theorems of the theory of manageable multiplicative unitary operators. These show how to construct a quantum group from a multiplicative unitary operator. Several examples are studied including the multiplicative unitary operator related to the quantum 'az+b' group. This operator is not manageable, but it has a weaker property of being modular. Results saying that all theorems valid for the class of manageable multiplicative unitary operators hold for the larger class of modular ones are stated. This in particular gives a way to construct quantum 'az+b' group along the lines of the theory of multiplicative unitary operators.

- **Agnieszka Jaroń, Jerzy Z. Kamiński**, *High-Harmonic Generation*

High-harmonic generation (HHG) is a nonperturbative strong-laser-field phenomenon of numerous challenging applications, such as coherent control of atomic and molecular processes, attosecond pulses generation and coherent x-rays generation. Intense sub-10-fs, few-cycle laser pulses available nowadays allow for generation

of harmonics well beyond the 300th order (down to wavelengths approaching 2 nm) with a reasonable efficiency, representing the shortest wavelength coherent radiation demonstrated in the laboratory to date. Peak intensities feasible at these wavelengths hold promise for the extension of nonlinear optics into the x-ray regime and production of few-femtosecond or possible sub-femtosecond soft x-ray pulses.

Latest theoretical and experimental results obtained in the context of coherent control of HHG as well as relatively new field of research, namely study of HHG in molecular gases, clusters and solid surfaces are reported. Applications of HHG in chemistry, medicine and biology are presented with particular emphasis on recently performed experiments on coherent control and generation of attosecond pulses. Moreover various theoretical approaches developed to describe HHG are discussed. Since according to commonly accepted models HHG can be described as the multiphoton ionization (MPI) of an atomic electron followed by the laser-assisted-recombination (LAR) of this electron with the parent ion, main features of both MPI and LAR are also reported.

- **Krzysztof Rejmer**, *Adsorption on the corrugated substrate*

The particle of a fluid near a solid substrate interacts not only with other particles of a fluid but additionally with the particles of the substrate. Depending on both kind of interactions a layer of a quasi-liquid can appear on the substrate, even in such thermodynamical conditions that only a gas is a stable bulk phase. The substrate is not a thermodynamical phase in this problem, it is a spectator phase. The wetting transition occurs when the adsorbed film thickness changes between microscopic and macroscopic value. It is a surface phase transition, it means that the surface contribution to the Gibbs function contains a nonanalyticity. There is a few kind of wetting transitions. When changing temperature along the bulk coexistence line (but on its gas side) the adsorbed film of the macroscopic thickness appears at the specific value of the temperature (lower than the bulk critical temperature), called the wetting temperature. The wetting transition can be first-order (mostly in experiment) or continuous transition. The second case is known as the critical wetting due to the divergency of the parallel correlation length at the wetting temperature. When growing the chemical potential on the gas side of the bulk coexistence line (at the temperature constant but lower than the wetting temperature) towards the bulk coexistence line, the complete wetting appears. It is a continuous transition.

The simplest nonplanar geometry is the geometry of the wedge. Far from the center of a wedge the system becomes wet at the same temperature as for the totally planar substrate. This is accompanied by a new adsorption phenomenon called the filling transition. It is connected to the nonanalyticity of the line contribution to the Gibbs function. The thickness of the adsorbed film grows to the macroscopic value at the center of the wedge, while far from the center the film thickness remains microscopical. The filling transition occurs at the temperature lower than the wetting transition. This temperature depends on the opening angle of the wedge. The sharper wedge, the lower value of the filling temperature. Thus, there is a hierarchy

of temperatures connected to the different nonanalyticities of different contributions to the Gibbs function: the bulk critical temperature, the wetting temperature, and the filling temperature. The lower dimension connected to the aforementioned contribution to the Gibbs function, the lower value of the transition temperature. If the wetting temperature is significantly different than the tricritical one, the order of the filling transition of a wedge is the same as the order of the wetting transition.

In the case of two dimensional substrate in one direction periodically corrugated (and invariant in the second direction) the world of phase transitions is more complicated. The amplitude of the corrugation of the substrate plays an important role. When the wetting of the planar substrate is a first-order transition, the wetting of the same kind of a corrugated substrate is also a first-order transition, however it occurs at the lower temperature. In the case of critical wetting both, the order of the transition, and the transition temperature does not change. For a periodically corrugated substrate the filling transition appears as well. It consists on the adsorption of the quasi-liquid in the hollows of the substrate, what is accompanied by the nonanalyticity of the line contribution to the Gibbs function at a specific temperature. Its value depends on the corrugation amplitude of the substrate. The sinusoidally corrugated substrate was discussed in detail. When the corrugation amplitude of the substrate exceeds the threshold value, the corrugation induced first-order transition appears, even when the wetting transition is critical. The filling transition ends in its own critical point.

When the wetting is a first-order transition, additionally the prewetting transition appears both, for a planar, and for a corrugated substrate. It is an off-coexistence phenomenon. It consists on the finite jump of the adsorbed film thickness (between two microscopic values) on the gaseous side of the phase diagram. The prewetting line also ends in its critical point. For a corrugated substrate there is additionally a prefilling transition. Both are connected to the nonanalyticities of the surface and line contribution to the Gibbs function, respectively.

- **Jerzy Krupski**, *Electron mobility in semiconductor quantum wells*

The mobility, i.e. the quantity closely related to the conductivity is calculated for two dimensional electron gas in a quantum well at  $T=0$  K. It is assumed that the only mechanism which limits the mobility is that of impurity scattering. The conductivity and what follows the mobility are expressed in terms of Green's functions according to the Kubo formula and the diagrammatic techniques (Born and self-consistent Born approximations) are used to perform the calculations. Multi-subband effects are taken into account. The screening of the scattering potential is described with the help of random phase approximation.

It is shown within the present approximation how the discontinuities in the electron mobility predicted by the relatively simple method based on the Boltzmann equation and the relaxation time approximation are washed out due to the collisional broadening of the electronic energy levels.

Theoretical results are in an agreement with the experimental data for electrons in

the quantum well in the delta-doped GaAs.

- **Konrad Bajer**, *Dynamics of vortices and magnetic fields*

The flow of a viscous fluid is governed by the Navier-Stokes equation,

$$\frac{\partial \mathbf{u}}{\partial t} + \mathbf{u} \cdot \nabla \mathbf{u} = -\nabla p + \nu \nabla^2 \mathbf{u}, \quad \nabla \cdot \mathbf{u} = 0, \quad (1)$$

where  $\mathbf{u}(\mathbf{x}, t)$  is the velocity field,  $p(\mathbf{x}, t)$  is the pressure and  $\nu$  is the viscosity of the fluid. Taking rotation of both sides we obtain an equation describing the evolution of vorticity  $\boldsymbol{\omega}(\mathbf{x}, t) = \text{rot } \mathbf{u}$ ,

$$\frac{\partial \boldsymbol{\omega}}{\partial t} = \text{rot}(\mathbf{u} \times \boldsymbol{\omega}) + \nu \nabla^2 \boldsymbol{\omega}, \quad (2)$$

$$\mathbf{u} = \text{rot}^{-1} \boldsymbol{\omega}. \quad (3)$$

The non-linearity, due to the relation (3) between  $\mathbf{u}$  and  $\boldsymbol{\omega}$ , makes the equation (2) one of the most serious challenges of modern mathematics. The uniqueness and regularity of solutions, i.e., the question whether a singularity can develop in finite time from smooth initial conditions, is one of the *Millennium Problems* attracting a million dollar prize ([www.claymath.org/prizeproblems](http://www.claymath.org/prizeproblems)). The problem of turbulent flows governed by the equations (2) also remains unsolved to this day. Put simply we are unable to calculate, from first principles, the force exerted on a solid body by the viscous fluid sweeping past at high speed.

The evolution of the magnetic field in an electrically conducting fluid moving with velocity  $\mathbf{u}(\mathbf{x}, t)$ , much smaller than the speed of light, is described by the theory called *magnetohydrodynamics* (MHD) which is an approximation of electrodynamics of continuous media. When the field is weak, i.e., its energy  $B^2$  is much smaller than the kinetic energy of the fluid  $\frac{1}{2}\rho u^2$ , we can neglect the influence of the field on the fluid motion (Lorenz force). The evolution of the field is then governed by the *induction equation*,

$$\frac{\partial \mathbf{B}}{\partial t} = \text{rot}(\mathbf{u} \times \mathbf{B}) + \nu \nabla^2 \mathbf{B}. \quad (4)$$

This is identical to the vorticity equation (2) but the velocity  $\mathbf{u}$  is now *given* and is not related to  $\mathbf{B}$  so the problem is *linear*. This is the, so called, *kinematic problem* of MHD.

Exploring the analogies and differences between the equations (2a-b) and (3) is most inspiring and sheds light on both theories. In the vorticity fields of typical high-speed flows and in magnetic fields of MHD one finds analogous characteristic structures: vortex tubes and magnetic flux tubes; vortex sheets and magnetic flux sheets. Their dynamics is in many ways similar. Deeper insight into the kinematic MHD problem which, in spite of being linear, still leaves many open questions (e.g. the nature of the dynamo action) would be a big step forward on the path to

understanding turbulence.

BAJER, K. & MOFFATT, H. K. *Tubes, Sheets and Singularities in Fluid Dynamics*, Kluwer, 2002. [www.igf.fuw.edu.pl/IUTAM](http://www.igf.fuw.edu.pl/IUTAM)

- **Przemysław Olbratowski**, *Spontaneous chiral symmetry breaking in rotational nuclei bands*

From the times of Louis Pasteur it is known, that some molecules exist in two species being mirror images of each other. This is called *chirality* from the greek word  $\chi\epsilon\rho$  meaning *hand*, in analogy to the difference between the two hands.

It turns out, that some atomic nuclei may assume shapes of a triaxial ellipsoid. In such nuclei the valence protons often align their angular momenta along the shortest axis and the valence neutrons in the direction of the longest one. Moreover, if the nucleus rotates, the collective angular momentum is generated preferably along the intermediate axis. The system of three perpendicular vectors, created in this way, may be either left- or right-handed thus giving rise to the nuclear chirality.

Rotational bands built on the left and right configurations have very similar structures because neither of the two chiralities is marked out. So, characteristic doublets appear. Serious candidates for such doublets were recently observed in  $^{130}\text{Cs}$ ,  $^{132}\text{La}$ ,  $^{134}\text{Pr}$  and  $^{136}\text{Pm}$ . These observations provide a strong evidence for nuclear triaxiality and spontaneous chiral symmetry breaking.

The nuclear mean-field methods are a tool suitable for theoretical description of chiral rotation. So far, the calculations were performed with phenomenological fields, leading to a satisfactory agreement with experimental data. Nevertheless, for final verification and more profound understanding of the mechanisms underlying the chiral rotation application of selfconsistent methods is necessary. In these methods the nuclear mean field is derived from the effective nucleon-nucleon interaction.

First selfconsistent results for chiral rotation were obtained quite recently in the Division of Nuclear Structure Theory in our institute. These calculations employ the Hartree-Fock method with the Skyrme effective interaction. They confirm the existence of chiral-type solutions and allow us to establish some limits of angular momenta in which such solutions can appear.

- **Robert Prus, Antoni Sym**, *Conformal geometry in pictures*

According to Klein's definition: a "geometry" is defined as a study of invariants of a Lie group acting on a manifold equipped with some additional structure. Our lecture was devoted to some aspects of conformal geometry in  $S^3$  ( $E^3$ ). Firstly we discussed various conformal invariants (curvature parametrization, canal surfaces, Dupin's cyclides, Darboux cyclides and isothermic surfaces). Secondly we discussed the importance of such invariants both in non-linear (soliton) and linear mathematical physics. Some formal details of the lecture were illustrated by relevant pictures which has been produces within Mathematica aided by additional program (MathGL3d, BMRT and POVRAY).



- **Jacek Tafel**, *Gravitational Radiation*

In this lecture a short introduction to the Einstein theory of gravity was given with an emphasis on gravitational radiation. Theoretical description of gravitational waves becomes now important because the sensitivity of detectors under construction (LIGO, VIRGO) can be sufficient to observe such waves. The standard method is to consider the linear approximation of the Einstein equations and calculate higher order corrections. In this way one can even obtain information about a shape of gravitational pulses produced by massive objects in Universe e.g. by double stars. In the framework of the Einstein theory there are also exact solutions of the wave nature e.g. pp waves and the Robinson-Trautman solutions. Due to the research of Trautman, Bondi, Sachs, Penrose and others one also knows global properties of spacetime which admits gravitational radiation from bounded sources.

- **Michał Jaroszyński**, *Gravitational Lenses*

The deflection of light rays in gravitational field has been self consistently described within General Relativity and verified experimentally in astronomical observations. In certain conditions multiple images of the same source may be visible because of the deflection. The apparent shape of the resolved sources and their angular sizes may change. The observed flux of energy from a source may increase leading to its (usually) temporal apparent amplification. The luminosity changes of different images of the same source may be seen at different times. These are all effects of gravitational lensing.

A more detailed discussion of the possible influence of gravitational lensing on the shape of spectral lines will be given.

## 7 DIVISION OF FIELD THEORY AND STATISTICAL PHYSICS

**Head:** Marek Napiórkowski

**Academic staff:** Iwo Białynicki-Birula, Bogdan Cichocki, Jarosław Piasecki, Krzysztof Rejmer, Piotr Szymczak

**Postgraduate students:** 2

### SCIENTIFIC ACTIVITIES

- rigorous solutions of models of non-equilibrium statistical mechanics
- dynamic correlations induced by dissipative collisions
- theory of suspensions
- hydrodynamic interactions
- surface and interfacial phase transitions
- line tension effects
- effective interfacial Hamiltonians
- vortex lines in quantum mechanics
- new properties of the quantized electromagnetic field
- fractals in quantum mechanics

### SCIENTIFIC ACHIEVEMENTS

- The complete solution of the sticky gas dynamics, where perfectly inelastic collisions lead to the formation of mass aggregates (proving the equivalence of the problem to the Brownian motion in the presence of parabolic barriers, and also to the dynamics of shock waves in Burgers' turbulence).
- The derivation of the equations of the deterministic trajectory in a scaling limit of the dynamics of both microscopic and massive piston separating finite volumes of an ideal gas in a cylindrical container (rigorous solution in one dimension).
- The derivation of a non-Markovian kinetic equation governing the 2d motion of the Lorentz gas acted upon by a magnetic field perpendicular to the plane of motion in the Grad limit, the memory term resulting from recollisions (particles follow the cyclotron orbits).

