

**INSTITUTE  
OF  
THEORETICAL PHYSICS**

**Faculty of Physics**

**Warsaw University**

**2002-2003**

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## INSTITUTE OF THEORETICAL PHYSICS

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### Scientific Council:

*Chairman:* Andrzej Szymacha

*Secretary:* Krzysztof Turzyński

*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, 2003):

*Academic teachers:* 48

*Librarians:* 5

*Secretaries:* 2

*Technical personnel:* 4

*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

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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 2003 the Institute of Theoretical Physics organized its fifth Symposium “IFT UW-03”. This prompted us to publish the present report which contains information about the Institute and its activities and achievements in 2002–2003, i.e., in the period between our fourth and the fifth 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 2003 it employed 48 academic teachers whose duties are scientific research and/or teaching. 38 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 12 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 2002–2003 is presented below for each Division separately. According to the classification of the Polish State Committee for Scientific Research (KBN) in 2002–2003 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.

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, 2001/2002 and 2002/2003, 18 students got their M.Sc. degrees, 7 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 38 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 2001/2002 and 2002/2003 the following seminars were organized (or coorganized together with colleagues from other units):

- 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
- Seminar on Theory of Hadrons and Leptons
- Seminar on Exact results in quantum theories

## 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, Marek Kuś and Grzegorz Wilk)

**LECTURES GIVEN ON THE LEOPOLD INFELD SEMINAR IN  
2001/2002 AND 2002/2003**

- 11.10.2001** Andrzej Udalski, Obserwatorium Astronomiczne UW  
*GRAVITATIONAL MICROLENSING.*
- 18.10.2001** Niels E. Christensen, Institute of Physics, Aarhus University  
*'SIMPLE' METALS UNDER PRESSURE: NEW STRUCTURES - PAIRED  
ATOMS?*
- 25.10.2001** Jerzy Lewandowski, IFT UW  
*RECENT ADVANCES OF QUANTUM GRAVITY.*
- 8.11.2001** Adam Doliwa, IFT UW  
*THE BASIC IDEAS OF INTEGRABLE DISCRETE GEOMETRY.*
- 22.11.2001** Wojciech Gawlik, IF UJ  
*NOBEL PRIZE 2001.*
- 6.12.2001** Kazimierz Rzążewski  
*HOW TO DESCRIBE A WEAKLY INTERACTING BOSE GAS.*
- 20.12.2001** Adam Sobiczewski, IPJ  
*DO DEFORMED SUPERHEAVY NUCLEI EXIST?*
- 10.01.2002** Iwo Białynicki-Birula, IFT UW  
*NUMBER OF PHOTONS AND THE STRUCTURE OF THE VACUUM.*
- 21.02.2002** Ryszard Kutner, IFD UW  
*NONGAUSSIAN STOCHASTIC PROCESSES AND RARE EVENTS AND THE RE-  
ALITY.*
- 7.03.2002** Krzysztof Wódkiewicz, IFT UW  
*TELEPORTATION OF LIGHT.*
- 21.03.2002** Jacek Kossut, IF PAN  
*LOW-DIMENSIONAL SEMICONDUCTOR STRUCTURES-HOW AND WHY DO  
WE PRODUCE THEM?*
- 11.04.2002** Marek Cieplak, IF PAN  
*UNIVERSALITY CLASSES IN FOLDING KINETICS OF PROTEINS.*
- 25.04.2002** Sylwester Porowski, High Pressure Research Center PAN  
*APPLICATION OF HIGH PRESSURE PHYSICS IN BLUE OPTOELECTRONICS.*
- 9.05.2002** Abhay Ashtekar, Center for Gravitational Physics, PennState  
*QUANTUM MECHANICS OF GEOMETRY AND ITS APPLICATIONS.*



- 23.05.2002** Lech Mankiewicz, CFT PAN  
*GENERALIZED PARTON DISTRIBUTIONS.*
- 10.10.2002** Zygmunt Lalak, IFT UW  
*THEORIES WITH EXTRA DIMENSIONS: A NEW PERSPECTIVE FOR PARTICLE PHYSICS.*
- 21.10.2002** Albrecht Wagner, DESY  
*LOOKING DEEP INTO THE PROTON AND BEYOND.*
- 7.11.2002** Charles Hellaby, University of Cape Town, RPA  
*FINDING THE METRIC OF THE COSMOS.*
- 21.11.2002** Janusz Hołyst, WF PW  
*EVOLVING NETWORKS - FROM PHYSICS TO INTERNET.*
- 5.12.2002** Krzysztof Byczuk, IFT UW  
*DYNAMICAL MEAN-FIELD THEORY OF STRONGLY CORRELATED ELECTRON SYSTEMS.*
- 19.12.2002** Mikołaj Misiak, IFT UW  
*RARE DECAYS OF THE B MESONS: A LABORATORY FOR THE ELECTROWEAK, STRONG AND SUPERSYMMETRIC INTERACTIONS.*
- 9.01.2003** Marek Demiański, IFT UW  
*NOBEL 2002; X-RAY ASTRONOMY.*
- 20.02.2003** Roman Juskiewicz, CAMK  
*RELIC RADIATION AND COSMOLOGICAL PARAMETERS.*
- 6.03.2003** Zbysław Wilamowski, IF PAN  
*WHAT THE SPINTRONICS IS?*
- 20.03.2003** Paweł Haensel, CAMK  
*STRANGE MATTER AND STRANGE STARS.*
- 3.04.2003** Arkadiusz Wójs, Politechnika Wrocławska  
*EXCITON COMPLEXES IN THE HALL SYSTEMS.*
- 24.04.2003** Stanisław Bajtlik, CAMK  
*BASIC CONSTITUENTS AT THE UNIVERSE.*
- 8.05.2003** Jerzy Dudek, Institut des Recherches Subatomiques et Université Strasbourg  
*DIRAC EQUATION FOR NUCLEI.*
- 22.05.2003** Jacek A. Majewski, Walter Schottky Institute and Physics Department, Technische Universität München  
*AB-INITIO METHODS IN MATERIALS SCIENCE: APPLICATIONS AND NEW DEVELOPMENTS.*

## 6 SYMPOSIUM IFT UW-03

Symposium IFT UW-03 has been organized in the Institute on December 12–13, 2003. In the 8 lectures topics related to main research subjects and achievements in 2002–2003 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 Chair of Mathematical Methods in Physics and Faculty of Mathematics, Informatics and Mechanics.

### PROGRAM OF THE SYMPOSIUM

#### Friday, December 12

##### Evening session

Chairperson: Iwo Białyński–Birula

- Leszek Plaskota, *Quantum computations*
- Jarosław Piasecki, *Bose-Einstein condensation*
- Marek Olechowski, *New ideas of weak symmetry breaking inspired with deconstruction*
- Andrzej Dragan, *Generation of entangled polarization states of light*

#### Saturday, December 13

##### Morning session

Chairperson: Wojciech Królikowski

- Wojciech Satuła, *From proton-neutron superconductivity to energy of symmetries*
- Piotr Chankowski, *Neutrinos and the Universe*
- Jacek Jezierski, *Conformal Yano-Killing tensors or how to turn a graviton into a photon*

##### Afternoon session

Chairperson: Andrzej Szymacha

- Anna Kauch, *Carbon nanotubes – new physics in one dimension*
- Marek Więckowski, *Effective particles dynamics in quantum field theory*

##### Evening session

Chairperson: Andrzej Trautman

- Ryszard Buczyński, *Photonic fibers*
- Marek Demiański, *Dark sides of the Universe*

## 7 DIVISION OF FIELD THEORY AND STATISTICAL PHYSICS

**Head:** Marek Napiórkowski

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

**Postgraduate students:** 3

### SCIENTIFIC ACTIVITIES

- rigorous solutions of models of non-equilibrium statistical mechanics
- Bose-Einstein condensation
- theory of suspensions
- hydrodynamic interactions
- surface and interfacial phase transitions
- line tension effects
- vortex lines in quantum electrodynamics

### SCIENTIFIC ACHIEVEMENTS

- Rigorous derivation of the self-consistent equation relating density, chemical potential, and temperature for the gas of bosons interacting via two-body forces (analysis of the equation of state in the mean-field limit for the repulsive Kac potential).
- Exact solutions of the Boltzmann equation for the process of ballistic annihilation.
- Derivation of the generalized Boltzmann equation for 2d Lorentz gas acted upon by a magnetic field perpendicular to the plane of motion  $i$  in the Grad limit.
- Determination of hydrodynamic interactions between spheres on a free interface.
- Derivation of the BBGKY hierarchy for suspension with Stokes dynamics.
- Construction of an effective algorithm for calculating the mobility tensor properties.
- Determination the position of an effective smooth boundary surface for the suspension above a rough surface.
- Derivation of the effective macroscopic equations for the suspension with memory effects.