- The expressions for long-time tails in the solid-body motion of a particle in suspension have been derived. Next on account of the fluctuation-dissipation theorem the long time tails of the velocity and angular velocity autocorrelation functions have been also found.
- An efficient algorithm for computing the many body hydrodynamic friction and mobility matrices describing the motion in a fluid of  $N$  hard spheres in the presence of a planar hard wall has been constructed.
- The problem of memory contribution to collective diffusion of interacting Brownian particles has been solved. A well-defined theoretical expression for the contribution has been derived. Its value has been numerically calculated for hard sphere suspension.
- The existence and order of the filling and wetting transitions accompanying adsorption on periodically corrugated substrate were analysed with the help of the effective Hamiltonian method. The influence of different types of substrate corrugation on the order of the wetting transition was examined.
- The height-height correlation function describing fluctuations of the interface in the wedge geometry close to the critical filling transition was obtained. The problem of uniqueness in constructing the propagator for the one-dimensional effective Hamiltonian describing interfacial fluctuations along the wedge-like substrate has been formulated and discussed.
- The phase diagram describing possible shapes of a non-volatile liquid drop placed in a cone-like substrate has been constructed. Both the surface and line tension effects have been taken into account.
- Wave functions in quantum theory may possess an elaborate and distinct vortex structure. Vortex lines move in an intricate manner as a result of the time evolution of the wave function. General characteristic of these motions has been given and various typical behaviors of the vortex lines were enumerated. The study of vortex lines has recently gained new impetus since their structure and motion is directly observable in the atomic systems that have undergone the Bose-Einstein condensation.
- Owing to their vanishing rest mass and relatively strong coupling to matter, photons have a special role to play in our understanding of the relation between quantum physics and classical physics. It has been shown that the quantum mechanics of photons may be derived by a straightforward canonical quantization of a (fictitious) point particle living in a  $4 \times 4$  dimensional phase space. In this study a special role is played by the conformal group — the largest symmetry group of Maxwell equations.

## PUBLICATIONS

1. *Ballistic aggregation: a solvable model of irreversible many particle dynamics*, L. Frachebourg, Ph.A. Martin, **J. Piasecki**, Physica A **279**, 69 (2000).
2. *A model of non-equilibrium statistical mechanics*, **J. Piasecki**, Ya.G. Sinai, Proceedings of the Advanced Study Institute on *Dynamics: Models and Kinetic Methods for Non-Equilibrium Many Body Systems*, Leiden, The Netherlands, 27 July – 8 August 1998, J. Karkheck, ed., NATO Science Series, Series E: Applied Sciences – Vol.371, pp.191-199 (Kluwer Academic Publishers, Dodrecht, 2000).
3. *Stationary states in systems with dissipative interactions*, **J. Piasecki**, Proceedings of the Advanced Study Institute on *Dynamics: Models and Kinetic Methods for Non-Equilibrium Many Body Systems*, Leiden, The Netherlands, 27 July – 8 August 1998, J. Karkheck, ed., NATO Science Series, Series E: Applied Sciences – Vol.371, pp.279-295 (Kluwer Academic Publishers, Dodrecht, 2000).
4. *Scaling dynamics of a massive piston in an ideal gas*, J.L. Lebowitz, **J. Piasecki**, Ya. Sinai, in *Hard ball systems and the Lorentz gas*, D. Szasz, ed., Series: Encyclopaedia of Mathematical Sciences, vol. 101, pp. 217-230 (Springer-Verlag Berlin/Heidelberg, 2000).
5. *Stochastic adiabatic wall*, **J. Piasecki**, J. Stat. Phys. **101**, 703 (2000).
6. *From the Liouville Equation to the Generalized Boltzmann Equation for Magnetotransport in the 2D Lorentz Model*, A.V. Bobylev, A. Hansen, **J. Piasecki**, E.H. Hauge, J. Stat. Phys. **102**, 1133 (2001).
7. *Precollisional velocity correlations in a hard-disk fluid with dissipative collisions*, R. Soto, **J. Piasecki**, M. Mareschal, Phys. Rev. E **64**, 031306 (2001).
8. *Drift velocity induced by collisions*, **J. Piasecki**, J. Stat. Phys. **104**, 1145 (2001).
9. *Stationary state of thermostated inelastic hard spheres*, T. Biben, Ph.A. Martin, **J. Piasecki**, Physica A (to appear, accepted for publication).
10. *Collisionless propagation in the Lorentz model: solution of the virtual BBGKY hierarchy*, F. Cornu, **J. Piasecki**, Physica A (to appear in 2002, accepted for publication).
11. *Interacting Brownian Particles*, **B. Cichocki**, in *Dynamics: Models and Kinetic Methods for Nonequilibrium Many Body Systems*, ed. J. Karkheck, Kluwer Academic Publishers, 2000, p.65.
12. *Friction and mobility for colloidal spheres in Stokes flow near a boundary: the multipole method and applications*, **B. Cichocki**, R.B. Jones, R. Kutteh, E. Wajnryb, J. Chem. Phys. **112**, 2548 (2000).
13. *Long-time tails in the solid-body motion of a sphere immersed in a suspension*, **B. Cichocki**, B.U. Felderhof, Phys. Rev. E **62**, 5383 (2000).
14. *Rotational velocity autocorrelation function of interacting Brownian particles*, **B. Cichocki**, B.U. Felderhof, Physica **289A**, 409 (2001).
15. *Comment on Response to Rotational velocity autocorrelation function of interacting Brownian particles*, **B. Cichocki**, B.U. Felderhof, Physica **297A**, 115 (2001).
16. *Three-particle contribution to sedimentation and collective diffusion in hard-sphere suspensions*, **B. Cichocki**, M.L. Ekiel-Jeżewska, **P. Szymczak**, E. Wajnryb, J. Chem. Phys. **117**, (2002).

17. *Effective boundary conditions for creeping flow along a periodic rough surface*, **B. Cichocki, P. Szymczak**, F. Feuillebois, in *Tubes, Sheets and Singularities in Fluid Dynamics* ed. K. Bajer and H.K. Moffatt, Kluwer, 2002.
18. *Adsorption on a periodically corrugated substrate*, **K. Rejmer, M. Napiórkowski**, Phys. Rev. **E62**, 588 (2000).
19. *The problem of uniqueness in the reduced description of adsorption on the wedge-shaped substrate*, **A. Bednorz, M. Napiórkowski**, J. Phys. A: Math. Gen. **33**, L353 (2000).
20. *Liquid drop in a cone — line tension effects*, **G.P. Kubalski, M. Napiórkowski**, J. Phys.: Cond. Matter **12** 9221 (2000).
21. *Interfacial fluctuations near the critical filling transition*, **A. Bednorz, M. Napiórkowski**, Phys. Rev. E **63**, 31602 (2001).
22. *Influence of substrate corrugation on wetting temperature*, **G.P. Kubalski, M. Napiórkowski, K. Rejmer**, J. Phys.: Cond. Matter **13** 4727 (2001).
23. *Filling transition on the corrugated substrate*, **K. Rejmer**, Phys. Rev. E, (to appear in 2002, accepted for publication).
24. *Motion of vortex lines in quantum mechanics*, **I. Białynicki-Birula**, Z. Białynicka-Birula, C. Śliwa, Phys. Rev. A **61**, 032110 (2000).
25. *The Wigner functional of the electromagnetic field*, **I. Białynicki-Birula**, Optics Communications **179**, 237 (2000).
26. *Time evolution of quantum fractals*, **I. Białynicki-Birula**, D. Wójcik, K. Życzkowski, Phys. Rev. Lett. **85**, 5022 (2000).
27. *Squeezing of electromagnetic field in a cavity by electrons in Trojan states*, P. Kocharński, **I. Białynicki-Birula**, Z. Białynicka-Birula, Phys. Rev. A **63**, 013811 (2001).
28. *Canonical quantization and the relativistic wave equations*, **I. Białynicki-Birula**, in *Quantization, Gauge Theory, and Strings*, Vol. II, Eds. A. Semikhatov, M. Vasiliev, and V. Zaikin, Scientific World, 2001, p. 9. 140.
29. *Lessons on time and on causality from quantum field theory*, **I. Białynicki-Birula**, in *Time's Arrows, Quantum Measurement and Superluminal Behavior*, Conference Proceedings, Napoli 2000, Istituto Italiano per gli Studi Filosofici, Napoli 2001.
30. *Motion of vortex lines in a model of nonlinear wave mechanics*, **I. Białynicki-Birula**, Z. Białynicka-Birula, Phys. Rev. A **65**, 014101 (2001).

## SCIENTIFIC DEGREES

### PH.D.

- P. Szymczak, *Memory Function for Collective Diffusion of Interacting Brownian Particles*  
supervisor B. Cichocki

### M.SC.

- A. Bednorz, *Correlation functions in systems with non-standard geometries*  
supervisor M. Napiórkowski

**GRANTS FOR RESEARCH PROJECTS****KBN GRANTS**

1. J. Piasecki, *Stationary states and scaling laws: effects of inelastic collisions*, 1999-2000.
2. B. Cichocki, *Dynamical scattering functions for interacting Brownian particle systems*, 1999-2001.
3. B. Cichocki, *Memory Function for Collective Diffusion of Interacting Brownian Particles*, 2001.

**POLLONIUM GRANTS**

1. J. Piasecki, *Non-equilibrium statistical mechanics of classical fluids*, 2002.
2. B. Cichocki, *Thermodynamics of dense plasma*, 2002.
3. B. Cichocki, *Hydrodynamic interactions between spherical particle and rough surface*, 2000-2001.

**FOUNDATION FOR POLISH-GERMAN COLLABORATION GRANTS**

1. M. Napiórkowski, *Wetting of geometrically inhomogeneous substrate; singularities in the related line tension*, 1998-2001.

## 8 DIVISION OF GENERAL RELATIVITY AND GRAVITATION

**Head:** Andrzej Trautman

**Academic staff:** Marek Demiański, Wojciech Kopczyński, Jerzy Lewandowski, Paweł Nurowski, Jacek Tafel

**Postgraduate students:** 7

### SCIENTIFIC ACTIVITIES

The scientific activity of the Division was concentrated around the following topics:

- Classical and quantum theory of gravitation,
- Cosmology and relativistic astrophysics,
- Gravitational waves and radiation
- Spinors, twistors and self-dual equations.

### SCIENTIFIC ACHIEVEMENTS

New results have been obtained by Lewandowski and his collaborators within the Ashtekar program of quantization of gravity. In particular, work was done on the relation between quantum geometry and the low-energy physics in Minkowski space-time. Lewandowski with his Ph. D. students found the state of quantum geometry that is the analog of the Fock vacuum.

Studying black holes defined in terms of an isolated horizon, a new hamiltonian formalism has been introduced. The zeroth and the first law of thermodynamics have been derived within this method, the quasi-local mass of an isolated horizon has been defined and all invariants of the exterior geometry of such a horizon have been determined. A necessary and sufficient condition has been found for the geometry of the isolated horizon to coincide with that of the Kerr metric, a result that may be applied in the numerical approach to physics of gravitation.

Einstein's equations for a gravitational field of type  $N$ , with a cosmological constant, have been maximally reduced and several examples of such fields have been presented; in particular, all metrics of this type, admitting 3 conformal Killing fields acting transitively on hypersurfaces have been explicitly determined.

The algebra of differential forms on a manifold has been extended, by Nurowski and his collaborators, by the adjunction of a form with a constant exterior derivative. This new formalism has been applied to writing Einstein's, Maxwell's and Klein-Gordon equations. The constant differential form generates terms analogous to the mass term appearing in the Proca equation.

Demiański, in collaboration with Doroshkevich, considered the conditions imposed on the topology of the locally flat Universe by the available cosmological observations,

such as the data on fluctuations of the temperature of the relict radiation. It follows from this study that, if the Universe is not simply connected, then the dimension of the fundamental cell cannot be smaller than the radius of the sphere of last scattering of photons on barionic matter.

Tafel and Szereszewski, his Ph. D. student, have studied the Rarita–Schwinger equation on Einstein spaces and found solutions of this equation on manifolds admitting a congruence of null geodesics without shear.

Trautman found the number of all inequivalent, double covers of the pseudo-orthogonal groups. It turns out that the Lorentz group has 16 and  $O(p, q)$ , for  $p$  and  $q > 1$ , has 32 such covers.

Robinson manifolds, generalizing the notion of space-times with a shear-free congruence of null geodesics, have been shown to be the Lorentzian analogs of Hermite manifolds. Their relation to Cauchy–Riemann spaces has been described in detail.

## PUBLICATIONS

1. *Formation of super large scale structure and large scale bias*, **M. Demiański**, A.G. Doroshkevich, *Astrophys. J.* **512** (1999) 527.
2. *Statistical characteristics of formation and evolution of structure in the universe*, **M. Demiański**, A.G. Doroshkevich, *Mon. Not. Roy. Astr. Soc.* **283** (1999) 1281.
3. *Diffeomorphism invariant quantum field theories of connections in terms of webs*, **J. Lewandowski**, T. Thiemann, *Class. Quantum Grav.* **16** (1999) 2299.
4. *Degenerate sectors of the Ashtekar gravity*, **J. Lewandowski**, J. Wiśniewski, *Class. Quantum Grav.* **16** (1999) 3057.
5. *Extensions of bundles of null directions*, **P. Nurowski**, L. Hughston, D. Robinson, *Class. Quantum Grav.* **16** (1999) 255.
6. *A four-dimensional example of a Ricci flat metric admitting almost-Kähler non-Kähler structure*, **P. Nurowski**, M. Przanowski, *Class. Quantum Grav.* **16** (1999) L9.
7. *Relativistic gravitational fields with close Newtonian analogs*, **P. Nurowski**, E. Schucking, **A. Trautman**, Ch. 23 in *On Einstein's Path*, ed. by A. Harvey, Springer-Verlag, New York 1999.
8. *On complex structures in physics*, **A. Trautman**, Ch. 34 in *On Einstein's Path*, ed. by A. Harvey, Springer-Verlag, New York 1999.
9. *Gauge and optical aspects of gravitation*, **A. Trautman**, *Class. Quantum Grav.* **16** (1999) A157.
10. *Space-Times Admitting Isolated Horizons*, **J. Lewandowski**, *Class. Quant. Grav.* **17** (2000) L53-L59.
11. *Isolated Horizons and their Applications*, A. Ashtekar, C. Beetle, O. Dreyer, S. Fairhurst, B. Krishnan, **J. Lewandowski**, J. Wiśniewski, *Phys. Rev. Lett.* **85** (2000) 3564.
12. *Mechanics of rotating isolated horizons*, A. Ashtekar, C. Beetle, **J. Lewandowski**, *Phys. Rev. D* **64** (2001) 044016.
13. *Bondi mass in terms of the Penrose conformal factor*, **J. Tafel**, *Class. Quantum Grav.* **17** (2000) 4397-4408.



14. *Relation between polymer and Fock excitations*, A. Ashtekar, **J. Lewandowski**, Class. Quantum Grav. **18** (2001) L117-L128.
15. *Non-vacuum twisting type N metrics*, **P. Nurowski**, J. Plebański, Class. Quantum Grav. **18** (2001) 341-351.
16. *Generalized exterior forms, geometry and space-time*, **P. Nurowski**, D.C. Robinson, Class. Quantum Grav. **18** (2001) L81-L86.
17. *Double covers of pseudo-orthogonal groups*, **A. Trautman**, pp. 377-388 in: *Clifford Analysis and its Applications*, ed. by F. Brackx et al., Kluwer Acad. Publ. Dordrecht 2001.
18. *Integrability of the Rarita-Schwinger equation* **A. Szereszewski**, **J. Tafel**, Class. Quantum Grav. **18** (2001) L129-L132.
19. *Robinson manifolds and Cauchy–Riemann spaces*, **A. Trautman**, Class. Quantum Grav. **19** (2002) R1–R10.
20. *A 2-surface quantization of the Lorentzian gravity*, **J. Lewandowski**, M. Bobieński, J.M. Mroczek, in: *Proceedings of the Ninth Marcel Grossmann Meeting on General Relativity*, ed. by R. T. Jantzen, V. Gurzadyan and R. Ruffini, World Scientific (Singapore 2002).

## WORKSHOPS AND CONFERENCES

- *Workshop on Canonical and Quantum Gravity III*, organized by J. Lewandowski at the Banach International Mathematical Centre in Warsaw, June 2001.

## SCIENTIFIC DEGREES

### M.SC.

- Michał Godliński, *The Cartan method and Sasakian structures*  
supervisor P. Nurowski
- Tomasz Pawłowski, *Axisymmetric type D isolated horizons*  
supervisor J. Lewandowski
- Jarosław Korbicz, *3+1 decomposition with respect to a null surface in spacetime*  
supervisor J. Tafel
- Adam Szereszewski, *Symmetry reduction of the Einstein equations*  
supervisor J. Tafel
- Monika Szymkowiak, *Nucleosynthesis of light elements in the early Universe*  
supervisor M. Demiański

**GRANTS FOR RESEARCH PROJECTS****KBN GRANTS**

- Mechanisms of formation and evolution of density perturbation and gravitational waves in open cosmological models, 1998-2001, (M. Demiański, J. Litwin)
- Classical and quantum theory of gravity and their geometrical methods, 1999-2002 (S. Bażański, W. Kopczyński, J. Lewandowski, P. Nurowski, J. Tafel, A. Trautman)

## 9 DIVISION FOR MATHEMATICAL AND COMPUTER PHYSICS

**Head:** Antoni Sym

**Academic staff:** Stanisław Bazański, Adam Doliwa, Maciej Pindor

### SCIENTIFIC ACTIVITIES

- Study of integrable geometries by means of spectral methods of soliton theory (A. Sym, P. Klimczewski and postgraduate students).
- Discrete integrable geometries vs discrete soliton systems (A. Doliwa, P. Klimczewski and postgraduate students).
- Various dynamical problems in the theory of relativity (S. Bazański).
- Rational approximations, in particular Pade approximants (M. Pindor).
- Klein geometries as roots of soliton theory (A. Sym, P. Klimczewski and postgraduate students).

### SCIENTIFIC ACHIEVEMENTS

Below we present only exemplary scientific achievements obtained by researchers of our group. Presentations is given according to classification of scientific activities of the Division.

- Ad. 1 (papers [1,2]). In general this subject contains two broad branches:
  - a) derivation of integrable geometry from underlying soliton system  
– and vice versa
  - b) derivation of soliton system from integrable geometry given in advance.

Both papers [1] and [2] belong to b)—branch. As is well known the theory of immersed  $n$ -dimensional Lobachevsky space into  $E^{2n-1}$  is an example of integrable geometry. In [1] and [2] for the first time the case of immersion of 2-dimensional Lobachevski space into  $E^4$  is discussed.

- Ad. 2 (papers [3-16]). All the papers by A. Doliwa (and his coworkers) cover a new and promising subject of the soliton theory: "discrete integrable geometries". The underlying idea is as follows: to lift the well known connections between classical differential geometry and integrable systems onto the level of a discrete geometry (and discrete integrable systems). The research project developed by A. Doliwa and his coworkers (from Rome, Madrid, Białystok and Warsaw) can be divided into three main branches.

- a) Discrete asymptotic nets as reductions of quadrilateral lattices and the study of the integrable case of the former.
- b) Applications of algebro–geometric techniques based on the theta–functions theory to explicit integration of Darboux equations and explicit construction of the corresponding nets.
- c) Construction and study of new integrable reductions of quadrilateral lattices.

In all these areas the authors obtained novel sometimes fundamental results. Probably the most important results obtained within a) are papers [13] and [14]. In particular, longstanding problem of integrable discretization of Bianchi system was solved in [14]. Another very important paper covering basic results of Doliwa group until 1998 is [3].

- Ad. 4 (papers [17-19]). The paper [19] contains important result within the Pade theory. The proposed construction of Pade approximants simultaneously enables one to formulate optimal error estimates in the most general case of investigated functions.
- Ad. 5 (papers [20-21]). The paper [21] gives another comprehensive introduction into conformal and projective roots of the modern soliton theory.

## PUBLICATIONS

1. *On Bianchi and Bäcklund Transformations of 2-dim Surfaces in  $E^4$* , Yu. Aminov, **A. Sym**, *Mathematical Physics, Analysis and Geometry* **3** (2000) n. 1, 75–89.
2. *On Bianchi and Bäcklund Transformations of Two-Dimensional Surfaces in Four-Dimensional Euclidian Space*, Yu. Aminov, **A. Sym**, in *Bäcklund and Darboux Transformations: The Geometry of Soliton Theory*, Halifax, 1999. *CMR Proceedings and Lecture Notes* **29**, pp. 91–93, AMS, Providence, 2001.
3. *Transformations of Quadrilateral Lattices*, **A. Doliwa**, P.M. Santini, M. Mañas, *J. Math. Phys.* **41** (2000) 944–990.
4. *The symmetric, D-invariant and Egorov reductions of the quadrilateral lattice*, **A. Doliwa**, P.M. Santini, *J. Geom. Phys.* **36** (2000) 60–102.
5. *Integrable Discrete Geometry: the Quadrilateral Lattice, its Transformations and Reductions*, **A. Doliwa**, P.M. Santini, in *SIDE III – Symmetries and Integrability of Difference Equations*, D. Levi, and O. Ragnisco (eds.), *CMR Proceedings and Lecture Notes*, Vol. 25, AMS, Providence, 2000 pp. 101–119.
6. *Integrable multidimensional discrete geometry: quadrilateral lattices, their transformations and reductions*, **A. Doliwa**, in *Integrable Hierarchies and Modern Physical Theories, Chicago 2000 NATO–ARW*, H. Aratyn i A.S. Sorin (eds.), pp. 355–389, Kluwer, Dordrecht, 2001.
7. *Lattice geometry of the Hirota equation*, **A. Doliwa**, in *SIDE III – Symmetries and Integrability of Difference Equations*, D. Levi and O. Ragnisco (eds.), *CMR Proceedings and Lecture Notes*, Vol. 25, AMS, Providence, 2000 pp. 93–100.

8. *Discrete asymptotic nets and  $W$ -congruences in Plücker line geometry*, **A. Doliwa**, *J. Geom. Phys.* **39** (2001) pp. 9–29.
9. *The Darboux-type transformations of integrable lattices*, **A. Doliwa**, *Rep. Math. Phys.* **48** (2001) pp. 59–66.
10. *Asymptotic Lattices and  $W$ -Congruences in Integrable Discrete Geometry*, **A. Doliwa**, *Journal of Nonlinear Mathematical Physics* **8** Supplement (2001) pp. 88–92.
11. *The Ribaucour congruences of spheres within Lie sphere geometry*, **A. Doliwa**, in *Bäcklund and Darboux Transformations: The Geometry of Soliton Theory, Halifax, 1999*, C. Rogers and P. Winternitz (eds.) *CMR Proceedings and Lecture Notes* **29** (2001), pp. 159–166, AMS, Providence.
12. *Integrable Multidimensional Discrete Geometry: Quadrilateral Lattices, their Transformations and Reductions*, **A. Doliwa**, *Integrable Hierarchies and Modern Physical Theories, Chicago 2000 NATO-ARW*, H. Aratyn (eds.), Kluwer.
13. *Asymptotic lattices and their integrable reductions I: the Bianchi and the Fubini-Ragazzi lattices*, **A. Doliwa**, M. Nieszporski, P.M. Santini, *J. Phys. A* **34** (2001) 10423–10439.
14. *The integrable discretization of the Bianchi-Ernst system*, **A. Doliwa**, M. Nieszporski, P.M. Santini, preprint `nlin.SI/0104065` (2001).
15. *Discrete asymptotic nets and  $W$ -congruences in Plücker line geometry*, **A. Doliwa**, *J. Geom. Phys.* **39** (2001), pp. 9–29.
16. *The Darboux-type transformations of integrable lattices.*, **A. Doliwa**, *Reports of Math. Phys.* **48** (2001), pp. 59–66.
17. prepr. CPT-2000/P.4038, J. Gilewicz, **M. Pindor**, J. Telega, S. Tokarzewski.
18. prepr. CPT-2001/P.4251 S. Tokarzewski, J. Telega, **M. Pindor**, J. Gilewicz.
19. *Optimal inequalities between contiguous two-point Pade approximant errors in the Stieltjes case*, J. Gilewicz, **M. Pindor**, lecture delivered by J. Gilewicz at *IV International Conference on Functional Analysis and Approximation Theory*, September 22–28, 2000.  
Remarks: Paper [17] *Continued fractions, two-point Pade Approximants and optimal estimates of error in the Stieltjes case* is published in *Journal of Computational and Applied Mathematics* **145** (2002), pp. 99–112.  
Results of [19] are published in *Supplemento del Circolo Matematico di Palermo* ser. 2 nr 68 (2002), pp. 455–466.
20. *Co starego w solitonach*, P. Klimczewski, **A. Sym**, *Postępy Fizyki* **51** (2000), zeszyt dodatkowy, pp. 85–87.
21. *Luigi Bianchi, Pasquale Calapso and solitons*, P. Klimczewski, M. Nieszporski, **A. Sym**, in *Proceedings of the International Convention of Differential Geometry in honour of Professor Pasquale Calapso* Messina, 12–14 October 1998 (edited 2001).

## 10 DIVISION OF NUCLEAR STRUCTURE THEORY

**Head:** Jacek Dobaczewski

**Academic staff:** Witold Nazarewicz<sup>1</sup>, Stanisław G. Rohoziński, Wojciech Satuła, Tomasz Werner

**Postgraduate students:** 1

### SCIENTIFIC ACTIVITIES

Scientific activities are focused on investigating the following main research subjects:

- Nuclear structure methods and models.
- Nuclei with large neutron or proton excess.
- Superheavy nuclei.
- Collective states.
- Nuclei with large deformations.
- Fast nuclear rotation.
- Pairing correlations in nuclei.

### SCIENTIFIC ACHIEVEMENTS

In 2000 and 2001, five members of the Division have published 40 papers in refereed periodicals (see the list below), and have presented 40 invited talks and 9 contributions at international conferences. During this period of time the following main research projects have been realized:

#### • NUCLEAR STRUCTURE METHODS AND MODELS

Paper [1] discusses the properties of the double point group (denoted  $D_{2h}^{TD}$ ) consisting of three mutually perpendicular symmetry axes of the second order, inversion, and time reversal. These properties are analysed in relation to the symmetry and symmetry-breaking effects within the mean-field (Hartree-Fock) theories, both in even and odd fermion systems. The paper provides a detailed description of space symmetries of local one-body densities, as well as the symmetries of electromagnetic moments, that appear when some or all of the  $D_{2h}^{TD}$  elements represent the symmetries obeyed by a nuclear system.

Paper [2] is a continuation of [1] and discusses breaking of symmetries that belong to the double point group  $D_{2h}^{TD}$ . Subgroup structure of the  $D_{2h}^{TD}$  group indicates that there can be as much as 28 physically different, broken-symmetry mean-field

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<sup>1</sup>on leave of absence

schemes — starting with solutions obeying all the symmetries of the  $D_{2h}^{TD}$  group, through 26 generic schemes in which only a non-trivial subgroup of  $D_{2h}^{TD}$  is conserved, down to solutions that break all of the  $D_{2h}^{TD}$  symmetries. Choices of single-particle bases and the corresponding structures of single-particle hermitian operators are analysed for several subgroups of  $D_{2h}^{TD}$ .

In Ref. [12] it was shown how to construct a basis in which two arbitrary complex antisymmetric matrices  $C$  and  $C'$  acquire simultaneously canonical forms. The construction is not restricted by any conditions on properties of the  $C^+C'$  matrix. Canonical bases pertaining to the generator-coordinate-method treatment of many-fermion systems were discussed.

Shell corrections of the finite deformed Woods-Saxon potential were calculated [22] using the Green's function method and the generalized Strutinsky smoothing procedure. They were compared with the results of the standard prescription which are affected by the spurious contribution from the unphysical particle gas. In the new method, the shell correction approaches the exact limit provided that the dimension of the single-particle (harmonic oscillator) basis is sufficiently large. For spherical potentials, the present method is faster than the exact one in which the contribution from the particle continuum states is explicitly calculated. For deformed potentials, the Green's function method offers a practical and reliable way of calculating shell corrections for weakly bound nuclei.

#### • PROPERTIES OF WEAKLY BOUND SYSTEMS

In Ref. [4] we introduced a local-scaling point transformation to allow for modifying the asymptotic properties of the deformed three-dimensional Cartesian harmonic oscillator wave functions. The resulting single-particle bases are very well suited for solving the Hartree-Fock-Bogoliubov equations for deformed drip-line nuclei. We also presented results of self-consistent calculations performed for the Mg isotopes and for light nuclei located near the two-neutron drip line. The results suggest that for all even-even elements with  $Z=10-18$  the most weakly-bound nucleus has an oblate ground-state shape.

Nuclei with large neutron-to-proton ratios have neutron skins, which manifest themselves in an excess of neutrons at distances greater than the radius of the proton distribution. In addition, some drip-line nuclei develop very extended halo structures. The neutron halo is a threshold effect; it appears when the valence neutrons occupy weakly bound orbits. In Ref. [6], nuclear skins and halos were analysed within the self-consistent Skyrme-Hartree-Fock-Bogoliubov and relativistic Hartree-Bogoliubov theories for spherical shapes. It was demonstrated that skins, halos, and surface thickness can be analysed in a model-independent way in terms of nucleonic density form factors. Such an analysis allows for defining a quantitative measure of the halo size. The systematic behavior of skins, halos, and surface thickness in even-even nuclei was discussed.