- Construction of the kinetic equation for hard spheres system for which the H-theorem can be proved.
- Construction of the stochastic algorithm for finding the solutions of the convection-diffusion equations in the presence of a wall with reflecting or absorbing boundary conditions.
- Discussion of the order of unbinding phase transitions in the system of multicomponent membranes and the influence of the membrane composition fluctuations on the membrane properties in the presence of a substrate.
- Derivation of the expressions for the surface and interfacial tensions, and the height-height correlation function for adsorption on a cylindrical substrate.
- Proof of the existence of the filling transition for a corrugated substrate with fixed sign of the curvature.
- New solutions of the Lorentz, Schroedinger, Klein-Gordon and Dirac equations for particle beams guided by electromagnetic vortices.

## PUBLICATIONS

1. *Some exact results for Boltzmann's annihilation dynamics*, F. Copex, M. Droz, **J. Piasecki**, E. Trizac, P. Wittwer, Phys.Rev. E **67**, 021103 (2003).
2. *On the first Sonin correction for granular gases*, F. Copex, M. Droz, **J. Piasecki** Physica A **329**, 114 (2003).
3. *Deterministic limit of tagged particle motion: effect of reflecting boundaries*, **J. Piasecki**, **K. Sadlej**, Physica A **323**, 171 (2003).
4. *Magnetotransport in the 2D Lorentz model: non-Markovian Grad limit of the BBGKY hierarchy*, F. Cornu, **J. Piasecki**, Physica A **326**, 88 (2003).
5. *Self-consistent equation for an interacting Bose gas*, Ph.A. Martin, **J. Piasecki**, Phys.Rev. E **68**, 016113 (2003).
6. *Three-particle contribution to effective viscosity of hard-sphere suspensions*, **B. Cichocki**, M.L. Ekiel-Jezewska, and E. Wajnryb, J.Chem.Phys. **119**, 606 (2003).
7. *Brownian dynamics: divergence of mobility tensor*, E. Wajnryb, **P. Szymczak** and **B. Cichocki**, Physica **335A**, 339 (2004).
8. *General H-Theorem for hard spheres*, **A. Bednorz** and **B. Cichocki**, J.Stat.Phys. **114**, 327 (2004).
9. *Symmetric Linear Kinetic Theory*, **A. Bednorz**, Phys. Rev. **E67**, 021201 (2003).
10. *Boundary conditions for stochastic solutions of the convection-diffusion equation*, **P. Szymczak** and T. Ladd, Phys. Rev. E **68**, 036704 (2003).
11. *The RSOS model for a slit with different walls*, **B. Różycki** and **M. Napiórkowski**, J.Phys. A: Math.Gen. 3 **36**, 4551 (2003).

12. *Phase transitions in multicomponent string model*, **B. Różycki** and **M. Napiórkowski**, *Europhys.Lett.* **6** **66**, 25 (2004).
13. *Interfacial correlation function for adsorption on a disc*, **P. Jakubczyk** and **M. Napiórkowski**, *Physica A* **334**, 173 (2004).
14. *Adsorption on a corrugated substrate*, **K. Rejmer**, *Fluid phase Equilibria*, in press
15. *Vortex lines of the electromagnetic field*, **I. Białynicki-Birula** and **Z. Białynicka-Birula**, *Phys.Rev. A* **67**, 062114 (2003).

## SCIENTIFIC DEGREES

### PH.D.

- A. Bednorz, *The H-theorems for hard a sphere fluid*  
supervisor B. Cichocki

## GRANTS FOR RESEARCH PROJECTS

### KBN GRANTS

- M. Napiórkowski, *Classical and quantum phase transitions: the influence of geometrical constraints ad types of interactions.*
- I. Białynicki-Birula, *Application of the theory of twistors to quantum optics and electrodynamics.*

### POLLONIUM GRANTS

- B. Cichocki, *Theoretical investigation of the dynamical electric response in dense plasma*

### CONFERENCES

- B. Cichocki, M. Napiórkowski, and J. Piasecki, co-organization of the 16-th Marian Smoluchowski Symposium of Statistical Physics, September 6-11, 2003, Zakopane.

## 8 DIVISION OF GENERAL RELATIVITY AND GRAVITATION

**Head:** Marek Demiański

**Academic staff:** Stanisław Bazański, Wojciech Kopczyński, Jerzy Lewandowski, Paweł Nurowski, Jacek Tafel, Andrzej Trautman

**Postgraduate students:** 7

### SCIENTIFIC ACTIVITIES

The scientific activity of the Division has been 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 were obtained by Jerzy Lewandowski and his PhD students in collaboration with relativists from Center for Gravitational Physics (Penn State) and Perimeter Institute within the program of diffeomorphism invariant quantization of geometry and the gravitational field. In particular, the uniqueness of a vacuum state of the Quantum Geometry was shown (Lewandowski, Okołów, Sahlmann, Thiemann). The invariance of the state plays a crucial role in this result. In case of a scalar field, the background independent quantization was introduced (Ashtekar, Lewandowski, Sahlmann). It provides a consistent framework for scalar fields coupled with gravity. The structure of a new quantum model proposed recently by Bojowald and called Loop Quantum Gravity was analyzed and certain corrections were made (Ashtekar, Bojowald, Lewandowski). The model describes the quantum evolution of the isotropic, homogeneous universe and solves the problem of the initial singularity (Big Bang). The background independent framework of quantization of a connection theory was naturally generalized to a non-commutative  $C^*$  algebra. This leads directly to the quantum group structure (Lewandowski, Okołów). The result can be considered as a theory of a quantum group connections.

Studying black holes defined in terms of Isolated Horizons, a general form of a cylindrically symmetric extremal black hole in equilibrium was found (Lewandowski, Pawłowski). Its geometry necessarily coincides with that of the extremal Kerr. An exact solution of the vacuum Einstein equations which defines a space-time foliated by isolated horizons was found (Lewandowski, Pawłowski). Finally, it was shown, that the basic theorems of the Isolated Horizon theory like the zeroth law of thermodynamics, continue to hold in arbitrary space-time dimension.

Lewandowski and Korzyński addressed the problem of generic non-existence of the Killing vectors raised by Chruściel in relation with a new technique of gluing solutions to the Einstein constraint equations. They gave a simple argument using the geometry invariants.

Nurowski and his collaborators developed further the calculus of generalized p-forms,  $-1 \leq p \leq n$ . In particular, for such a calculus a Hodge star operator, inner product, co-differential, Lie derivative with respect to vector fields and Laplacian were introduced. Examples of applications of the calculus to Hamiltonian mechanics, field theories and Einstein's vacuum equations were given. In a series of papers they studied the differential geometries associated with ordinary differential equations. The relations between such equations and conformal and projective geometries were explained and their description in terms of Cartan normal conformal and projective connections were given.

Demiański, in collaboration with Doroshkevich, proposed a new method of deriving the primordial power spectrum of density perturbations at small scales. This method has been applied to study a sample of 4500 Lyman- $\alpha$  spectral lines obtained from spectra of 14 quasars. At scales  $\geq 300h^{-1}$  kpc the observed power spectrum is consistent with the power spectrum in the CDM model but at scales smaller than  $\sim 10 - 300h^{-1}$  kpc the observed spectrum differs from that of the CDM model. The observed deviation from the standard spectrum suggests that the process of inflation could have been more complicated than is usually assumed. The observed Lyman- $\alpha$  lines were identified with intergalactic clouds of neutral hydrogen. Evolution of these clouds has been described by the standard theory of gravitational instability. Using this model of such clouds it was possible to link column density and condensation rate of dark matter and gas with directly observed characteristics of these clouds like column density of neutral hydrogen, redshift at which they appear and Doppler parameter. Demianski and Doroshkevich estimated the first moment of the power spectrum of density perturbations which is related to a cutoff in the spectrum caused by the finite mass of dark matter particles. In this way it was possible to show that the mass of dark matter particles  $m_{DM} \geq 1.5 - 5$  keV.

Demiański and his collaborators have shown that non homogeneous matter distribution in the universe can influence distance determination to galaxies at  $z > 0.5$ . This effect mimics the influence of cosmological constant or dark energy on distance determination and could play an important role in the interpretation of observations of distant supernovae of type Ia.

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.

Tafel and Szereszewski proposed a new method of generation of solutions of the Einstein equations with perfect fluid. These solutions possess two spacelike symmetries. In this construction one chooses a 2-dimensional spacelike surface, with the negative Gauss curvature, in the 3-dimensional Minkowski space. From the second fundamental form of the surface and its normal vector one can construct the spacetime metric up to a conformal factor. The Einstein equations reduce to equations for this factor. Using this approach several classes of homogeneous cosmological solutions (Bianchi types II, VI and VII) were obtained and a way to obtain nonhomogeneous models was indicated.

Asymptotically flat Bondi-Sachs metrics were investigated by Tafel in the relation to the Penrose conformal approach. These metrics can represent gravitational radiation from spatially bounded sources. They are based on a null slicing of spacetime. The action integral was expressed in a form similar to that of Arnowitt, Deser and Misner. The variational principle leads to all the Einstein equations provided some boundary equations are satisfied. The field equations were divided into constraints and evolution equations. The corresponding Hamiltonian was constructed and constraints were investigated using the Dirac approach to constrained systems.