In Ref. [30] particle and pairing densities in spherical even-even neutron-rich nuclei were studied within the Skyrme-Hartree-Fock-Bogoliubov approach with the

density-dependent pairing interaction. The influence of the density dependence of the pairing interaction on asymptotic properties of nucleonic distributions were analysed. It was demonstrated that the size of the neutron halo dramatically depends on the behavior of the pairing interaction at low density.

In Ref. [31] the high-spin behavior of deformed neutron-rich nuclei was discussed. In particular, quasi-particle Routhian spectra of heavy Er isotopes were discussed within the deformed shell model, and rotational properties and isovector shape deformations of heavy Ne and Mg isotopes were studied with the self-consistent cranked Skyrme-Hartree-Fock theory. What is the response of the neutron drip-line nuclei, the large, diffused, and possibly superfluid many-body systems to rotation? Both the schematic and self-consistent calculations contained in this paper gave interesting insights to this question. On the one hand, the variation of the neutron shell structure with neutron number, mainly influencing the position of the high- $j$  unique-parity shell, is expected to modify the pattern of quasiparticle excitations in the rotating nucleus. On the other hand, since the Coriolis force mainly acts on the high- $j$  orbitals which are strongly localized within the nuclear volume because of the large centrifugal barrier, no strong isovector effects (due to neutron halo or skin) are expected at high spins. For instance, our unpaired calculations indicate that proton and neutron deformations are very similar at high rotational frequencies.

Life in nuclear “terra incognita” is different from that around the stability line; the promised access to completely new combinations of proton and neutron numbers offers prospects for new structural phenomena. The main objective of Ref. [37] was to discuss some of the challenges and opportunities for nuclear structure research with radioactive nuclear beams.

- **SUPER-HEAVY NUCLEI**

Shell corrections to the nuclear binding energy, as a measure of shell effects in superheavy nuclei, were studied within the self-consistent Skyrme-Hartree-Fock and relativistic mean-field theories. As a result of the presence of a low-lying proton continuum resulting in a free particle gas, special attention was paid to the treatment of the single-particle level density. To cure the pathological behavior of the shell correction around the particle threshold, in Ref. [8] a method based on the Green’s function approach has been adopted. It was demonstrated that for the vast majority of Skyrme interactions commonly employed in nuclear structure calculations, the strongest shell stabilization appears for  $Z = 124$  and  $126$ , and for  $N = 184$ . On the other hand, in the relativistic approaches the strongest spherical shell effect appears systematically for  $Z = 120$  and  $N = 172$ . This difference probably has its roots in the spin-orbit potential. We have also shown that, in contrast to shell corrections which are fairly independent of the force, macroscopic energies extracted from self-consistent calculations strongly depend on the actual force parametrization used. That is, the  $A$  and  $Z$  dependence of the mass surface when extrapolating to unknown superheavy nuclei is prone to significant theoretical uncertainties.



Two applications of mean-field calculations based on 3D coordinate-space techniques were presented in Ref. [16]. The first concerns the structure of odd- $N$  superheavy elements that have been recently observed experimentally and shows the ability of the method to describe, in a self-consistent way, very heavy odd-mass nuclei. Our results are consistent with the experimental data. The second application concerns the introduction of correlations beyond a mean-field approach by means of projection techniques and configuration mixing. Results for Mg isotopes demonstrate that the restoration of rotational symmetry plays a crucial role in the description of  $^{32}\text{Mg}$ .

Radii and diffuseness parameters of heavy and superheavy nuclei were in Ref. [28] analysed for spherical and axially deformed shapes within the Skyrme-Hartree-Fock+BCS theory with zero-range pairing force. The characteristics of self-consistent density distributions have been analysed using the generalized Helm model extended to the case of deformation.

In Ref. [40], quantum stabilization of superheavy elements was quantified in terms of the shell-correction energy. The shell correction was computed at spherical shape using self-consistent nuclear models: the non-relativistic Skyrme-Hartree-Fock approach and the relativistic mean-field model, for a number of parametrizations. All the forces applied predict a broad valley of shell stabilization around  $Z=120$  and  $N=17-184$ . Also two broad regions of shell stabilization in hyperheavy elements with  $N \simeq 258$  and  $N \simeq 308$  were predicted. Due to the large single-particle level density, shell corrections in the superheavy elements differ markedly from those in lighter nuclei. With increasing proton and neutron numbers, the regions of nuclei stabilized by shell effects become poorly localized in particle number, and the familiar pattern of shells separated by magic gaps is basically gone.

- **PROTON EMITTERS**

The coupled-channel Schrödinger equation with outgoing wave boundary conditions was employed [19] to study the fine structure seen in the proton decay of deformed even- $N$ , odd- $Z$  rare earth nuclei  $^{131}\text{Eu}$  and  $^{141}\text{Ho}$ . Experimental lifetimes and proton-decay branching ratios were reproduced and variations with the standard adiabatic theory were discussed.

The newly developed nonadiabatic method based on the coupled-channel Schrödinger equation with Gamow states was used [21] to study the phenomenon of proton radioactivity. The new method, adopting the weak coupling regime of the particle-plus-rotor model, allows for the inclusion of excitations in the daughter nucleus. This can lead to rather different predictions for lifetimes and branching ratios as compared to the standard adiabatic approximation corresponding to the strong coupling scheme. Calculations were performed for several experimentally seen, non-spherical nuclei beyond the proton dripline. By comparing theory and experiment, we were able to characterize the angular momentum content of the observed narrow resonance.

Theoretical approaches to deformed proton emitters were briefly reviewed in Ref. [36].

- **COLLECTIVE QUADRUPOLE EXCITATIONS**

Although the quadrupole character of the lowest collective excitations of even-even nuclei is well established, the microscopic calculations of the inertial parameters and potential of the collective quadrupole Hamiltonian (the Bohr Hamiltonian) have, in spite of many attempts of using different methods and different microscopic models, failed in reproducing quantitatively the experimental data. It seems that coupling the quadrupole degrees of freedom to the pairing vibrations would improve the theory of collective excitations. In Refs. [5,26] a "Pairing-Plus-Quadrupole" collective model was formulated. This is a generalization of the Bohr Hamiltonian in which the quadrupole and the pairing collective coordinates are treated on an equal footing. Thus, the proton and neutron energy gaps and gauge angles, apart from the quadrupole deformations and the Euler angles, are the dynamical variables in the model. In Ref. [26] the model was extended onto odd nuclei within a generalization of the core-quasiparticle coupling model. Some approximation scheme for investigation of only the quadrupole part of the quadrupole-pairing collective energy spectrum was also proposed [18]. It consists in finding the zero-point pairing vibration for every quadrupole deformation and then using the most probable energy gap in solving the Bohr Hamiltonian. In this approximation the collective spectra of Ru and Pd isotopes, and nuclei from the  $50 < Z, N < 82$  mass region have been earlier described and great improvement in reproducing experimental data has been achieved [5,26,18]. The same approximation scheme has been applied to description of the collective excitations in Gd and Er [20], and No and Fm isotopes [27]. Even for classical regions of deformed rare-earth and actinides nuclei, the effect of zero-point pairing vibration improves description of the rotational bands.

During the last years much theoretical and experimental work was devoted to the physics of  $K$ -isomers. In several Coulomb-excitation experiments surprisingly strong population of these states were observed in spite of that the transitions linking them to the ground state are forbidden due to the  $K$  number. A natural explanation is that the Coulomb excitation goes via some intermediate states, although these states are not yet identified. Paper [29] reported on Coulomb excitation of  $^{181}\text{Ta}$ , which is a relatively easy case, because the forbidness in question is not due to  $K$ , but to the asymptotic Nilsson numbers, and thus not so strong. It was possible, therefore, to observe the mediating states. Reduced transition probabilities were derived from the experimental data and it was calculated, that feeding through intermediate states was about fifty times more efficient than the direct way from the ground state. Comparison of the data with calculations within the Quasiparticle-Plus-Phonon model shows that the newly found states are one-phonon gamma-vibrational excitations.

- **SUPERDEFORMED STATES**

In Ref. [3] superdeformed configurations in  $^{32}\text{S}$ , and in neighboring nuclei  $^{33}\text{S}$ ,  $^{31}\text{S}$ ,  $^{33}\text{Cl}$ , and  $^{31}\text{P}$ , were determined within the Hartree-Fock approach with the Skyrme interaction. Energies, angular momenta, quadrupole moments, particle-emission  $Q$ -values, and relative alignments and quadrupole moments were calculated for a number of superdeformed rotational bands in these nuclei. A new mechanism implying an existence of signature-separated rotational bands, distinct from the well-known signature-split bands, was discussed and associated with the time-odd channels of effective interactions.

Structure of eight experimentally known superdeformed bands in the nucleus  $^{151}\text{Tb}$  was in Ref. [7] analysed using the results of the Hartree-Fock and Woods-Saxon cranking approaches. It was demonstrated that far going detailed similarities between the two approaches exist and predictions related to the structure of rotational bands calculated within the two models are nearly parallel. An interpretation scenario for the structure of the superdeformed bands was presented and predictions related to the exit spins were made. Small but systematic discrepancies between experiment and theory, analysed in terms of the dynamical moments,  $\mathcal{J}^{(2)}$ , were shown to exist. These discrepancies could be parametrized in terms of a scaling factor  $f$ , such that modifications  $\mathcal{J}^{(1),(2)} \rightarrow f\mathcal{J}^{(1),(2)}$  together with the implied scaling of the frequencies  $\omega \rightarrow f^{-1}\omega$ , correspond systematically better with the experimental data ( $f \simeq 0.9$ ) for both the Woods-Saxon and Hartree-Fock with Skyrme SkM\* interactions.

In Ref. [13] we described the new version (v1.75r) of the code HFODD which solves the nuclear Skyrme-Hartree-Fock problem by using the Cartesian deformed harmonic-oscillator basis. Three minor errors that went undetected in the previous version have been corrected. The new version contains an interface to the LAPACK subroutine ZHPEV. Several methods of terminating the Hartree-Fock iteration procedure, and an algorithm that allows to follow the diabatic configurations, have been implemented.

Three superdeformed bands were established in  $^{65}\text{Zn}$  using the  $^{40}\text{Ca}(^{29}\text{Si}, 4\text{p})^{65}\text{Zn}$  reaction, and the lifetimes were measured for two of the three bands [14]. The configurations of these bands were assigned based on the Hartree-Fock calculations. One of the three bands exhibits at low  $\hbar\omega$  a rise in the  $J^{(2)}$  dynamic moments of inertia that is similar to the alignment gain observed in  $^{60}\text{Zn}$ . A comparison of the superdeformed band configurations and their  $J^{(2)}$  dynamic moments of inertia for light Zn isotopes supports the suggestion that the rise in  $J^{(2)}$  may be related to the  $T=0$  pair correlations.

In Refs. [15,38], high-spin states in  $^{59}\text{Cu}$  and  $^{57}\text{Co}$ , respectively, were found by using the Gammasphere array in conjunction with ancillary detector systems that allowed for the identification of superdeformed rotational bands in these nuclei, which were firmly linked to low-spin yrast states. Using directional correlations of oriented states, a spin-parity assignments of the band heads were possible. The average quadrupole moments of the bands were measured. The characteristics of

the bands were compared to neighboring nuclei and predictions of different mean-field theories were analysed.

- **PROPERTIES OF ROTATIONAL BANDS**

In Ref. [9] the signature inversion in  $\pi h_{11/2} \otimes \nu h_{11/2}$  bands of Cs and La isotopes and in the  $\pi h_{11/2} \otimes \nu i_{13/2}$  bands of Tb, Ho and Tm nuclei was investigated using pairing and deformation selfconsistent total routhian surface (TRS) calculations. It was shown, that  $K$ -mixing due to  $(\lambda\mu)=(22)$  component of the double-stretched quadrupole pairing interaction to the mean-field can invert signature already at axially symmetric shape. Satisfactory agreement between calculations and experiment was reached.

It has been possible, using Gammasphere plus Microball, to extract differential lifetime measurements free from common systematic errors for over 15 different nuclei (various isotopes of Ce, Pr, Nd, Pm and Sm) at high spin within a single experiment. A comprehensive study [32] established the effective single-particle quadrupole moments in the  $A \sim 135$  light rare-earth region. Detailed comparisons were made with calculations using the self-consistent cranked mean-field theory.

In Ref. [34] rotational structures in  $N \sim Z \sim 40$  nuclei, calculated using the standard TRS model, were presented. It was shown, that the model involving only isovector pairing force reveals in  $N = Z$  nuclei certain shortcomings. It was argued that inclusion of isoscalar pairing may improve agreement to the data. In particular, the presence of such correlations can shift crossing frequencies [signature conserving isoscalar pairing mode] and enhance rigidity [signature breaking isoscalar pairing mode] of moment of inertia (MoI) at very high-spins.

- **PAIRING CORRELATIONS IN NUCLEI**

In Ref. [10] the pairing phenomenon in finite nuclei was briefly reviewed. Attention was paid to the effect of pairing correlations on odd-even staggering of binding energies and nuclear rotational motion. Basic concepts related to the proton-neutron pairing in  $N \approx Z$  nuclei were also briefly discussed.

In Ref. [11] a model including proton-neutron pairing and extension of Lipkin-Nogami approximate number projection to non-separable proton-neutron systems was presented. It was shown that the number projection allows for mixing of different pairing phases but, simultaneously, acts destructively on the proton-neutron correlations. An impact of isoscalar pairing on the binding energy was also analysed. It was shown that these correlations may provide a natural microscopic explanation of the Wigner energy, lacking in mean-field models. A possibility of phase transition from isovector to isoscalar phase at high angular momenta was discussed as well.

In Ref. [17] we discussed pairing correlations in weakly bound neutron rich nuclei, by using the coordinate-space Hartree-Fock-Bogolyubov approach which allows to take into account the coupling to particle continuum. We showed that the additional pairing binding energy acts against a development of an infinite rms radius

that characterizes standard  $\ell=0$  mean-field eigenfunctions in the limit of vanishing binding energy. As a result, neutron radii of even- $N$  nuclei do not diverge in the limit of vanishing Fermi energy. Only the broken-pair ground states of odd- $N$  nuclei can exhibit diverging neutron radii, provided an  $\ell=0$  (or 1) quasiparticle state appears near the Fermi surface. We also show that the pairing-increased (although not infinite) rms radii of even- $N$  nuclei result from the coupling to low-lying  $\ell=0$  continuum, which is always available for virtual pair excitations, independently of what are the angular momenta of least-bound single-particle levels.

In Ref. [23] odd-even staggering of binding energies in finite fermion systems with pairing correlations was discussed. The binding energy indicators which measure the magnitude of pairing correlations and the effective single-particle spacings in a given system were constructed and studied for several exactly solvable many-body Hamiltonians. Analytical formulas were derived that can be applied in the weak and strong pairing limits.

In Ref. [24] the concept of isospin cranked mean-field was introduced, and the response of various phases of pairing correlations to rotation in isospace was worked out in detail. In particular, it was shown that isoscalar pairing strongly reduces the MoI in isospace in a similar way as the isovector pairing reduces the spatial MoI. Moreover, the MoI undergoes a phase transition similar to the well-known Meissner effect in semiconductors. In turn, the  $T=2$  states in even-even nuclei which were calculated to be beyond the phase transition, were shifted up in energy in agreement with experimental data.

In Ref. [25] the isospin cranking model was extended to deal with the  $T=1$  excitations in even-even (e-e)  $N=Z$  nuclei and  $T=0$  and  $T=1$  states in odd-odd (o-o)  $N=Z$  nuclei. It was shown that the  $T=0$  states in o-o nuclei, and the  $T=1$  states in e-e nuclei must be treated as two-quasiparticle (2qp), time-reversal symmetry-breaking excitations to account for their angular momenta  $I \neq 0$ . On the other hand, the lowest  $T=2$  states in e-e nuclei, and the lowest  $T=1$  states in o-o nuclei are both 0qp type states, but excited in the isospace. This interpretation was found to be consistent with an interpretation of their isobaric analogue states.

In Ref. [33] various aspects and consequences of application of isoscalar-paired and isospin cranked model were overviewed. Among others such issues like: (i) the Wigner energy problem, (ii) the influence of shell-structure on the excitation energies of the lowest isobaric excitations, (iii) the influence of isovector pairing on the MoI in isospace (analytical discussion), and (iv) structure of the so called terminating states were discussed in detail.

- **INFLUENCE OF NUCLEAR STATES ON ATOMIC PROPERTIES**

In Ref. [35] the quadrupole and hexadecapole coupling constants for  $^{127}\text{I}$  in LiI were determined from relativistic Dirac-Fock electronic structure and self-consistent nuclear structure calculations. While the calculated quadrupole coupling constant agrees with the experimental value, the predicted hexadecapole coupling constant ranges between +6 and +20 mHz, which is of opposite sign and about three

orders of magnitude smaller than the value deduced from recent high resolution radio-frequency molecular beam measurements [J. Cederberg *et al.*, J. Chem. Phys. **110** (1999) 2431].

The nuclear quadrupole moment (NQM) of the  $I=3/2^-$  excited nuclear state of  $^{57}\text{Fe}$  at 14.41 keV, important in Mossbauer spectroscopy, was in Ref. [39] determined from the large-scale nuclear shell-model calculations for  $^{54}\text{Fe}$ ,  $^{57}\text{Fe}$ , and also from the electronic *ab initio* and density functional theory calculations including solid state and electron correlation effects for the molecules  $\text{Fe}(\text{CO})$  and  $\text{Fe}(\text{C}_5\text{H}_5)_2$ . Both independent methods yield very similar results. The recommended value is 0.15(2)eb. The NQM of the isomeric  $10^+$  in  $^{54}\text{Fe}$  has also been calculated. The new NQM values for  $^{54}\text{Fe}$  and  $^{57}\text{Fe}$  are consistent with the perturbed angular distribution data.

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38. *Rotational bands near  $^{56}\text{Ni}$* , W. Reviol, D.G. Sarantites, R.J. Charity, V. Tomov, D. Rudolph, R.M. Clark, M. Cromaz, P. Fallon, A.O. Macchiavelli, M.P. Carpenter, D. Seweryniak, **J. Dobaczewski**, Nucl. Phys. **A682** (2001) 28c
39. *Nuclear quadrupole moment of  $^{57}\text{Fe}$  from microscopic nuclear and atomic calculations*, G. Martínez-Pinedo, P. Schwerdtfeger, E. Caurier, K. Langanke, **W. Nazarewicz**, T. Söhnel, Phys. Rev. Lett. **87** (2001) 062701
40. *Shell stabilization of super- and hyperheavy nuclei without magic gaps*, M. Bender, **W. Nazarewicz**, P.-G. Reinhard, Phys. Lett. **B515** (2001) 42

## SCIENTIFIC DEGREES

### PH.D.

- Elżbieta Perlińska, *Self-consistent description of proton-neutron correlations in atomic nuclei*  
supervisor J. Dobaczewski

## GRANTS FOR RESEARCH PROJECTS

### KBN GRANTS

- Study of effective nuclear interactions via application of nuclear models and methods to the description of nuclear phenomena (1998–2000)



- Description of nuclear states in nuclei far from stability and nuclear states in rapidly rotating nuclei (2001–2003)
- Investigation of the collective properties of transitional nuclei (2000–2003)

**GRANTS OF THE POLISH-FRENCH COOPERATION POLONIUM:**

- Magnetic rotation of atomic nuclei and the associate quantum effects (2001–2002)

**GRANTS OF THE POLISH-WALLOON COOPERATION:**

- Mean-field description of nuclear states and excitations (2000–2002)

**ORGANIZED CONFERENCES**

**HIGH SPIN PHYSICS 2001**

Warsaw, February 6-10, 2001. Conference dedicated to the memory of Zdzisław Szymański.

## 11 DIVISION FOR THEORY OF PARTICLES & ELEMENTARY INTERACTIONS

**Head:** Stefan Pokorski

**Academic staff:** Zygmunt Ajduk, Jan Bartelski, Piotr Chankowski, Bohdan Grządkowski, Jan Kalinowski, Maria Krawczyk, Wojciech Królikowski, Zygmunt Lalak, Krzysztof Meissner, Mikołaj Misiak, Marek Olechowski, Jacek Pawełczyk, Janusz Rosiek

**Postgraduate students:** 12

### SCIENTIFIC ACTIVITIES

A broad spectrum of interests is represented, ranging from phenomenological studies within the scope of the Standard Model to formal aspects of extradimensional theories. Special emphasis is given to supersymmetric extensions of the Standard Model, unification scenarios, string theory, extra dimensions, supergravity, and the problem of fermion mass generations. The other topics include the structure of hadrons and photons, and substructure of quarks and leptons. Some members of our group are also actively involved in cosmological research.

### SCIENTIFIC ACHIEVEMENTS

The research conducted in the Division for Theory of Particles and Elementary Interactions during the two year period 2000-2001 has been mainly focussed on physics beyond the Standard Model. The major part of altogether 100 publications is devoted to various aspects of supersymmetric and extradimensional theories.

Minimal supersymmetric extension of the Standard Model (MSSM) provides a well defined theoretical framework for studying low energy effective supersymmetry as a (still hypothetical) fundamental symmetry of Nature. One should stress that experimental search for supersymmetry is the main goal for future accelerators. A number of papers has been published by the members of our Division which provide a very systematic study of the phenomenological aspects of the low energy supersymmetry. The papers by Chankowski et al. give the complete picture of the potential supersymmetric effects in the flavour changing neutral currents and, vice versa, of the impact of the present experimental data on our ideas about low energy supersymmetry. The papers by Misiak et al. concentrate on the next-to-leading QCD corrections to some of the flavour changing neutral current processes (e.g.  $b \rightarrow s\gamma$ ) and of a systematic study of such processes in the MSSM. Potential new sources of CP violation in the MSSM have been studied by Pokorski et al. Both groups of papers belong now to classic literature on the subject and the summary of the results has also been published as contributions to some books.

A crucial issue for physics beyond the Standard Model is the existence of a Higgs boson(s) and its (their) properties. A number of papers has been published on the properties of the Higgs sector in the Standard Model and beyond (Chankowski et al., Kalinowski et al., Krawczyk et al.). The results are important for experimental groups. Several of the

explored ideas have been earlier pioneered by our group (e.g. the large  $\tan\beta$  scenario in the MSSM and the search for the Higgs boson in bremsstrahlung-like processes). Kalinowski et al. devoted a number of papers to study the sensitivity of future experiments to the parameter space of the MSSM. Search for new physics in the top quark and Higgs sector is the subject of several interesting papers by Grzadkowski et al. In particular the possibility of the CP violating effects in those sectors has been thoroughly investigated.

The discovery of neutrino masses and mixing is the first experimental signal of physics beyond the Standard Model. Very important papers on quantum corrections to neutrino masses (Chankowski et al.) and their link to flavour changing in the lepton sector (Pokorski et al.) have been published by members of the Division. The potential role of sterile neutrinos has been extensively studied by Królikowski.

On the more theoretical side, novel ideas have been proposed for the physics of extra dimensions and brane models (Falkowski, Lalak, Pawełczyk, Pokorski). In particular, the supersymmetric version of the Randall-Sundrum warped geometry has been constructed (Falkowski et al.) and investigated in some detail. A new interpretation of gauge theories in extra dimensions has been proposed by Pokorski et al. In that approach the physics of extra dimensions is obtained in four-dimensional theories with more gauge symmetry. This approach known now as latticized or deconstructed extra dimensions opens up totally new avenues for physics beyond the Standard Model.

Particle physics, and particularly physics at the Planck scale, is strongly linked to cosmological and astrophysical questions. Physics beyond the Standard Model so intensively investigated by our group cannot avoid this link. Lalak et al., Olechowski et al., Meissner et al. devoted important part of their research to study the interface of particle physics and cosmology. Among the most important results one should mention the results on the problem of the cosmological constant.

The research topics of our group include also some aspects of strong interaction physics. Bartelski et al. have several interesting results on the polarized nucleon structure functions. The important issue of the photon structure functions has been discussed in a number of papers by Krawczyk et al. This subject is topical due to the new generation of deep inelastic experiments at HERA (DESY).

## PUBLICATIONS

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2. *Polarized Parton Densities from the Fits to the Deep Inelastic Spin Asymmetries on Nucleons*, **J. Bartelski**, S. Tatur, Acta Physica Polonica **B32**, 2101 - 2114 (2001)
3. *Do Precision Electroweak Constraints Guarantee  $e^+e^-$  Collider Discovery of at Least One Higgs Boson of a Two-Higgs-Doublet Model?*, **P. Chankowski**, T. Farris, **B. Grzadkowski**, J.F. Gunion, **J. Kalinowski**, **M. Krawczyk**, Physics Letters **B496**, 195-205 (2000)
4. *Report of the SUGRA Working Group for Run II of the Tevatron*, **P. Chankowski**, **S. Pokorski**, V. Barger et al., (2000)

5. *Fixed Points in the Evolution of Neutrino Mixings*, **P. Chankowski**, **W. Królikowski**, **S. Pokorski**, Physics Letters **B473**, 109-117 (2000)
6. *TESLA Technical Design Report. pt. 3: Physics at an  $e^+e^-$  Linear Collider*, **P. Chankowski**, **B. Grzadkowski**, **P. Jankowski**, **J. Kalinowski**, **M. Krawczyk**, **J. Żochowski** et al., DESY-2001-011 (2001)
7.  $\Delta M_s/\Delta M_d$ ,  $\sin 2\beta$  and the Angle  $\gamma$  in the Presence of New  $\Delta F = 2$  Operators, **P. Chankowski**, **J. Rosiek**, **Ł. Ślawianowska**, A. Buras, Nuclear Physics **B619**, 434 - 466 (2001)
8. *Neutrino Unification*, **P. Chankowski**, A. Ioannissian, **S. Pokorski**, J.W.F. Valle, Phys. Rev. Letters **86**, 3488-3491 (2001)
9. *Leptonic Decays of  $B_0(d,s)$  Mesons in the MSSM with Large  $\tan\beta$* , **P. Chankowski**, **Ł. Ślawianowska**, Acta Physica Polonica **B32**, 1895 - 1907 (2001)
10.  $B_{d,s}^0 \rightarrow \mu^+\mu^-$  in the MSSM, **P. Chankowski**, **Ł. Ślawianowska**, Phys. Rev. **D63**, 054012 (2001)
11. *Supersymmetric Warped Brane Worlds*, **A. Falkowski**, Proc. of the Int. Europ. Conf. on HEP, Budapest, (2001)
12. *Testing CP Violation in the Higgs Sector at Muon Colliders*, **B. Grzadkowski**, Proceedings of 35th Rencontres de Moriond: Electroweak Interactions and Unified Theories, Les Arcs (2000)
13. *Optimal Observable Analysis of the Angular and Energy Distributions for Top Quark Decay Products at Polarized Linear Colliders*, **B. Grzadkowski**, Z. Hioki, Nuclear Physics **B585**, 3-27 (2000)
14. *Extra Dimension Kaluza-Klein Excitations and Electroweak Symmetry Breaking*, **B. Grzadkowski**, J.F. Gunion, Proceedings of PASCOS 99, Granlibakken, Tahoe City, 1999 (2000)
15. *Measuring the Relative CP Even and CP Odd Yukawa Couplings of a Higgs Boson at a Muon Collider Higgs Factory*, **B. Grzadkowski**, **J. Pliszka**, J.F. Gunion, Proceedings of PASCOS 99, Granlibakken, Tahoe City, 1999 (2000)
16. *Signals of CP Violation in Distributions of Top-Quark Decay Products at Linear Colliders*, **B. Grzadkowski**, Z. Hioki, Proceedings of PASCOS 99, Granlibakken, Tahoe City, 1999 (2000)
17. *How Valuable Is Polarization at a Muon collider? A Test Case: Determining the CP Nature of a Higgs Boson*, **B. Grzadkowski**, **J. Pliszka**, J.F. Gunion, Nucl. Phys. **B583**, 49-75 (2000)
18. *Probing Top Quark Couplings at Polarized NLC*, **B. Grzadkowski**, Z. Hioki, Phys. Rev. **D61**, 014013 (2000)
19. *Search Strategies for Non-Standard Higgs Bosons at Future  $e^+e^-$  Colliders*, **B. Grzadkowski**, **J. Kalinowski**, J.F. Gunion, Phys. Lett. **B480**, 287-295 (2000)
20. *New Hints for Testing Anomalous Top Quark Interactions at Future Linear Colliders*, **B. Grzadkowski**, Z. Hioki, Phys. Lett. **B476**, 87-94 (2000)
21. *Kaluza-Klein Excitations and Electroweak Symmetry Breaking*, **B. Grzadkowski**, J.F. Gunion, Phys. Lett. **B473**, 50-60 (2000)
22. *Triviality and Vacuum Stability Bounds on the Higgs-Boson Mass beyond the Standard Model*, **B. Grzadkowski**, J. Wudka, Acta Physica Polonica **B32**, 3769-3782 (2001)