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. *The Jacobi Variational Principle Revisited in Classical and Quantum Integrability*, **S. Bażański**, eds. J. Grabowski, G. Marmo, P. Urbanski, Banach Center Publications, **59**, 99, 2003.
2. *Anisotropy of the cosmic microwave background radiation and topology of the Universe*, **M. Demiański**, A.G. Doroshkevich, Acta Phys. Pol. **33**, 1729, 2002.
3. *Can we observe the shape of the Universe?*, **M. Demiański**, in: *General Relativity, Cosmology and Gravitational Lensing*, edited by G. Marmo, C. Rubano and P. Scudellaro, Bibliopolis, Napoli, 2002.
4. *The Dyer–Roeder equation in a universe with a nonzero cosmological constant*, **M. Demiański**, E. Piedipalumbo in: *General Relativity, Cosmology and Gravitational Lensing*, edited by G. Marmo, C. Rubano and P. Scudellaro, Bibliopolis, Napoli, 2002.
5. *Large scale matter distribution*, **M. Demiański**, A.G. Doroshkevich, in: *Proceedings of the Ninth Marcel Grossmann Meeting on General Relativity*, edited by V.G. Gurzadyan, R.T. Jantzen and R. Ruffini, World Scientific, Singapore, 2002.
6. *Cosmological implications of heavy dark matter particles*, **M. Demiański**, A.G. Doroshkevich, Advances in Space Research, **31**, 437, 2003
7. *Large scale structure and the nature of dark matter*, **M. Demiański**, A.G. Doroshkevich, R. Ruffini Festschrift, World Scientific, 2004
8. *Statistical characteristics of the observed Ly alpha forest and the shape of the initial power spectrum*, **M. Demiański**, A.G. Doroshkevich, V. Turchaninov, Mon. Not. Roy. Astr. Soc., **340**, 525, 2003.
9. *Observational estimates of the initial power spectrum at small scale from Lyman-alpha absorbers*, **M. Demiański**, A.G. Doroshkevich, Astroph. J., **597**, 81, 2003.
10. *Approximate angular diameter distance in a locally inhomogeneous universe with nonzero cosmological constant*, **M. Demiański**, R. de Ritis, A.A. Marino, E. Piedipalumbo, Astron. Astrophys. **411**, 33, 2003.



11. *A comparison of measured Crab nad Vela glitch healing parameters with predictions of neutron star models*, F. Crawford, **M. Demiański**, *Astrophys. J.*, **595**, 1052, 2003.
12. *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.
13. *Geometry of non-expanding horizons and their neighborhoods*, **J. Lewandowski**, in: *Proceedings of the Ninth Marcel Grossmann Meeting on General Relativity*, edited by V.G. Gurzadyan, R.T. Jantzen and R. Ruffini, World Scientific, Singapore, 2002.
14. *Geometric characterizations of the Kerr isolated horizon*, **J. Lewandowski**, **T. Pawłowski**, *Int. J. Mod. Phys.* **11**, 739, 2002.
15. *Polymer and Fock representations for a Scalar field*, A. Ashtekar, **J. Lewandowski**, H. Sahlmann, *Class. Quant. Grav.* **20**, L11, 2003.
16. *Mathematical structure of loop quantum cosmology*, A. Ashtekar, M. Bojowald, **J. Lewandowski**, *Adv. Theor. Math. Phys.* **7**, 233, 2003.
17. *Diffeomorphism covariant representations of the holonomy-flux star-algebra*, **A. Okołów**, **J. Lewandowski**, *Class. Quant. Grav.* **20**, 3543, 2003.
18. *Extremal Isolated Horizons: A Local Uniqueness Theorem*, **J. Lewandowski**, **T. Pawłowski**, *Class. Quant. Grav.* **20**, 587, 2003.
19. *The Normal Conformal Cartan Connection and the Bach Tensor*, **M. Korzyński**, **J. Lewandowski**, *Class. Quant. Grav.* **20**, 3745, 2003.
20. *Generalized forms and their applications*, **P. Nurowski**, D.C. Robinson, *Class. Q. Grav.* **19**, 2425, 2002.
21. *Cartan Normal Conformal Connections from Differential Equations*, **P. Nurowski**, S. Frittelli, C. Kozameh, E.T. Newman, *Class. Q. Grav.* **19**, 5235, 2002.
22. *Robinson manifolds as the Lorentzian analogs of Hermite manifolds*, **P. Nurowski**, **A. Trautman**, *Diff. Geom. Appl.* **17**, 175, 2002.
23. *Projective connections associated with second order ODEs*, **P. Nurowski**, E.T. Newman, *Class. Q. Grav.*, **20**, 2325, 2003.
24. *Conformal Einstein equations and Cartan conformal connection*, **P. Nurowski**, C. Kozameh, E.T. Newman, *Class. Q. Grav.* **20**, 3029, 2003.
25. *3-dimensional CR structures and 2nd order ordinary differential equations*, **P. Nurowski**, G.A.J. Sparling, *Class. Q. Grav.* **20**, 4995, 2003.
26. *Conformal Lorentzian metrics on the spaces of curves and 2-surfaces*, **P. Nurowski**, S. Frittelli, E.T. Newman, *Class. Q. Grav.* **20**, 3649, 2003.
27. *Solutions of the Rarita-Schwinger equations in Einstein spaces*, **A. Szereszewski**, **J. Tafel**, *Phys. Lett.* **A297**, 359, 2002.
28. *Spinors in geometry and physics*, **A. Trautman**, in: *Proc. Intern. Conf. Science and Culture, Losinj 2001*, edited by F. Bradamante and G. Furlan, Consorzio per l'Incremento degli Studi e delle Ricerche dei Dipartimenti di Fisica dell'Universita di Trieste, 2002.
29. *Robinson manifolds and Cauchy-Riemann spaces*, **A. Trautman**, *Class. Quantum Grav.* **19**, R1, 2002.

30. *Robinson manifolds and the shear-free condition*, **A. Trautman**, Int. J. Modern Phys. **A17**, 2735, 2002.
31. *Lectures on general relativity (a "Golden Oldie")*, **A. Trautman**, GRG Journal **34**, 721, 2002.
32. *Pin<sup>c</sup> and Lipschitz structures on products of manifolds*, M. Bobieński, **A. Trautman**, Ann. Glob. Anal. Geom. **22**, 291, 2002.
33. *Modele matematyczne w fizyce czasoprzestrzeni*, **A. Trautman**, in *Przestrzeń we współczesnej nauce*, eds. W.A. Kamiński, Wydawnictwo Wyższej Szkoły Zarządzania i Administracji w Zamościu, Zamość, 2003.
34. *Clifford algebras and their representations*, **A. Trautman** Encyclopedia of Mathematical Physics, Elsevier Science 2005.

### 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.

- Justyna Demkowicz-Dobrzańska, *Polarization of the cosmic microwave background - theoretical estimates and observational limits*  
supervisor M. Demiański
- Mikołaj Korzyński, *The Bach tensor as a Yang-Mills current of the conformal Cartan connection*  
supervisor J. Lewandowski

### GRANTS FOR RESEARCH PROJECTS

#### KBN GRANTS

- Physical and Mathematical Aspects of Classical and Quantum Gravity, 2004 - 2005, (S. Bażanski, A. Krasiński, W. Kopczyński, J. Lewandowski, P. Nurowski, J. Tafel)
- Generation of primordial cosmological perturbations and their observational consequences, 2004 - 2006, (M. Demiański, Z. Lalak, K. Turzyński, P. Bielewicz)
- Representations of Quantum Geometry (J. Lewandowski, A. Okołów)
- Isolated Horizons a Quasi Local Theory of Black Holes (J. Lewandowski, T. Pawłowski)

#### FIFTH FRAMEWORK PROGRAMME

- Cosmic Microwave Background Network in Europe for Theory and Data Analysis, 2000 - 2004.

**AWARDS AND HONOURS**

- A. Trautman, Officer's Cross of Polonia Restituta Order, 2003

## 9 DIVISION FOR MATHEMATICAL AND COMPUTER PHYSICS

**Head:** Antoni Sym<sup>1</sup>

**Academic staff:** Stanisław Bazański<sup>2</sup>, Adam Doliwa<sup>3</sup>, Maciej Pindor

### SCIENTIFIC ACTIVITIES

- Discrete integrable geometries vs discrete soliton systems (A. Doliwa).
- Various dynamical problems in the theory of relativity (S. Bazański).
- Rational approximations, in particular Pade approximants (M. Pindor).
- Separation of variables and conformal geometry (A. Sym).

### 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 (see above).

- Ad. 1 (papers [2,3,4]). 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 four 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.
  - d) Developing a theory of integrable ultra–discrete systems (cellular automata).

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<sup>1</sup>from 1.10.2003 at Department of Mathematical Methods of Physics of Warsaw University

<sup>2</sup>from 1.10.2003 at Division of General Relativity and Gravitation

<sup>3</sup>from 1.10.2002 at University of Warmia and Mazury

In particular in a pioneering paper [4] the authors formulate a general method of solving the fundamental discrete Hirota equation over finite fields. The method is based on mathematically advanced theory of Riemann surfaces over finite fields. The papers [4] and [3] belong to branch d), while the paper [2] belongs to branch c) mentioned above.