23. *CP Violation in Higgs Boson Interactions*, **B. Grzadkowski, J. Pliszka**, Acta Physica Polonica **B32**, 1919 - 1934 (2001)
24. *Testing Scalar Sector CP Violation in Top Quark Production and Decay at Linear  $e^+e^-$  Colliders*, **B. Grzadkowski, J. Pliszka**, Physical Review **D63**, 115010 (2001)
25. *Heavy Quark Production at a Linear  $e^+e^-$  and Photon Collider and Its Sensitivity to the Gluon Content of the Photon*, **P. Jankowski, M. Krawczyk**, A. De Roeck, Proceedings of Workshop on the Development of Future Linear Electron-Positron Colliders for Particle Physics Studies and for Research Using Free Electron Lasers, Lund, Sweden, 23-26 Sep 1999 (2000)
26. *Search Strategies for Non-Standard Higgses at  $e^+e^-$  Colliders*, **J. Kalinowski**, Proceedings ICHEP'2000, Osaka (2000)
27. *Reconstruction of the Chargino Parameters*, **J. Kalinowski**, Proceedings of Granlibakken Workshop (2000)
28. *Measuring the Chargino Parameters*, **J. Kalinowski**, Pramana **55**, 259-264 (2000)
29. *The Higgs Working Group: Summary Report*, **J. Kalinowski**, A. Djouadi et al., Proceedings of Workshop on Physics at TeV Colliders, Les Houches, June 1999 (2000)
30. *Chargino Pair Production at  $e^+e^-$  Colliders with Polarized Beams*, **J. Kalinowski**, S.Y. Choi, M. Guchait, P.M. Zerwas, Phys. Lett. **B479**, 235-244 (2000)
31. *Reconstructing the Chargino System at  $e^+e^-$  Linear Colliders*, **J. Kalinowski**, S.Y. Choi, A. Djouadi, M. Guchait, H.S. Song, P.M. Zerwas, Eur. Phys. J. **C14**, 535-546 (2000)
32. *Report of the beyond the Standard Model Working Group of the 1999 UK Phenomenology Workshop on Collider Physics (Durham)*, **J. Kalinowski** et al., J. Phys. **G26**, 551-592 (2000)
33. *Library of SM and Anomalous  $WW\gamma$  Couplings for the  $e^+e^- \rightarrow f\bar{f}n\gamma$  Monte Carlo Programs*, **J. Kalinowski**, A. Jacholkowska, Z. Was, Comput. Phys. Commun. **124**, 238-242 (2000)
34. *Supersymmetric Lepton Flavour Violation at  $e^+e^-$  Linear Colliders*, **J. Kalinowski**, Acta Physica Polonica **B32**, 3755-3768 (2001)
35. *Analysis of the Neutralino System in Supersymmetric Theories*, **J. Kalinowski**, S.Y. Choi, G. Moortgat-Pick, P.M. Zerwas, Eur. Phys. J., **C22**, 563-579 (2001)
36. *Linear Collider Physics Resource Book for Snowmass 2001: Introduction, Higgs and Supersymmetry Studies, Studies of Exotic and Standard Model Physics, Theoretical, Accelerator, and Experimental Options*, **J. Kalinowski**, T. Abe et al., resource book (2001)
37. *Supersymmetric Lepton Flavor Violation in a Linear Collider: the Role of Charginos*, **J. Kalinowski**, M. Guchait, P. Roy, Eur. Phys. J. **C21**, 163 - 169 (2001)
38. *Reconstructing the chargino/neutralino system at  $e^+e^-$  colliders*, **J. Kalinowski**, Proceedings of Rencontres du Vietnam '2000 (2001)
39. *Phenomenology of the Chargino and Neutralino Systems*, **J. Kalinowski**, Proceedings of Int. Linear Collider Workshop '2000, Batavia, 434 - 438 (2001)
40. *Structure Functions for the Virtual and Real Photons*, **M. Krawczyk**, Proceedings of PHOTON'2000, Ambleside 2000, (2000)
41. *Parametrisation of  $F_\gamma^2$  at Low  $Q^2$  and of  $\sigma(\gamma, \gamma)$  and  $\sigma(\gamma^*, \gamma)$  at High Energies*, **M. Krawczyk**, B. Badelek, J. Kwieciński, A.M. Stasto, Phys. Rev. **D62**, 074021 (2000)

42. *The Forward Photon Production and the Gluonic Content of the Real and Virtual Photon at the HERA Collider*, **M. Krawczyk, A. Zembrzusi**, Nucl. Phys. Proc. Suppl. **82**, 167-172 (2000)
43. *Distinguishing Higgs Models at Photon Colliders*, **M. Krawczyk**, I.F. Ginzburg, P. Osland, Proceedings of World-Wide Study of Physics and Detectors for Future Colliders, Sitges 1999, p. 524-528, Universitat Autònoma de Barcelona (2000)
44. *A Model of  $F_\gamma^2$  at arbitrary  $Q^2$  and the Total Photon Photon Cross-Sections at High Energies*, **M. Krawczyk**, B. Badełek, J. Kwieciński, A.M. Stasto, Nucl. Instrum. Meth. **A472**, 222-228 (2001)
45. *Charm Production at Linear  $e^+e^-$  and Photon collider and its Sensitivity to the Gluon Content of the Photon*, **M. Krawczyk, P. Jankowski**, A. De Roeck, Nucl. Instrum. Meth. **A472**, 212-216 (2001)
46. *Photoproduction of the Isolated Photon at HERA in Next-to-Leading Order QCD*, **M. Krawczyk, A. Zembrzusi**, Phys. Rev. **D64**, 114017 (2001)
47. *TESLA: The Superconducting Electron Positron Linear Collider with an Integrated X-ray Laser Laboratory. Technical Design Report. pt. 6: Appendices. Chapter 1: The Photon Collider at TESLA*, **M. Krawczyk** et al., report DESY-TESLA (2001)
48. *TESLA: The Superconducting Electron Positron Linear Collider with an Integrated X-ray Laser Laboratory. Technical Design Report. pt. 6: Appendices. Chapter 2: THERA: Electron Proton Scattering at  $s^{*}(1/2)$  Approx. 1-TEV*, **M. Krawczyk** et al., report DESY-TESLA (2001)
49. *Standard Model-like Scenarios in the 2HDM and Photon Collider Potential*, **M. Krawczyk**, I. Ginzburg, P. Osland, Proceedings of 5th International Linear Collider Workshop, Batavia, October 2000, 304 - 311 (2001)
50. *Potential of photon collider in resolving SM like scenarios*, **M. Krawczyk**, I. Ginzburg, P. Osland, Nucl. Instrum. Meth. **A472**, 149 - 154 (2001)
51. *Resolving SM-like scenarios via Higgs boson production at photon collider: I. 2HDM versus SM*, **M. Krawczyk**, I. Ginzburg, P. Osland, Proc. of 2nd ECFA/DESY Study 1998-2001, 1705 - 1733 (2001)
52. *Survey of present data on photon structure function and resolved photon processes*, **M. Krawczyk, A. Zembrzusi**, M. Staszal, Physics Reports **345**, 265-450 (2001)
53. *The Light Higgs Window in the 2HDM at GigaZ*, **M. Krawczyk, J. Żochowski**, P. Mättig, European Physical Journal **C19**, 463-469 (2001)
54. *Two Sterile Neutrinos as a Consequence of Matter Structure*, **W. Królikowski**, Acta Physica Polonica **B31**, 1913 - 1930 (2000)
55. *A Four-Neutrino Texture Implying Bimaximal Flavor Mixing and Reduced LSND Effect*, **W. Królikowski**, Acta Physica Polonica **B31**, 1759-1765 (2000)
56. *An Unorthodox Alternative for Righthanded Neutrinos: Lefthanded Seesaw*, **W. Królikowski**, Acta Physica Polonica **B31**, 673-679 (2000)
57. *Option of Three PseudoDirac Neutrinos*, **W. Królikowski**, Acta Physica Polonica **B31**, 663-672 (2000)
58. *An Effective Model for Quark Masses and Mixings*, **W. Królikowski**, Acta Physica Polonica **B32**, 2961-2980 (2001)

59. *Toward Neutrino Texture Dominated by Majorana Lefthanded Mass Matrix*, **W. Królikowski**, Acta Physica Polonica **B32**, 2129 - 2142 (2001)
60. *Possible LSND effect as a small perturbation of the bimaximal texture for three active neutrinos*, **W. Królikowski**, Acta Physica Polonica **B32**, 1245 - 1252 (2001)
61. *An Alternative: Two Mixing Texture for Three Neutrinos or Three Mixing Texture for Four Neutrinos*, **W. Królikowski**, Acta Physica Polonica **B32**, 75-84 (2001)
62. *Supersymmetry Breaking in M Theory*, **Z. Lalak**, Proceedings of the Trieste Meeting of the TNMR Network on Physics beyond the SM (2000)
63. *The Cosmological Constant Problem from a Brane World Perspective*, **Z. Lalak**, S. Forste, S. Lavignac, H.P. Nilles, JHEP **0009**, 034 (2000)
64. *Supersymmetrizing Branes with Bulk in Five-Dimensional Supergravity*, **Z. Lalak**, **A. Falkowski**, **S. Pokorski**, Physics Letters **B491**, 172-182 (2000)
65. *A Comment on Selftuning and Vanishing Cosmological Constant in the Brane World*, **Z. Lalak**, S. Forste, S. Lavignac, H.P. Nilles, Phys. Lett. **B481**, 360-364 (2000)
66. *Scales of Gaugino Condensation and Supersymmetry Breaking in Nonstandard M Theory Embeddings*, **Z. Lalak**, S. Thomas, Nuclear Physics **B575**, 151 - 176 (2000)
67. *Target-Space Duality in Heterotic and Type I Effective Lagrangians*, **Z. Lalak**, S. Lavignac, H.P. Nilles, Nuclear Physics **B576**, 399-429 (2000)
68. *Boundary Terms in Brane Worlds*, **Z. Lalak**, **R. Matyszkiewicz**, JHEP **0111**, 027 (2001)
69. *Supersymmetry in Five-Dimensional Brane Worlds*, **Z. Lalak**, New developments in fundamental interaction theories: 37th Karpacz Winter School of Theoretical Physics (2001), AIP Conference Proceedings **589**, 84-97, AIP Melville (2001)
70. *Non-BPS Branes of Supersymmetric Brane Worlds*, **Z. Lalak**, **A. Falkowski**, P. Brax, Physics Letters **B521**, 105 - 113 (2001)
71. *Supersymmetry and Vacuum Energy in Five Dimensional Brane Worlds*, **Z. Lalak**, Nucl. Phys. Proc. Suppl. **101**, 366 - 374 (2001)
72. *Four Dimensional Supergravities from Five Dimensional Brane Worlds*, **Z. Lalak**, **A. Falkowski**, **S. Pokorski**, Nucl. Phys. **B613**, 189 - 217 (2001)
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74. *Anomaly Cancellation in M Theory on Orbifolds*, **K. Meissner**, **M. Olechowski**, Nuclear Physics **B590**, 161-172 (2000)
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76. *Domain Walls without Cosmological Constant in Higher Order Gravity*, **K. Meissner**, **M. Olechowski**, Physical Review Letters **86**, 3708-3711 (2001)
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87. *Quark Mass Effects in  $\bar{B} \rightarrow X_s\gamma$* , **M. Misiak**, P. Gambino, Nucl. Phys. **B611**, 338 - 366 (2001)
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90. *Matrix Model for Yang-Mills Interactions*, **J. Pawelczyk**, JHEP **0002**, 038 (2000)
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95. *Physics of Extra Dimensions as IR Limit of Four-Dimensional Theories*, **S. Pokorski**, J. Phys. **G27**, 2479 - 2484 (2001)
96. *The Standard Model in the Latticized Bulk*, **S. Pokorski**, Hsin-Chia Cheng, Christopher T. Hill, Jing Wang, Phys. Rev. **D64**, 065007 (2001)
97. *Gauge Invariant Effective Lagrangian for Kaluza-Klein Modes*, **S. Pokorski**, Christopher T. Hill, Jing Wang, Phys. Rev. **D64**, 105005 (2001)
98. *Brane effects on extra dimensional scenarios: A tale of two gravitons*, **S. Pokorski**, M. Carena, A. Delgado, J. Lykken, M. Quiros, C.E.M. Wagner, Nucl. Phys. **B609**, 499 - 517 (2001)
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100. *Neutral MSSM Higgs Boson Production at  $e^+e^-$  Colliders in the Feynman-Diagrammatic Approach*, J. Rosiek, S. Heinemeyer, W. Hollik, G. Weiglein, Eur. Phys. J. **C19**, 535-546 (2001)

## SCIENTIFIC DEGREES

### D.SC.

- Janusz Rosiek, *Procesy naruszenia zapachu i symetrii CP w Minimalnym Rozszerzeniu Modelu Standardowego (Processes with Violation of Flavour and CP in the Minimal Extension of the Standard Model)*

### PH.D.

- Mirosław Kurzela, *Badanie struktury spinowej nukleonu (Study on Spin Structure of a Nucleon)*  
supervisor: J. Bartelski
- Jacek Pliszka, *Non-Standard Higgs-Boson Interactions at Future Colliders*  
supervisor: B. Grzadkowski

### M.SC.

- Adam Falkowski, *Five-Dimensional Locally Supersymmetric Theories with Branes*  
supervisor S. Pokorski
- Kamila Kowalska, *Gauge and Yukawa Couplings Unification in the Minimal Supersymmetric Standard Model*  
supervisor S. Pokorski
- Stefan Kreuztlinger, *Superprzestrzeń w wielowymiarowych teoriach supergravitacji (Superspace in Multi-Dimensional Theorie of Supergravity)*  
supervisor M. Olechowski
- Radosław Matyszkiewicz, *Hierarchia mas i stabilizacja pól modułów w pięciu wymiarach (Mass Hierarchy and Moduli Stabilization in Five Dimensions)*  
supervisor Z. Lalak
- Andrzej Perez-Veitia, *Radion Stabilization in Five-Dimensional Brane World*  
supervisor S. Pokorski
- Łucja Sławianowska, *Rozpad mezonu  $B^0 \rightarrow \bar{l}l$  w MSSM (Decay of the Meson  $B^0 \rightarrow \bar{l}l$  in MSSM)*  
supervisor P. Chankowski

- Rafał Suszek, *Struktury niekomutatywnej geometrii w teorii strun (Structures of Non-Commutative Geometry in String Theory)*  
supervisor J. Pawełczyk
- Krzysztof Turzyński, *Proton Decay in SUSY SO(10) Grand Unified Theories*  
supervisor S. Pokorski