- Ad. 2 (paper [1]) The paper contains a new method of derivation of Jacobi principle from Hamilton principle in classical mechanics.
- Ad. 3 (papers [5,6,7]). The paper [6] is an extension of the paper [5]. Both contain new and important results within the so called two-point Pade approximants approach. In work [7] it is shown that the error estimations discussed in [5,6] are still valid for some sequences of multi-point Pade approximants.
- Ad. 4 (paper [8]) It is well known that the so called regular (in a sense of Kalnins–Miller) R-separation in 3-dimensional Helmholtz equation admits only Stäckel forms of metric in  $E^3$ . In the paper we give, probably for the first time, an example of non-regular (non-Stäckel) coordinates in  $E^3$  which are R-separable in 3-dimensional Helmholtz equation. These coordinates are used to simplify derivation of Friedlander’s formulae for modulated soliton of wave equation and to correct some errors of his paper.

## PUBLICATIONS

1. *Jacobi variational principle revisited*, **S. Bazański**
2. *Geometric discretization of the Koenigs nets*, **A. Doliwa**, preprint arXiv, nlin. SI/0203011
3. *The discrete KP and KdV equations over finite fields*, **A. Doliwa**, M. Białecki, to be published
4. *The Hirota equation over finite fields: algebro-geometric approach and multisoliton solutions*, **A. Doliwa**, M. Białecki, P. Klimczewski, J. Phys. A **36** (2003), str. 4827–4839.
5. *Continued fractions, two-point Pade approximants and errors in the Stieltjes case*, J. Gilewicz, **M. Pindor**, J.J. Telega, S. Tokarzewski, J. of Comp. and Applied Math., vol 145 (2002), str. 99-112
6. *Optimal inequalities between the contiguous two-point Pade approximant errors in the Stieltjes case*, J. Gilewicz, **M. Pindor**, Rendiconti del Circolo Matematico di Palermo, Serie II Suppl. 68 (2002), str. 455-466
7. *Non-regular (non-Stäckel) R-separation in 3-dim. Helmholtz equation and general modulated soliton of wave equation*, R. Prus, **A. Sym**, submitted to Phys. Lett. A
8. *Basic inequalities for multipoint Pade approximants to Stieltjes functions*, J. Gilewicz, **M. Pindor**, J.J. Telega, S. Tokarzewski, Archives for Mechanics, vol. 54 (2002) str. 141-153.

## 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:** 2

### SCIENTIFIC ACTIVITIES

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

- Properties of rotational nuclear states
- Collective excitations
- Nuclear structure methods and models
- Pairing correlations in nuclei
- Superheavy nuclei
- Shell structure in nuclei
- Properties of proton emitters
- Continuum shell model
- Shape coexistence and configuration mixing
- Nuclei with large neutron or proton excess
- Interface between nuclear and atomic physics

### SCIENTIFIC ACHIEVEMENTS

In 2002 and 2003, members of the Division have published 30 papers in refereed periodicals (see the list below), and have presented 28 invited talks and 16 contributions at international conferences. During this period of time the following main research projects have been realized:

- **PROPERTIES OF ROTATIONAL NUCLEAR STATES**

In Ref. [3], rotational bands were found in  $^{57}\text{Co}$  using the  $^{28}\text{Si}(^{32}\text{S},3\text{p})$  reaction at 130 MeV. The bands, extending the mass 60 region of large deformation down to  $Z = 27$ , are signature partner sequences. Their quadrupole moments are similar to

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

those of bands in the neighboring nuclei. The features of the new bands were described by Skyrme Hartree-Fock calculations favoring a configuration assignment with one neutron and one proton excited in the respective  $1g_{9/2}$  intruder orbital. An attempt to describe the magnetic ( $M1$ ) properties of the signature partner structure was also presented.

First fully self-consistent Skyrme-Hartree-Fock calculations have been performed [4] for a nucleus rotating about an axis that is not a principal axis of the density distribution (Tilted-Axis Cranking). It was shown that an excited rotational band in  $^{142}\text{Gd}$  has the character of a shears band, in which the angular momentum is generated mainly from the gradual alignment of a few valence nucleons. However, the important role of the collective rotation was also pointed out. In addition, paper [4] discusses the symmetries of the mean field and differences between the self-consistent and phenomenological implementations of the Tilted-Axis Cranking method.

In Ref. [8], nearly degenerate partner bands observed in  $A \approx 130$  odd-odd nuclei were interpreted as a manifestation of chirality in the intrinsic reference frame. A phenomenological approach, based on a core-particle-hole coupling model, has been developed to address the experimental observables. This laboratory-frame model, in which chiral symmetry has been restored, includes a triaxial core, a particle and hole single-particle Hamiltonians, and quadrupole-quadrupole interactions. The optimal model parameters were investigated. The results of the calculations indicated the existence of  $\pi h_{11/2}\nu^{-1}h_{11/2}$  states with the same spin, parity, and similar excitation energy forming partner bands that were nearly degenerate over a range of spins. These calculated partner bands were consistent with the chiral band interpretation and were in agreement with experimental observations in this region. The model has been applied to excited states in  $^{132}\text{La}$ .

In Ref. [9], the superdeformed bands in  $^{58}\text{Cu}$ ,  $^{59}\text{Cu}$ ,  $^{60}\text{Zn}$ , and  $^{61}\text{Zn}$  were analyzed within the frameworks of the Skyrme-Hartree-Fock as well as Strutinsky-Woods-Saxon total routhian surface methods with and without the  $T=1$  pairing correlations between like particles. It was shown that a consistent description within these standard approaches cannot be achieved. A  $T=0$  neutron-proton pairing configuration mixing of signature-separated bands in  $^{60}\text{Zn}$  was suggested as a possible solution to the problem.

Paper [16] contains systematic experimental and theoretical study of superdeformed (SD) bands in  $^{80-83}\text{Sr}$ ,  $^{82-84}\text{Y}$ , and  $^{83,84}\text{Zr}$ . Two types of mean-field models, such as Strutinsky-type calculations with pairing and unpaired self-consistent Skyrme-Hartree-Fock approach, were used to analyze the data. For both models, experimental data appear to place rather stringent conditions on configuration assignment, leading to a consistent understanding of the underlying configurations. Both models provide a satisfactory quantitative description of moments of inertia and quadrupole moments in these bands.

Ref. [17] presents results of differential lifetime measurements, free from common

systematic errors, for more than 30 rotational bands in over 15 different nuclei in the  $A \sim 135$  mass region. The extracted single-particle effective quadrupole moments are compared to theoretical values obtained within self-consistent Skyrme-Hartree-Fock as well as within relativistic-Hartree mean-field models. Detailed comparison convincingly demonstrates a validity of the additivity of single-particle quadrupole moments in this mass region. Similar additivity scheme was previously firmly established [Satuła *et al.* Phys. Rev. Lett. 77 (1996) 5182] to hold in super-deformed bands in the  $A \sim 150$  mass region.

In Ref. [26], the latest experimental data on the high-spin states in  $^{141}\text{Eu}$  were analysed. One new magnetic band was identified, and the known level schemes of other two were extended. The level energies and reduced transition probabilities were compared with the phenomenological Tilted-Axis Cranking calculations. A satisfactory agreement was obtained, which allowed for the assignment of proper single-particle configurations to the observed bands.

#### • COLLECTIVE EXCITATIONS

In Ref. [5], we investigated the effects of the spin-isospin channel of the Skyrme energy functional on predictions for Gamow-Teller distributions and superdeformed rotational bands. We used the generalized Skyrme interaction SkO' to describe even-even ground states and then analyzed the effects of time-odd spin-isospin couplings, first term by term and then together via linear regression. Some terms affect the strength and energy of the Gamow-Teller resonance in finite nuclei without altering the Landau parameter  $g'_0$  that to leading order determines spin-isospin properties of nuclear matter. Though the existing data are not sufficient to uniquely determine all the spin-isospin couplings, we were able to fit them locally. Altering these coupling constants does not change the quality with which the Skyrme functional describes rotational bands.

In Refs. [10] and [22], the quadrupole collective excitations of even-even transactinide nuclei, U, Pu, Cm, Cf, Fm i No, were described in the framework of the microscopic Bohr Hamiltonian modified by including the coupling between the quadrupole degrees of freedom and collective pairing vibrations. The excitation energies of the states of the ground-state,  $\beta$  and  $\gamma$  bands as well as the  $B(E2)$  reduced transition probabilities were calculated. A reasonable agreement of the results with experimental data available so far was obtained with no adjustable parameters. The mean values of the  $\beta$  and  $\gamma$  deformations in the ground states and in the  $\beta$ - and  $\gamma$ -vibrational states were calculated and analysed. Superdeformed states localized in the second minimum of the collective potential energy surface for  $^{254}\text{No}$  were also studied.

In certain neutron-rich Te isotopes, a decrease in the energy of the first excited  $2^+$  state is accompanied by a decrease in the E2 strength to that state from the ground state, contradicting simple systematics and general intuition about quadrupole collectivity. In Ref. [24], we used a separable quadrupole-plus-pairing Hamiltonian and the quasiparticle random phase approximation to calculate energies,



$B(E2, 0^+ \rightarrow 2^+)$  strengths, and  $g$  factors for the lowest  $2^+$  states near  $^{132}\text{Sn}$ . We trace the anomalous behavior in the Te isotopes to a reduced neutron pairing above the  $N=82$  magic gap.

In Ref. [29], we calculated the low-lying  $B(E2, 0^+ \rightarrow 2^+)$  distribution of strength in  $^{68}\text{Ni}$  and other nickel isotopes using several theoretical approaches. We find that in  $^{68}\text{Ni}$  the calculated  $B(E2)$  transition to the first  $2^+$  state exhausts only a fraction of the low-lying  $B(E2)$  strength, while the remainder of the low-lying strength is mainly collected in the group of states lying above 4 MeV. This fragmentation is sensitive to the size of the  $N=40$  gap. We argue that the small experimental  $B(E2)$  value to the first  $2^+$  state is not strong evidence for the double-magic character of  $^{68}\text{Ni}$ .

In Ref. [30], we performed shell model Monte Carlo calculations for proton-rich Kr, Sr, and Zr isotopes in the mass range of  $A=72-84$ . We employed a complete  $1p0f-0g1d2s$  configuration space and an effective quadrupole-plus-pairing residual interaction. Our calculation reproduced the large  $B(E2)$  values observed in these nuclei. We related these values to the gain in correlation energy obtained by moving nucleons across the  $N=40$  subshell closure into  $g_{9/2}$  orbitals.

## • NUCLEAR STRUCTURE METHODS AND MODELS

According to standard textbooks, the nuclear symmetry energy is divided into parts originating from the *kinetic energy* and *interaction*. In Ref. [11] we argued that this traditional view requires modifications and we proposed an alternative scenario. Starting from the idea of isospin cranking model we ascribed the physical origin of the *kinetic term* to the granularity of fermionic levels of an arbitrary, in principle, fermionic quantal system. In nuclear physics, such a scenario connects the symmetry energy directly to the isoscalar mean-potential. The reliability of this concept was verified using fully self-consistent Skyrme-Hartree-Fock calculations.

Using relations between wave functions obtained in the framework of the relativistic mean field theory, in Ref. [12] we investigated the effects of pseudospin and spin symmetry breaking on the single nucleon wave functions in spherical nuclei. In our analysis, we applied both relativistic and non-relativistic self-consistent models, as well as the harmonic oscillator model. In the pseudospin symmetry limit, radial wave functions of the upper components of pseudospin doublets satisfy certain differential relations. We demonstrated that these relations are not only approximately valid for the relativistic mean field eigenfunctions but also for the non-relativistic Hartree-Fock and harmonic oscillator eigenfunctions. Generally, we expect them to be approximately valid for eigenfunctions of any non-relativistic phenomenological nuclear potential that fits the spin-orbit splittings of nuclei. Likewise in the spin symmetry limit, the radial amplitudes of the upper components of the Dirac eigenfunctions of spin doublets were predicted to be equal, and this is approximately valid for both non-relativistic and relativistic mean-field models. Also the spatial amplitudes of the lower components of the Dirac eigenfunctions of spin doublets

satisfy differential relations in spin symmetry limit, and these relations are approximately valid in the relativistic mean field model.

- **PAIRING CORRELATIONS IN NUCLEI**

In Ref. [2], we performed large-scale Hartree-Fock-Bogolyubov calculations using finite range Gogny force DIS, in order to extract theoretical mass dependence of the nuclear pair gap,  $\Delta_{th}(A)$ . The theoretical values of the gap were compared to the experimental data extracted according to the method given in our previous paper [Satała *et al.* Phys. Rev. Lett. 81 (1998) 3599]. This method is supposed to remove, or minimize, the contamination due to the mean-level-spacing contribution, which may otherwise be present in the experimentally deduced gap. Good overall agreement was found between theory and experiment, without discrepancies in light nuclei, confirming that mass-dependence of the nuclear pairing gap is indeed weaker than the commonly accepted one, vis.  $12/\sqrt{A}$  MeV.

- **SUPERHEAVY NUCLEI**

In paper [1], the theory of the superheavy elements was reviewed with the main focus on nuclear structure aspects. Structure of odd- $N$  superheavy elements was investigated using a variety of self-consistent approaches. Microscopic shell corrections, extracted from the Skyrme-Hartree-Fock and relativistic mean-field calculations, elucidated the question of the centre-of-shell-stability in the superheavy region. Finally, the existence of exotic configurations, having gross non-uniformities of nucleonic density, expected to occur in nuclei with very large atomic numbers, was addressed.

The discovery of new superheavy nuclei has brought much excitement to the atomic and nuclear physics communities. Hopes of finding regions of long-lived superheavy nuclei, predicted in the early 1960s, have reemerged. The superheavy elements mark the limit of nuclear mass and charge; they inhabit the upper right corner of the nuclear landscape, but the borderlines of their territory are unknown. The stability of the superheavy elements has been a longstanding fundamental question in nuclear science. How can they survive the huge electrostatic repulsion? What are their properties? How large is the region of superheavy elements? We do not know yet all the answers to these questions. In short article [21] we presented the current status of research in this field.

- **SHELL STRUCTURE IN NUCLEI**

Recent mass measurements show a substantial weakening of the binding energy difference  $\delta_{2p}(Z, N) = E(Z - 2, N) - 2E(Z, N) + E(Z + 2, N)$  in the neutron-deficient Pb isotopes. As  $\delta_{2p}$  is often attributed to the size of the proton magic gap, it might be speculated that the reduction in  $\delta_{2p}$  is related to a weakening of the spherical  $Z=82$  shell. In Ref. [19] we demonstrated that the observed trend is described quantitatively by self-consistent mean-field models in terms of deformed ground states of Hg and Po isotopes.

- **PROPERTIES OF PROTON EMITTERS**

In papers [20] and [27], a new 7 ms isomer in the

drip line nucleus  $^{140}\text{Dy}$  was selected from the products of the  $^{54}\text{Fe}$  (315 MeV)  $^{192}\text{Mo}$  reaction by a recoil mass spectrometer and studied with recoil-delayed  $\gamma$ - $\gamma$  coincidences. Five cascading  $\gamma$ -transitions were interpreted as the decay of an  $I=8$   $K$ -isomer via the ground-state band. The probability of proton emission from  $^{141}\text{Ho}$  to the  $I=0$  ground state and to the  $I=2$  excited state in  $^{140}\text{Dy}$  was discussed.

- **CONTINUUM SHELL MODEL**

Work [23] presents the first continuum shell-model study of weakly bound neutron-rich nuclei involving multiconfiguration mixing. For the single-particle basis, the complex-energy Berggren ensemble representing the bound single-particle states, narrow resonances, and the non-resonant continuum background is taken. Our shell-model Hamiltonian consists of a one-body finite potential and a zero-range residual two-body interaction. The systems with two valence neutrons are considered. The Gamow shell model, which is a straightforward extension of the traditional shell model, is shown to be an excellent tool for the microscopic description of weakly bound systems. It is demonstrated that the residual interaction coupling to the particle continuum is important; in some cases, it can give rise to the binding of a nucleus.

In Ref. [28], we presented the study of weakly bound, neutron-rich nuclei using the nuclear shell model employing the complex Berggren ensemble representing the bound single-particle states, unbound Gamow states, and the non-resonant continuum. In the proposed Gamow Shell Model, the Hamiltonian consists of a one-body finite depth (Woods-Saxon) potential and a residual two-body interaction. We discussed the basic ingredients of the Gamow Shell Model. The formalism was illustrated by calculations involving several valence neutrons outside the double-magic core:  $^{6-10}\text{He}$  and  $^{18-22}\text{O}$ .

- **SHAPE COEXISTENCE AND CONFIGURATION MIXING**

In Ref. [18], nuclear binding energies and two-neutron separation energies were analysed starting from the liquid-drop model and the nuclear shell model in order to describe the global trends of the above observables. We subsequently concentrated on the Interacting Boson Model (IBM) and discussed a new method in order to provide a consistent description of both, ground-state and excited-state properties. We addressed the artefacts that appear when crossing mid-shell using the IBM formulation and performed detailed numerical calculations for nuclei situated in the 50–82 shell. We also concentrated on local deviations from the above global trends in binding energy and two-neutron separation energies that appear in the neutron-deficient Pb region. We addressed possible effects on the binding energy, caused by mixing of low-lying  $0^+$  intruder states into the ground state, using configuration mixing in the IBM framework. We also studied ground-state properties using a

macroscopic–microscopic model. Detailed comparisons with recent experimental data in the Pb region were amply discussed.

- **NUCLEI WITH LARGE NEUTRON OR PROTON EXCESS**

In years to come, we shall see substantial progress in our understanding of nuclear structure – a rich and many-faceted field. An important element in this task will be to extend the study of nuclei into new domains. The journey to “the limits” of isospin, angular momentum, and mass and charge is a quest for new and unexpected phenomena which await us in uncharted territories. What is extremely important from a theoretical point of view is that the new data are also expected to bring qualitatively new information about the effective nucleon-nucleon interaction and hence about the fundamental properties of the nucleonic many-body system. In Ref. [6] we discussed some of the challenges and opportunities for nuclear structure research with radioactive nuclear beams.