## **GRANTS FOR RESEARCH PROJECTS**

### **KBN GRANTS**

- Studies on Electroweak Interactions of Higgs Particles and Heavy Quarks (1998-2000)
- Unification of Fundamental Interactions in Supergravity, String Theory and M-Theory (1998-2000)
- Studies on Interactions from Planck Scale to Electroweak Scale (1999-2000)
- Phenomenological Consequences of Supersymmetric Models (2000-2001)
- Description of Inelastic Processes with Nucleons and Photons at High Energies (2000-2003)
- Studies on Physical Predictions of Extensions of the Standard Model (2001-2002)
- Studies on String Theory, M-Theory and Their Applications in Unification of Fundamental Interactions (2001-2002)
- Study of Properties of Heavy Quarks and Higgs Bosons in Search for Interactions beyond the Standard Model (2001-2003)

### **PROJECTS OF THE US-POLAND MARIA SKŁODOWSKA-CURIE JOINT FUND II:**

- High Energy Physics, Particle Cosmology and Large Scale Structures (1996-2000)

### **GRANTS OF THE POLISH-GERMAN COOPERATION FOUNDATION:**

- Theoretical Research on Fundamental Interactions (1998-2001)

### **GRANTS OF THE POLISH-FRENCH COOPERATION POLONIUM:**

- Study of Rare Decays in the Standard Model and Its Extensions (2000-2001)
- Phenomenology of Supersymmetric Theories in Hadron and Electron Colliders (2000)

**POLISH-SWEDISH JOINT RESEARCH PROJECT:**

- Physics beyond the Standard Model at the LHC and the Tevatron (2001)

**FIFTH FRAMEWORK PROGRAMME:**

- Physics across the Present Energy Frontier: Probing the Origin of Mass (2000-2004)
- Supersymmetry and the Early Universe (2000-2004)
- Particle Physics Phenomenology at High Energy Colliders (2000-2004)

**WORKSHOPS AND CONFERENCES**

- Workshop *Physics in Extra Dimensions*, Warsaw, February 10-17, 2001

## 12 DIVISION OF THEORY OF HADRONS AND LEPTONS

**Head:** Andrzej Szymacha

**Academic staff:** Aleksy Bartnik, Stanisław Głazek, Jacek Jasiak, Józef Namysłowski, Piotr Rączka

**Postgraduate students:** 6

### SCIENTIFIC ACTIVITIES

The scientific activity of the Division was concentrated on the following topics:

- Theory of effective interactions of quarks and gluons.
- Singularities of multipoint Green functions in model quantum field theories.
- Renormalization group procedure for hamiltonians in quantum field theory and its application in particle physics.
- Variational estimates of hadron bound states in quantum chromodynamics in hamiltonian approach.
- Resummation and optimization of higher order perturbative predictions in quantum chromodynamics.

### SCIENTIFIC ACHIEVEMENTS

- Głazek calculated the running coupling constant in QCD hamiltonian. It turned out that this coupling constant depends on inverse size of gluons,  $\lambda$ , in exactly the same way, as the usual running coupling constant depends on the renormalization scale in Feynman diagrams. The results obtained open the possibility of deducing the dynamics of constituent quarks and gluons from the first principles.
- Głazek and Masłowski presented an original scheme of constructing the Poicaré algebra for effective particles in an interacting QFT. They shown how quantum states of extended, composite particles in Fock space transform under the full Poincaré group.
- Bartnik with his students investigated spectra of charmonium and bottomium in QCD. Two different approach have been used. First, in which low momenta of QCD Hamiltonian are treated explicitly, while for high momenta the usual perturbative expansion is used (with Al-Nadara). The promising, though very preliminary numerical results has been obtained. Second (with Al-Hadrani), based on nonperturbative quark propagator of Stingl, and a simple potential of one gluon exchange, leads also to resonable qualitative agreement with experiment.

- Rączka analyzed chromodynamical corrections to the Gross–Llewellyn–Smith sum rule for deep inelastic neutrino scattering on nucleons. Applying the modified evolution generator for effective coupling constant, he achieved much better stability of the results. They are not only more stable, and therefore more reliable, but, at the same time, they eliminate an awkward earlier discrepancy between the QCD  $\Lambda$  fits to low and high energy experiments.

## PUBLICATIONS

1. *3 bilions DNA bases and human brain*, **E.A. Bartnik**, 7th Biotechnology School, Twardy Róg
2. *Influence of exciton — phonon interaction on long energy transport in J-aggregates*, **E.A. Bartnik**, M. Bednarz, J. Che. Phys.
3. *Improved Perturbation Expansion in Quantum Chromodynamics*, **P.A. Rączka**, in Proceedings of Conference Moshe Flato, Eds. G. Dito and D. Sternheimer, Kluwer Academic Publishers 2000, vol. I, p. 257-265
4. *Running Couplings in Hamiltonians*, **St.D. Głazek**, Acta Physica Polonica B31, 909-930 (2000)
5. *Asymptotically free running couplings in Hamiltonians*, **St.D. Głazek**, in *Light-cone QCD and Nonperturbative Hadron Physics*, Eds. A.W. Schreiber and A.G. Williams, World Scientific, 2000, 51-57
6. *Renormalization group procedure for effective particles in light-front Hamiltonian dynamics*, **St.D. Głazek**, Nucl. Phys. B(Proc. Suppl) 90, 175-181 (2000)
7. *Dynamics of Effective Gluons*, **S.G. Głazek**, Physical Review D **63** (2001) 116006.
8. *Gluon coupling strength in H(QCD) with small cutoffs*, **S.G. Głazek**, Nucl. Phys. B(Proc. Suppl.) **108**, 170(2002).
9. *Large momentum convergence of Hamiltonian bound state dynamics of effective fermions in quantum field theory*, **S.G. Głazek**, **M. Więckowski**, Physical Review D **66**, 016001 (2002).
10. *Renormalized Poincaré algebra for effective particles in quantum field theory*, **S.G. Głazek**, **T. Masłowski**, Physical Review D **65**, 065011 (2002).

## SCIENTIFIC DEGREES

### M.SC.

- Hatim Al-Nadary, *Estimates of Masses of Heavy Quarkonia Within Nonperturbative Hamiltonian QCD*, 2001, supervisor A.E. Bartnik
- Harith I-Hadrani, *Meson Structure in a Potential Model with Quark Confining Green's Function*, 2001, supervisor A.E. Bartnik
- Błażej Rusczycki, *Hadrons in Heavy Quark System*, 2001, supervisor J. Namysłowski

## 13 DIVISION OF THEORY OF SOLID STATE

**Head:** Jan Blinowski

**Academic staff:** Witold Bardyszewski, Krzysztof Byczuk, Jerzy Krupski, Jakub Tworzydło

**Postgraduate students:** 2

### SCIENTIFIC ACTIVITIES

One of the main research interests in the modern condensed matter theory is a study of correlated electron systems. Collective behavior of interacting electrons, beyond simple one electron picture, has been realized to be crucial in describing properties of very diverse materials. The most studied examples are high  $T_c$  superconductors, low dimensional semiconductor systems and magnetic materials. The electron-electron interaction leading to their collective behavior is believed to be a cause for exotic phases in HTCS (strange metal, unusual superconductor, stripe phase, pseudo-gape phase etc.) and in transition metal oxides, in particular in the presence of impurities. The world of low dimensional electron systems manufactured from semiconductor heterostructures extends now from high-mobility 2d electron gas, via quantum wires down to quantum dots. New opportunities have been opened by discovery of carbon nanotubes: ideal one dimensional quantum wires. The importance of electron interactions in semiconductor systems is of both academic interest as well as industrial one, especially in the field of active optical devices. All magnetic properties of matter are fundamentally caused by quantum effects involving interacting electrons, new chapter in this domain started with the improved technology of low dimensional magnetic structures. All the systems enumerated above have been studied in our group in collaboration with physicists from many other polish and foreign scientific institutions. Quantum description of dissipative systems and the propagation of elastic waves in random media formed separate additional subjects of interest not directly related to the main stream of our activities.

### SCIENTIFIC ACHIEVEMENTS

- A quantitative theory of electroabsorption and electrorefraction in multiple quantum wells with built in strains was developed for accurate modeling of Mach-Zehnder modulators. (Bardyszewski)
- Theory of many-body effects in highly excited semiconductors and lasers has been worked out. (Bardyszewski, Prywata)
- A simple model accounting for many-body effects in X-ray absorption fine structure has been developed. (Bardyszewski)
- Optical properties of spin polarized two-dimensional electron gas have been described within a self-consistent field theory. (Bardyszewski)
- A phenomenological model of light absorption in disordered semiconductor alloys was developed. (Bardyszewski)

- Electronic sub-band structure of  $\delta$ -doped semiconductor has been determined by the Thomas-Fermi-Dirac method and in the more laborious self-consistent approximation. (Krupski)
- It was studied how the band nonparabolicity reduces the mobility of 2D electron gas in  $\delta$ -doped semiconductor. (Krupski)
- Single- and two-particle properties of correlated electrons forming the spin-charge separated Luttinger liquid in a magnetic field were described, possible application of this system to the modeling of high  $T_c$  superconductors were indicated. (Byczuk)
- An effective Coulomb interaction in a quantum wire made of a semiconductor with extremely large dielectric constant has been derived and shown to affect the properties of the 1d system of interacting electrons. (Byczuk)
- The puzzling results concerning spin configurations in carbon nanotubes have been theoretically explained by taking into account the spatial nonuniformity of external potentials. (Byczuk)
- Theory of superconducting fluctuations in the thinnest carbon nanotubes was formulated and a new microscopic mechanism leading to formation of Cooper pairs was presented. (Byczuk)
- Analytical derivation of the Curie-Weiss law in correlated electron systems within the dynamical mean-field theory was presented. (Byczuk)
- Phenomenological modeling of photoemission spectroscopy in strongly correlated electron system was presented. (Byczuk)
- Ferromagnetism and metal-insulator transition in the disordered Hubbard model were studied within the dynamical mean-field theory. A new type of the metal-insulator transition was found. (Byczuk)
- The decay of quasiparticles in quantum dots has been described using the non-Caley-tree model. (Tworzydło)
- A coupled spin-ladder model has been applied to study the quantum magnetism in stripe phases in relation to the zero-temperature critical point for a transition from the superconducting to the stripe phase. (Tworzydło)
- The coupling between both ferro- and antiferromagnetic layers mediated by valence-band electrons in all-semiconductors superlattices has been calculated within a tight-binding model. (Blinowski)
- The scale-dependence of the velocity of the seismic waves has been explained in terms of a nonperturbative model of the propagation in the medium with the random velocity fluctuations. (Tworzydło)

- An original method of quantization of equations of motion for dissipative systems has been proposed. (Wysocki)

## PUBLICATIONS

1. *Interference between extrinsic and intrinsic losses in X-ray absorption fine structure.*, L. Campbell, L. Hedin, J.J. Rehr, **W. Bardyszewski**, Physical Review B-Condensed Matter, vol.65, no.6, 1 Feb. 2002, p.064107
2. *Optical absorption in random media: Application to Ga<sub>1-x</sub>Mn<sub>x</sub>As epilayers*, J. Szczytko, **W. Bardyszewski**, A. Twardowski, Physical Review B-Condensed Matter, vol.64, no.7, 15 Aug. 2001, p.075306
3. *Multiphonon excitonic absorption in semiconductors and quantum wells*, **W. Bardyszewski**, M. Prywata, D. Yevick, Journal of Applied Physics, vol.90, no.1, 1 July 2001, p.222.
4. *Cumulant expansion approach to stimulated emission in semiconductor lasers*, **W. Bardyszewski**, D. Yevick, M. Prywata, Physical Review B-Condensed Matter, vol.62, no.3, 15 July 2000, p.1835.
5. *Ordered magnetic phase in Cd<sub>1-x</sub>Mn<sub>x</sub>Te/Cd<sub>1-y-z</sub>Mg<sub>y</sub>Zn<sub>z</sub>Te:N heterostructures: magneto-optical studies*, P. Kossacki, D. Ferrand, A. Arnoult, J. Cibert, S. Tatarenko, A. Wasiela, Y. Merle d'Aubigne, J-L. Staehli, J-D. Ganiere, **W. Bardyszewski**, K. Świątek, M. Sawicki, J. Wróbel, T. Dietl, Elsevier. Physica E, vol.6, no.1-4, Feb. 2000, p.709.
6. *Resonant exciton contributions to quantum-well electroabsorption* **W. Bardyszewski**, D. Yevick, C. Rolland, E. Dupont, Phys. Rev. B60, 16563 (1999)
7. *Resonant-level effects in the absorption spectra of shallow quantum wells*, **W. Bardyszewski**, C. Rolland, S. Bradshaw, D. Yevick in *Conference on Lasers and Electro-Optics* Vol. 6, 1998 OSA Technical Digest Series (Optical Society of America, Washington DC, 1998) pp.469-470.
8. *On the kinetic exchange in A/sup III/B/sup V/ diluted magnetic semiconductors* **J. Blinowski**, P. Kacman, Acta Physica Polonica A, vol.100, no.3, Sept. 2001, p.343.
9. *Antiferromagnetic interlayer coupling in ferromagnetic semiconductor EuS/PbS(001) superlattices* H. Kępa, J. Kutner-Pielaszek, **J. Blinowski**, A. Twardowski, C.F. Majkrzak, T. Story, P. Kacman, R.R. Gałazka, K. Ha, H.J.M. Swagten, W.J.M. De Jonge, A. Yu. Sipatov, V. Volobuev, T.M. Giebultowicz, Europhysics Letters, vol.56, no.1, 1 Oct. 2001, p.54.
10. *Interlayer exchange coupling mediated by valence-band electrons*, **J. Blinowski**, P. Kacman, Physical Review B-Condensed Matter, vol.64, no.4, 15 July 2001, p.045302.
11. *Neutron diffraction and reflectivity studies of interlayer correlations in magnetic semiconductor superlattices*, T.M. Giebultowicz, H. Kępa, **J. Blinowski**, P. Kacman, Elsevier. Physica E, vol.10, no.1-3, May 2001, p.411.
12. *Interlayer exchange in antiferromagnetic-nonmagnetic semiconductor superlattices*, H. Kępa, **J. Blinowski**, P. Kacman, G. Springholz, G. Bauer, C.F. Majkrzak, T.M. Giebultowicz, Proc. 24th. Int. Conf. on the Physics of Semiconductors, ed. D. Gershoni, World Scientific, Singapore 1999, 1199
13. *Spin-Charge Separated Luttinger Liquid in the Magnetic Field*, **K. Byczuk**, Phys.Rev.B 57 3821-3828, (1998).