In Ref. [7], the volume and surface effects in the nuclear local energy density and the volume and surface components of the pairing interaction were discussed in the context of the mean-field, Hartree-Fock-Bogoliubov description of atomic nuclei. Predictions of properties of exotic nuclei close to the particle drip lines were presented.

Nuclear life in neutron-rich and proton-rich *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. [13] was to discuss some of the theoretical challenges and opportunities for nuclear structure research with new Electro-Magnetic Isotope Separators.

In Ref. [15], an improved prescription for choosing a transformed harmonic oscillator (THO) basis for use in configuration-space Hartree-Fock-Bogoliubov (HFB) calculations was presented. The new HFB+THO framework that follows accurately reproduces the results of coordinate-space HFB calculations for spherical nuclei, including those that are weakly bound. Furthermore, it is fully automated, facilitating its use in systematic investigations of large sets of nuclei throughout the periodic table. As a first application, we have carried out calculations using the Skyrme Force SLy4 and volume pairing, with exact particle number projection following application of the Lipkin-Nogami prescription. Calculations were performed for all even-even nuclei from the proton drip line to the neutron drip line having proton numbers  $Z = 2, 4, \dots, 108$  and neutron numbers  $N = 2, 4, \dots, 188$ . We focused on nuclei near the neutron drip line and found that there exist numerous particle-bound even-even nuclei (i.e., nuclei with negative Fermi energies) that have at the same time negative two-neutron separation energies. This phenomenon, which was earlier noted for light nuclei, is attributed to bound shape isomers beyond the drip line.

- **INTERFACE BETWEEN NUCLEAR AND ATOMIC PHYSICS**

In Ref. [14], we used the Skyrme-Hartree-Fock method, allowing all symmetries to be broken, to calculate the time-reversal-violating nuclear Schiff moment (which induces atomic electric dipole moments) in the octupole-deformed nucleus  $^{225}\text{Ra}$ . Our calculation included several effects neglected in earlier work, including self consistency and polarization of the core by the last nucleon. We found that the Schiff moment, while large compared to those of reflection-symmetric nuclei, is generally a few times smaller than the recent estimates.

In Ref. [25], K-shell and L-shell ionization potentials for the superheavy elements with  $Z=112, 114, 116,$  and  $118$  are predicted to an accuracy of a few 10 eV using Dirac-Hartree-Fock theory and taking into account quantum electrodynamic and nuclear size effects. The data obtained are for any number of electrons and can be used in future theoretical and experimental studies of these elements involving K-electron conversion spectroscopy. As a by-product of our work, we performed systematic calculations of K (1s) and L (2s) ionization potentials for the neutral atoms from hydrogen to lawrencium and obtained excellent agreement with experiment. The major cause of the 5–10 eV deviation from experiment seems to come from solid-state effects present in the experimental data.

## PUBLICATIONS

1. *Theoretical description of superheavy nuclei*, **W. Nazarewicz**, M. Bender, S. Ćwiok, P.H. Heenen, A.T. Kruppa, P.-G. Reinhard, T. Vertse, Nucl. Phys. **A701** (2002) 165c
2. *Mass number dependence of nuclear pairing*, S. Hilaire, J.-F. Berger, M. Girod, **W. Satuła**, P. Schuck, Phys. Lett. **B531** (2002) 61
3. *Highly deformed band structure in  $^{57}\text{Co}$* , W. Reviol, D.G. Sarantites, R.J. Charity, V. Tomov, **J. Dobaczewski**, D. Rudolph, R.M. Clark, M. Cromaz, P. Fallon, A.O. Macchiavelli, M.P. Carpenter, D. Seweryniak, Phys. Rev. **C65** (2002) 034309
4. *The shears mechanism in  $^{142}\text{Gd}$  in the Skyrme-Hartree-Fock method with the tilted-axis cranking*, **P. Olbratowski**, **J. Dobaczewski**, J. Dudek, T. Rząca-Urban, Z. Marcinkowska, R. M. Lieder, Acta Phys. Pol. **B33** (2002) 389
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6. *Mean-field and pairing properties of exotic nuclei: exploring the nuclear landscape*, **J. Dobaczewski**, **W. Nazarewicz**, Progress of Theoretical Physics **146** (2002) 70
7. *Nuclear ground-state properties from mean-field calculation*, **J. Dobaczewski**, **W. Nazarewicz**, M.V. Stoitsov, Eur. Phys. J. **A15** (2002) 21
8. *Role of chirality in angular momentum coupling for  $A\sim 130$  odd-odd triaxial nuclei:  $^{132}\text{La}$* , K. Starosta, C.J. Chiara, D.B. Fossan, T. Koike, T.T.S. Kuo, D.R. LaFosse, **S.G. Rohoziński**, Ch. Droste, T. Morek, J. Srebrny, Phys. Rev. **C65** (2002) 044328
9.  *$T=0$  neutron-proton pairing correlations in the superdeformed rotational bands around  $^{60}\text{Zn}$* , **J. Dobaczewski**, J. Dudek, R. Wyss, Phys. Rev. **C67** (2003) 034308

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11. *Comments on the nuclear symmetry energy*, **W. Satuła**, R. Wyss, Phys. Lett. **B572** (2003) 152
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## SCIENTIFIC DEGREES

### M.SC.

- Sebastian Głowacz, *Application of the method of isorotations to study pairing correlations in  $N=Z$  nuclei*, 2002.

## GRANTS FOR RESEARCH PROJECTS

### KBN GRANTS

- 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)

### GRANT OF THE POLISH-FRENCH COOPERATION POLONIUM:

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

### GRANT OF THE POLISH-WALLOON COOPERATION:

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

## 11 DIVISION FOR THEORY OF PARTICLES & ELEMENTARY INTERACTIONS

**Head:** Stefan Pokorski

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

**Postgraduate students:** 10

### 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 sub-structure 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 2002-2003 has been mainly focussed on physics beyond the Standard Model. The major part of altogether 96 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. 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 Grządkowski et al.

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 and on the link to flavour changing in the lepton sector have been published by members of the Division (Chankowski et al.). Models of neutrino masses have 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). 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.

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).

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2. *Comparison of the Fits to Data on Polarized Structure Functions and Spin Asymmetries*, **J. Bartelski**, S. Tatur, Physical Review D65, 034002 (1-7) (2002)
3. *A New Determination of Polarized Parton Densities in the Nucleon*, **J. Bartelski**, S. Tatur, Acta Physica Polonica B34, 2731-2740 (2003)
4. *Supersymmetry (at Large  $\tan \beta$ ) and Flavour Physics*, **P. Chankowski**, **J. Rosiek**, Acta Physica Polonica B33, 2329-2353 (2002)
5. *Correlation between  $\Delta m(s)$  and  $B^0(s, d) \rightarrow \mu^+ \mu^-$  in Supersymmetry at Large  $\tan \beta$* , **P. Chankowski**, A. Buras, **J. Rosiek**, **Ł. Ślavianowska**, Physics Letters B546, 96-107 (2002)
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44. *CJK-Improved LO Parton Distributions in the Real Photon and Their Experimental Uncertainties*, F. Cornet, P. Jankowski, **M. Krawczyk**, in Proc. of Photon 2003, Frascati, April 2003 (2003)
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91. *Neutrino Masses - Theory*, **S. Pokorski**, in *Neutrino Physics (Proceedings of The International School of Physics Enrico Fermi"*, Varenna (2002)), IOS Press, Amsterdam 2003, pp. 1 - 19
92. *Electroweak Breaking and Supersymmetry Breaking*, **S. Pokorski**, in Proc. of PASCOS Conference, Bombay, January 2003 (2003)
93. *Deconstructed U(1) and Supersymmetry Breaking*, E. Dudas, **A. Falkowski**, **S. Pokorski**, Phys. Lett. B568, 281 - 290 (2003)
94. *Chargino Searches at LEP for Complex MSSM Parameters*, **J. Rosiek**, N. Ghodbane, S. Katsanevas, I. Laktineh, Nuclear Physics B647, 190 - 214 (2000)
95. *On Tachyon Potential in Boundary String Field Theory and Problems with Boundary Fermions*, **P. Sulkowski**, Acta Physica Polonica B34, 4167 - 4183 (2003)
96. *On Suppressing the Higgsino Mediated Proton Decay in SUSY SO(10) GUT's*, **K. Turzyński**, JHEP 0210, 044 (2002)

## SCIENTIFIC DEGREES

### D.SC.

- Mikołaj Misiak, *Niewiodące poprawki QCD do rozpadu  $\bar{B} \rightarrow X_s \gamma$  (Next-to-Leading QCD Corrections to the  $\bar{B} \rightarrow X_s \gamma$  Decay)*

**PH.D.**

- Rafał Ciesielski, *Stabilizacja pól modułów w teoriach supersymetrycznych (Stabilization of Moduli Fields in Supersymmetric Theories)*  
supervisor: Z. Lalak
- Adam Falkowski, *Models with Replicated Gauge Group*  
supervisor: S. Pokorski

**M.SC.**

- Krzysztof Rolbiecki, *Badanie sektora gaugin minimalnego modelu supersymetrycznego (Study on the Gaugino Sector of the Minimal Supersymmetric Model)*  
supervisor: J. Kalinowski
- Piotr Sułkowski, *Efektywne oddziaływania D-bran w teorii I superstrun (Effective Interactions of D-branes in Superstrings I Theory)*  
supervisor: J. Pawełczyk
- Jakub Wagner, *Efekty kwantowe w czterowymiarowych modelach wyższych wymiarów (Quantum Effects in Fourdimensional Models of Extra Dimensions)*  
supervisor: P. Chankowski
- Paweł Wąsowicz, *Niskoenergetyczne poprawki progowe do mas i kątów mieszania neutrin w MS i w MSSM (Low-energy Threshold Corrections to Masses and Mixing Angles of Neutrinos in MS and MSSM)*  
supervisor: P. Chankowski

**GRANTS FOR RESEARCH PROJECTS**

**KBN GRANTS**

- 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)
- Flavour Physics as a Laboratory for beyond the Standard Model Theories (2003-2004)
- 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)
- Branes: their Dynamics and Application to Unification of Fundamental Interactions (2003-2005)

- Parameters of the Supersymmetric Model from the Accelerator Experiments (2003-2005)
- Physics at TESLA (2003-2005)

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

- Study of Rare Processes in the Standard Model and Its Extensions (2002)
- Physics of Extra Dimensions (2002-2003)
- Unification of Fundamental Interactions in the Framework of Brane Worlds (2002-2003)

**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)
- European Investigation of Daphne and Other International Collider Experiments Using Effective Theories of Colours and Flavours for High Precision Elementary Particles Physics from the Phi to the Upsilon (2002-2006)

**WORKSHOPS AND CONFERENCES**

- Fifth European Meeting *From the Planck Scale to the Electroweak Scale: Supersymmetry and Brane Worlds*, Kazimierz, May 25-29, 2002

**AWARDS AND HONOURS**

- S. Pokorski, Officer's Cross of Polonia Restituta Order, 2002
- S. Pokorski, Marian Smoluchowski Medal, 2003
- S. Pokorski, A. Humboldt Research Award, 2003



## 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

### 12.1 SCIENTIFIC ACTIVITIES

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

- Theory of effective interactions of quarks and gluons.
- Renormalization group procedure for hamiltonians in quantum field theory and its application in particle physics.
- Universality and limit cycle in quantum mechanics.
- Singularities of multipoint Green functions in model quantum field theories.
- 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 Hamiltonian QCD. It turned out that this coupling constant depends on the inverse size of effective gluons,  $\lambda$ , in exactly the same way as the usual running coupling constant depends on the renormalization scale in Feynman diagrams. His method was then used to calculate the Hamiltonian  $H_\lambda$  for constituent quarks and gluons from first principles using perturbation theory, which applies as long as  $\lambda$  is much larger than  $\Lambda_{QCD}$ . This  $H_\lambda$  defines the Schrödinger equation that should describe hadrons when solved on a computer.
- Głazek and Masłowski explained how one can construct the Poincaré algebra for effective particles in the same approach to interacting quantum field theory (QFT). They have shown how quantum states of extended, composite particles transform under the full Poincaré group in the Fock space, where their composite nature is under explicit control in terms of wave functions.

- Głazek and Więckowski have described the entire program of solving QFT using this method on the example of Yukawa-like theories. They have shown that the form factors  $f_\lambda$  that appear in the interaction vertices for effective particles as a result of solving renormalization group (RG) equations for Hamiltonians remove ultraviolet (UV) divergences from the few-body effective particle dynamics. This is why the effective particle approach is free from the UV divergences that plague other approaches and has a chance to converge in the effective-particle basis in the Fock space.
- Głazek and Szczepaniak have constructed a simplified constituent model for decays of hybrids according to the rules implied by analogy with the Hamiltonian  $H_\lambda$  in QCD. They have shown that one can satisfy constraints of the special relativity symmetry on the decay amplitude despite the limitation of the Hilbert space to only a few particles because the form factors  $f_\lambda$  contribute to the amplitude and allow us to preserve the symmetry in the model through adjustment of the parameters in the wave functions of the hybrid and mesons that come out of the decay. The model hybrid-structure appears to resemble a gluonium built from two constituent gluons in which one gluon is replaced by a fermion-antifermion pair.
- Głazek and Młynik performed extensive numerical studies of exactly soluble matrix models of theories with asymptotic freedom and bound states. In these studies, they have tested the RG group methods for Hamiltonians in great detail and they have found that in the models one can reach 1% accuracy in calculations of the bound state energy. The RG procedures they developed, including also the case where they used Wegner's flow equation, must be optimized in order to reach such high precision when the effective coupling constant becomes comparable with 1 (a typical situation in QCD). They have found a set of practical rules that must be observed in procedures for solving the Schrödinger equation with  $H_\lambda$  numerically when one aims at 10% accuracy. Once these rules are known, one can apply them in the process of solving eigenvalue equation for  $H_\lambda$  in QCD.
- Narębski has applied an early version of this approach to study van der Waals forces between heavy quarkonia. In the simplest version of the procedure in lowest order of perturbation theory, he found that the resulting forces are on the border of parameters allowed by experiment if one assumed absence of many-body states in the effective particle dynamics. But if these states are allowed, as they should, the scheme is expected to remain well in agreement with the experimental bounds on the van der Waals forces between hadrons. In any case, the approach avoids problems with spurious van der Waals effects of typical potential models that are based on color-sensitive forces but do not include self-interactions that naturally appear in effective QCD.
- Głazek has applied his renormalization group procedure for effective particles to QCD with only one flavor of quarks with large mass  $m$  in order to calculate light-front Hamiltonians for heavy quarkonia,  $H_\lambda$ , using perturbative expansion in the

coupling constant  $\alpha_\lambda$ , where  $\lambda$  is the renormalization group parameter with the interpretation of an inverse of the spatial size of the color charge distribution in the effective quarks and gluons. The eigenvalue equation for  $H_\lambda$  couples quark-anti-quark states with sectors of a larger number of constituents. The coupling to states with more than one effective gluon, and interactions in the quark-anti-quark-gluon sector, are removed at the price of introducing an ansatz for the gluon mass,  $\mu^2$ . The simplified equation was used to evaluate a new Hamiltonian of order  $\alpha_\lambda$  that acts only in the effective quark-anti-quark sector. In the non-relativistic limit, this Hamiltonian turns out to contain the Coulomb term with Breit-Fermi corrections and a new, spin-independent harmonic oscillator term with frequency  $\omega = [(4/3)(\alpha_\lambda/\pi)]^{1/2} \lambda(\lambda/m)^2 (\pi/1152)^{1/4}$ . The latter originates from the hole excavated in the overlapping quark self-interaction gluon clouds by the exchange of effective gluons between the quarks. The new term is largely independent of the details of  $\mu^2$  and in principle can fit into the ball park of phenomenology. The first approximation can be improved by including more terms in  $H_\lambda$  and solving the eigenvalue equations numerically.

- Masłowski used a similar idea to calculate in pure glue QCD the effective dynamics of gluons in gluonium. He constructed a basis of states for gluons of width  $\lambda$  in which he was able to define an effective mass for gluons in three-gluon states, remove all small- $x$  divergences from the Schrödinger equation for gluonium built from two constituent gluons, and solve it for a whole set of eigenstates. He obtained gluonium masses of similar size to lattice results, but his method applies to many states, including excited ones, and can handle gluonium in arbitrary motion as a whole, which is impossible on the lattice. This work is being submitted as his Ph. D. Thesis.
- Głazek and Wilson have discovered a model of limit cycles in quantum mechanics that they could solve exactly. They have described features of universality and generic properties of marginal operators in the case of limit cycle using this model with great numerical precision, and they have shown the complete procedure of tuning a Hamiltonian to approach a limit cycle as close as possible. The same principles can be used in condensed matter, nuclear, and particle physics.
- 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 reasonable 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. *Gluon coupling strength in  $H(QCD)$  with small cutoffs*, **S.D. Glazek**, Nucl. Phys. B(Proc. Suppl.) **108**, 170(2002).
2. *Renormalized Poincaré algebra for effective particles in quantum field theory*, **S.D. Glazek**, **T. Masłowski**, Physical Review D **65**, 065011 (2002).
3. *Large momentum convergence of Hamiltonian bound state dynamics of effective fermions in quantum field theory*, **S.D. Glazek**, **M. Więckowski**, Physical Review D **66**, 016001 (2002).
4. *Renormalization group and special relativity in the Fock space*, **S.D. Glazek**, Acta Physica Slovaca **52**, 581 (2002).
5. *Limit cycles in quantum theories*, **S.D. Glazek**, K.G. Wilson, Physical Review Letters **89**, 230401 (2002).
6. *Special relativity constraints on an effective constituent theory of hybrids*, **S.D. Glazek**, A. Szczepaniak, Physical Review **D67**, 034019 (2003).
7. *Optimization of perturbative similarity renormalization group for Hamiltonians with asymptotic freedom and bound states*, **S.D. Glazek**, **J. Młynik**, Physical Review **D67**, 045001 (2003).
8. *Accuracy estimate for a relativistic Hamiltonian approach to bound-state problems in theories with asymptotic freedom*, **S.D. Glazek**, **J. Młynik**, Acta Physica Polonica **B35**, 723 (2004).
9. *Color van der Waals forces between heavy quarkonia in effective QCD*, **J. Narębski**, Modern Physics Letters **A19**, 307 (2004).
10. *Harmonic oscillator force between heavy quarks*, **S.D. Glazek**, Physical Review **D69**, 065002 (2004).
11. *Universality, marginal operators, and limit cycles*, **S.D. Glazek**, K.G. Wilson, Physical Review **B69**, 094304 (2004).