14. *Realistic Electron-Electron Interaction in a Quantum Wire*, **K. Byczuk**, T. Dietl, Phys.Rev. **B 60**, 1507 (1999).
15. *Ballistic quantum transport in constriction of n-PbTe*, G. Grabecki, J. Wrobel, T. Dietl, **K. Byczuk**, E. Papis, E. Kamińska, A. Piotrowska, G. Springholz, M. Pinczolits, G. Bauer, Phys.Rev. **B 60**, R5133 (1999).
16. *Spectral Properties of Luttinger Liquid and Comparison Fermi Liquid*, **K. Byczuk**, J. Spałek, W. Wójcik, Molecular Phys.Rep. **20**, 39-50 (1998).
17. *Electronic Properties of High temperature Superconductors within a Phenomenological Anderson-Luttinger Picture*, **K. Byczuk**, J. Spałek, W. Wójcik, Acta Phys. Pol. **B 29** 3871-3884, (1998).
18. *Ballistic quantum transport in n-PbTe*, G. Grabecki, J. Wrobel, T. Dietl, **K. Byczuk**, E. Papis, E. Kamińska, A. Piotrowska, G. Springholz, M. Pinczolits, G. Bauer, Pro. of Conference on Semiconductors in Jerozolima (1998).
19. *Spin configuration of carbon nanotube in a nonuniform external potential*, Y. Oreg, **K. Byczuk**, B.I. Halperin, Phys.Rev.Lett. **85**, 365 (2000).
20. *Derivation of the Curie-Weiss Law in Dynamical Mean-Field Theory*, **K. Byczuk**, D. Vollhardt, Phys. Rev. **B 65**, 134433 (2002)
21. *Phenomenological Modeling of Photoemission Spectra in Strongly Correlated Electron Systems*, **K. Byczuk**, R. Bulla, R. Claessen, D. Vollhardt, cond-mat/0205149.
22. *Theory of superconducting fluctuations in the thinnest carbon nanotubes*, **K. Byczuk**, cond-mat/0206086.
23. *Ferromagnetism and Metal-Insulator Transition in the Disordered Hubbard Model*, **K. Byczuk**, M. Ulmke, D. Vollhardt, cond-mat/0210296
24. *Spin Configurations in Carbon Nanotubes*, **K. Byczuk**, Acta Phys.Polonica **B 31**, 2997 (2000).
25. *Effect of band nonparabolicity on mobility in a delta-doped semiconductor*, L.R. Gonzalez, **J. Krupski**, M. Pietka et al., Phys. Rev. B 60: (11) 7768-7771 (1999)
26. *On the accuracy of the Thomas-Fermi-Dirac method applied to sub-band structure calculations in a delta-doped semiconductor*, **J. Krupski**, M. Pietka, Solid State Comm. 107: (3) 141-144 (1998)
27. *Two-dimensional Electron Gas Mobility in  $\delta$ -Doped Semiconductors* (invited talk), **J. Krupski**, Proc. XIV Int. School of Condensed Matter Phys., Electron and Spin Correlations in Solids, Supraśl 2001 Institute of Experimental Physics, University of Białystok, Dec. 2001
28. *Quantum optical communication rates through an amplifying random medium* **J. Tworzydło**, C.W.J. Beenakker, Physical Review Letters, vol.89, no.4, 22 July 2002, p.043902
29. *The geometric order of stripes and Luttinger liquids* J. Zaanen, O.Y. Osman, H.V. Kruis, Z. Nussinov, **J. Tworzydło**, Taylor & Francis. Philosophical Magazine B-Physics of Condensed Matter Structural Electronic Optical & Magnetic Properties, vol.81, no.10, Oct. 2001, p.1485.
30. *Hierarchical model for the scale-dependent velocity of waves in random media*. **J. Tworzydło**, C.W.J. Beenakker, Physical Review Letters, vol.85, no.3, 17 July 2000, p.674.
31. *Non-Cayley-tree model for quasiparticle decay in a quantum dot*, X. Leyronas, **J. Tworzydło** and C.W.J. Beenakker, Phys. Rev. Lett. 82, 4894 (1999)

32. *Quantum magnetism in the stripe phase: bond- versus site order*, J. Tworzydło, O.Y. Osman, C.N.A. van Duin, J. Zaanen, Phys. Rev. B **59**, 115 (1999)
33. *Influence of local potentials on spin-splitting in diluted magnetic semiconductors*, M. Herbich, L. Kłopotowski, W. Mac, A. Stachow, A. Twardowski, J. Tworzydło, M. Demianiuk, J. of Crystal Growth 185: 992-995, (1998)

## SCIENTIFIC DEGREES

### PH.D.

- R. Doradziński *Magnetic Kondo Lattices*  
supervisor J. Spałek
- M. Prywata *Wpływ oddziaływania coulombowskiego na widmo ekscytonowe w silnie wzbudzonych strukturach półprzewodnikowych*  
supervisor W. Bardyszewski
- R. Wysocki *Kwantowanie równania ruchu dla układów dysypatywnych*  
supervisor W. Bardyszewski
- M. Piętka *Ruchliwość elektronów w półprzewodniku z domieszkowaniem typu  $\delta$  w obecności napięcia bramkowego*  
supervisor J. Krupski

### M.SC.

- P. Krupiński *Wpływ swobodnych nośników na renormalizację przerwy energetycznej w półprzewodnikowych studniach kwantowych*  
supervisor W. Bardyszewski
- R. Wąsowicz *Widmo absorpcyjne dziur w studniach kwantowych GaAs/AlGaAs*  
supervisor J. Blinowski
- Ł. Cywiński *Wpływ nieporządku i swobodnych nośników na absorpcję międzypas-mową w półprzewodnikach*  
supervisor W. Bardyszewski

## 14 DIVISION OF QUANTUM OPTICS AND ATOMIC PHYSICS

**Head:** Krzysztof Wódkiewicz

**Academic staff:** Agnieszka Jaroń, Jerzy Kamiński, Krzysztof Pachucki

**Postgraduate Students:** 5

### SCIENTIFIC ACTIVITIES

- Quantum Optics. Nonclassical states of light
- Quantum information and quantum entanglement
- Operational quantum measurements in phase space
- Interaction of atoms with strong laser fields
- Multiphoton processes in atoms and solids
- Relativistic scattering processes in laser light
- Control of quantum processes by external electromagnetic fields
- Relativistic Quantum Electrodynamics
- QED effects in hydrogenic and two-electron atoms
- Physics of exotic atoms
- Parity nonconservation in atomic systems

### SCIENTIFIC ACHIEVEMENTS

- A direct method of measuring the Wigner function of light has been proposed, and an experiment has been performed. It was shown that it is possible to reconstruct the phase space Wigner function of light from photon statistics collected in a homodyne measurement.
- The nonlocality of correlated quantum states has been established using the phase space Wigner function or the  $Q$ -function. Violations of Bell inequality for various entangled states described by continuous variables has been established.
- Various aspects of quantum information theory such as the fidelity balance in quantum operations and the stochastic decoherence of qubits have been investigated.

- The relativistic scattering of electrons by an atom, being approximated by a static potential, in a extremely powerful electromagnetic plane wave has been considered. In order to study the spin effects the dynamics has been described by the Klein-Gordon as well as Dirac equations. The results for the differential cross sections of induced and inverse bremsstrahlung have been compared for various parameter values and angular configurations. It appeared that in most cases the spin effects are marginal even at very high laser powers. Also the nonlinear Compton scattering, induced by a linearly polarized laser field, has been studied for relativistically intense laser fields and for several scattering configurations.
- A two dimensional electron system interacting with an impurity and placed in crossed magnetic and electric fields has been investigated. It is assumed that the impurity center interacts as an attractive  $\delta$ -like potential, and for this reason a renormalization procedure for the retarded Green's function has to be carried out. It is shown that by switching on the electric field new long-living resonance states can be generated, which manifest a peculiar dependence on the electric field intensity, i.e., although the electric field increases the lifetime of these states grows up. It is explained that this phenomenon, called the stabilization effect, is a close consequence of quantum-mechanical vortices induced by the magnetic field and controlled by a changing electric field.
- The effective hamiltonian approach to bound state QED has been developed and the long standing problem of relativistic corrections to positronium energy levels of order  $O(\alpha^4)$  has been solved. Results indicate a strong disagreements with measurements of positronium hyperfine structure.
- With the help of variational numerical approach, various QED effects in helium atom have been obtained: nuclear recoil corrections,  $m\alpha^6$  contribution to energy levels and  $m\alpha^7$  to fine structure of  $2^3P_J$  state. These allow for the improved tests of QED and more precise determination of physical constants
- Two-loop correction to the Lamb shift in hydrogen has been significantly improved, correcting the former disagreements with experimental values.

## PUBLICATIONS

1. *Interference, Schrödinger Cat and Quantum Blurring*, **K. Wódkiewicz**, Opt. Commun. **179**, 215 (2000)
2. *Fractional dynamics in phase space*, **K. Banaszek**, **K. Wódkiewicz**, W. Schleich, Laser Physics **10**, 123 (2000)
3. *Nonlocality of the Schrödinger Cat*, **K. Wódkiewicz**, New Journal of Physics **2**, 21 (2000)
4. *Quantum Interference in Phase Space*, **K. Banaszek**, **K. Wódkiewicz**, XVII Workshop on Geometric Methods in Physics, Ed.: M. Schlichenmaier et al., Wydawnictwa UW, p. 99 (2000).

5. *Direct Measurement of the Wigner Function of Optical Fields*, **K. Banaszek**, C. Radzewicz, **K. Wódkiewicz**, J.S. Krasinski, Proceeding of Sixth International Conference on Squeezed States and Uncertainty Relations, NASA/CP-2000-209899, p. 400 (2000).
6. *Stochastic Decoherence of Qubits*, **K. Wódkiewicz**, Optics Express **8**, No. 2, 145 (2001).
7. *Fidelity balance in quantum operations*, **K. Banaszek**, Phys. Rev. Lett. **86**, 1366 (2001).
8. *Homodyne Bell's inequalities for entangled mesoscopic superpositions*, **A. Dragan**, **K. Banaszek**, Phys. Rev. A **63**, 062102 (2001).
9. *Contributions to helium fine structure of order  $m\alpha^7$* , **K. Pachucki**, J. Sapirstein, J. Phys. B **33**, 5297, (2000)
10. *Improved result for helium  $2^3S_1$  ionization energy*, **K. Pachucki**, Phys. Rev. Lett. **84**, 4561 (2000)
11. *Recoil correction to the Lamb shift in helium*, **K. Pachucki**, J. Sapirstein, J. Phys. B **33**, 455 (2000)
12. *Nuclear spin mixing oscillations in  $^{229}\text{Th}^{89+}$* , **K. Pachucki**, S. Wycech, J. Żylicz, M. Pfutzner, Phys. Rev. C **64**, 064301 (2001)
13. *Quantum Electrodynamics and all that*, **K. Pachucki**, *Laser Physics at the Limits*, Springer Verlag, 2001
14. *Forbidden transition in the helium atom*, G. Łach, **K. Pachucki**, Phys. Rev. A **64**, 042510 (2001)
15. *Hyperfine splitting of  $2^3S_1$  state in  $\text{He}^3$* , **K. Pachucki**, J. Phys. B **34**, 3357 (2001)
16. *Logarithmic two-loop correction to the Lamb shift*, **K. Pachucki**, Phys. Rev. A **63**, 042503 (2001)
17. *Hyperfine structure of muonic helium*, **K. Pachucki**, Phys. Rev. A **63**, 032508 (2001)
18. *Relativistic and QED corrections to the polarizability of helium*, **K. Pachucki**, J. Sapirstein, Phys. Rev. A **63**, 012504 (2001).
19. *Floquet analysis of laser-induced continuum structures*, **A. Jaroń**, E. Mese, R. Potvliege, J. Phys. B **33**, 1487 (2000).
20. *Asymmetry, angular and polarization effects in relativistic free-free transitions in a powerful laser field*, **J.Z. Kamiński**, **P. Panek**, F. Ehlotzky, Laser Phys. **10**, 163–170 (2000).
21. *Stimulated radiative recombination and x-ray generation*, **A. Jaroń**, **J.Z. Kamiński**, F. Ehlotzky, Phys. Rev. A **61**, 023404-(1–6) (2000).
22. *Systematic study of resonance and off-energy-shell effects in laser-assisted electron scattering*, **A. Jaroń**, **J.Z. Kamiński**, L.B. Madsen, K. Taulbjerg, AIP Conference Proceedings, vol. **525**, Melville, New York, 2000 (wyd. L.F. DiMauro, R.R. Freeman i K.C. Kulander), str 583-592 (2000).
23. *Laser-assisted radiative recombination and x-ray generation*, **A. Jaroń**, **J.Z. Kamiński**, F. Ehlotzky, Laser Phys. **11**, 174–182 (2001).
24. *X-ray generation via stimulated recombination of electrons and Bohr's correspondence principle*, **A. Jaroń**, **J.Z. Kamiński**, F. Ehlotzky, NATO Science Series: Mathematics, Physics and Chemistry, vol. **12**, str. 265–274, Kluwer, 2001 (wyd. B. Piraux i K. Rzażewski) (2001).

25. *Bohr's correspondence principle and x-ray generation by laser-stimulated electron-ion recombination*, **A. Jaroń, J.Z. Kamiński, F. Ehlötzky**, Phys. Rev. A **63**, 055401(4) (2001).
26. *Coherent phase-control in laser-assisted radiative recombination and x-ray generation*, **A. Jaroń, J.Z. Kamiński, F. Ehlötzky**, J. Phys. B **34**, 1221-1232 (2001).
27. *Teoria Kwantów. Mechanika Falowa*, **I. Białynicki-Birula, M. Cieplak, J. Kamiński**, Wydawnictwo Naukowe PWN, Warszawa, 2001.

### GRANTS FOR RESEARCH PROJECTS

- K. Wódkiewicz, *Diagnostics of classical and quantum interference properties of electromagnetic radiation*, 1999-2000
- J. Kamiński, *Multiphoton processes in the presence of intense laser beams*, 1999-2000.
- J. Kamiński, *Control of quantum processes with external electromagnetic fields*, 2000-2003.
- K. Wódkiewicz, European Program *QUEST* 2001-2003
- K. Pachucki, *Precyzyjne policzenie poziomów energetycznych atomu helu w ramach elektrodynamiki kwantowej*, 1999-2002.

## 15 WOJCIECH RUBINOWICZ LIBRARY

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- alphabetical catalogue of books by authors
- subject catalogue of books
- catalogue of Ph.D. theses since 1984
- microfiche catalogue

## 16 LIST OF ACADEMIC TEACHERS (31.12.2001)

The following english names of university positions are admitted as equivalent to the corresponding positions of polish academic teachers:

full professor (*profesor zwyczajny*)  
associate professor (*profesor nadzwyczajny*)  
assistant professor (*adiunkt*)  
senior lecturer (*starszy wykładowca*)  
postgraduate student (*doktorant*)

The acronyms for the Divisions of the Institute (see page 2) are given in parentheses.

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