## 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 Ruszczycki, *Hadrons in Heavy Quark System*, 2001, supervisor J. Namysłowski.
- Michał Kulik, *Interactive Computer Program for Learning about the Lorentz Transformation*, 2003, supervisor S. Glazek.

## 13 DIVISION OF THEORY OF SOLID STATE

**Head:** Witold Bardyszewski

**Academic staff:** Jerzy Krupski, Krzysztof Byczuk, 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, propagation of elastic waves in random media and light propagation in optoelectronic devices formed separate additional subjects of interest not directly related to the main stream of our activities.

### SCIENTIFIC ACHIEVEMENTS

- 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)
- 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)
- An efficient random walk method was proposed for modeling the polarization mode dispersion in optical waveguides. (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)
- 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)
- 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)
- A self-consistent theory of metal-insulator transitions induced by electronic correlations and disordered was developed and the phase diagram of the disordered Hubbard model was obtained within the dynamical mean-field theory. (Byczuk)
- An estimate of the quantum optical communication rates through an amplifying random medium using the scattering matrix approach was proposed. (Tworzydło).
- Hypersensitivity to perturbations of quantum-chaotic wave-packet dynamics was examined in the context of the problem of the Loschmidt echo. (Tworzydło)
- The quantum mechanical limits to the plasmon-assisted entanglement transfer were analysed. (Tworzydło)
- 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 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. *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.
2. *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.
3. *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.
4. *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.
5. *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
6. *A Random Walk Procedure for Evaluating Probability Distribution Functions in Communication Systems*, D. Yevick and **W. Bardyszewski**, IEEE Photonics Technology Letters, **16**, 108, (2004)
7. *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
8. *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
9. *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.
10. *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.

11. *Ordered magnetic phase in  $Cd_{1-x}Mn_xTe/Cd_{1-y-z}Mg_yZn_zTe:N$  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.
12. *Resonant exciton contributions to quantum-well electroabsorption* **W. Bardyszewski**, D. Yevick, C. Rolland, E. Dupont, Phys. Rev. B **60**, 16563 (1999)
13. *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.
14. *Mott-Hubbard transition vs. Anderson localization of correlated, disordered electrons*, **K. Byczuk**, W. Hofstetter, D. Vollhardt, cond-mat/0403765.
15. *Mott-Hubbard metal-insulator transition at non-integer filling*, **K. Byczuk**, W. Hofstetter, D. Vollhardt, Phys. Rev. B **69**, 045112 (2004).
16. *Ferromagnetism and Metal-Insulator Transition in the Disordered Hubbard Model*, **K. Byczuk**, M. Ulmke, D. Vollhardt, Phys. Rev. Lett. **90**, 196403 (2003).
17. *Theory of superconducting fluctuations in the thinnest carbon nanotubes*, **K. Byczuk**, cond-mat/0206086.
18. *Phenomenological Modeling of Photoemission Spectra in Strongly Correlated Electron Systems*, **K. Byczuk**, R. Bulla, R. Claessen, D. Vollhardt, Int. J. Mod. Phys. B **16**, 3759 (2002).
19. *Derivation of the Curie-Weiss Law in Dynamical Mean-Field Theory*, **K. Byczuk**, D. Vollhardt, Phys. Rev. B **65**, 134433 (2002)
20. *Spin configuration of carbon nanotube in a nonuniform external potential*, Y. Oreg, **K. Byczuk**, B.I. Halperin, Phys.Rev.Lett. **85**, 365 (2000).
21. *Realistic Electron-Electron Interaction in a Quantum Wire*, **K. Byczuk**, T. Dietl, Phys.Rev. B **60**, 1507 (1999).
22. *Spin-Charge Separated Luttinger Liquid in the Magnetic Field*, **K. Byczuk**, Phys.Rev.B **57** 3821-3828, (1998).
23. *Low Temperature Electron Mobility in Delta Doped Semiconductor*, **J. Krupski**, 105th Annual Meeting of the American Ceramic Society w Nashville, TN USA. Abstrakt nr AM-S11-59-2003 w Annual Meeting Abstracts, invited talk.
24. *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
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** 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. Piętko, Solid State Comm. **107** 141-144 (1998)
27. *Quantum-to-classical crossover of mesoscopic conductance fluctuations*, **J. Tworzydło**, A. Tajic, C.W.J. Beenakker, preprint cond-mat/0311283, Phys. Rev. B (in print)
28. *Scattering theory of plasmon-assisted entanglement transfer and distillation*, J.L. van Velsen, **J. Tworzydło**, and C.W.J. Beenakker, Phys. Rev. A **68**, 043807 (2003)



29. *Dynamical model for the quantum-to-classical crossover of shot noise*, **J. Tworzydło**, A. Tajic, H. Schomerus, C.W.J. Beenakker, Phys. Rev. B **68**, 115313 (2003)
30. *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
31. *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.
32. *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.
33. *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)
34. *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)
35. *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 międzypasmową w półprzewodnikach*  
supervisor W. Bardyszewski
- A. Kauch *Prądy nadprzewodzące w drutach kwantowych i nanorurkach węglowych.*  
supervisor K. Byczuk
- J. Simiński *Prądy w zwężających się złączach nadprzewodnik – metal – nadprzewodnik)*  
supervisor J. Tworzydło

## 14 DIVISION OF QUANTUM OPTICS AND ATOMIC PHYSICS

**Head:** Krzysztof Wódkiewicz

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

**Postgraduate Students:** 10

### 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
- Explicitly correlated basis sets for precise calculation of wave functions and energies of few electron atoms.
- Quantum Electrodynamics of nonrelativistic systems
- Precise calculation of QED effects in hydrogenic and few-electron atoms
- Physics of exotic atoms
- Parity nonconservation in atomic systems

### SCIENTIFIC ACHIEVEMENTS

- Gaussian operators play an important role in Quantum Optics and Quantum Information Science, both in discussions about conceptual issues and in practical applications. A systematic operator method characterizing such states has been proposed. Gaussian states have been investigated using the operator method, and associated Wigner's and Glauber's phase space functions.
- The optimal cloning of the spin coherent states in Hilbert spaces of different dimensionality  $d$  has been investigated. Explicit form of optimal cloning transformation for spin coherent states in the 3-dimensional space, analytical results for the fidelity of the optimal cloning in  $d = 3$  and  $d = 4$  as well as numerical results for higher dimensions have been obtained.

- Various aspects of quantum information theory such as the fidelity balance in quantum operations and the stochastic decoherence of qubits have been investigated.
- It is possible to describe noisy channels by a master equations that possess a memory kernel, leading to a replacement of white noise by colored noise. Using the random telegraph signal, an exact analytical solution to such an equation is presented. The conditions under which this leads to a completely positive, trace-preserving map are discussed.
- It has been shown, by solving numerically the time-dependent Schrödinger equation, that the resonant transmission of electrons through double barrier semiconductor hetero-structures can significantly be modified and controlled by intense laser fields. A new numerically stable algorithm for such problems has been developed. An electron-ion recombination in the presence of a very short laser pulse has been analyzed. In particular, the development of the  $x$ -ray spectrum as a function of time within the duration of the laser pulse has been investigated.
- The relativistic scattering processes 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 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.
- 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. Similar results hold for a parabolic quantum well.
- Two-loop corrections to the Lamb shift and the fine structure in hydrogen have been calculated, significantly improving QED test on hydrogen atom.
- Precise calculation of helium fine structure have been performed for the determination of the fine structure constant.
- Higher order relativistic and QED effects for  $2^3P_J$  states of helium have been obtained.
- Forbidden transitions in light atoms have been analyzed and previous results have been corrected.

- Radiative corrections to parity nonconserving transitions in atoms have been obtained.
- QED effects in Lithium atoms have been calculated with the high precision.

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27. *Vortices and stabilization of resonance states in crossed magnetic and electric fields*, **K. Krajewska, J.Z. Kamiński**, Phys. Rev. B **68**, 064418(6) (2003).
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32. *Dependence of strong-field photoelectron angular distributions on molecular orientation*, **A. Jaroń-Becker**, A. Becker, F.H.M. Faisal, J. Phys. B**36**, L375-380 (2003).

## GRANTS FOR RESEARCH PROJECTS

- K. Wódkiewicz, KBN 2 P03B 021 23, *Entanglement of Photons and Atoms*, (200-2004).
- K. Wódkiewicz, *Quantum entangled states of trapped particles* QUEST, HPRN-CT-2000-00121, (2001-2004).
- K. Wódkiewicz, KBN PBZ-MIN-008/P)3/2003, (*Quantum information and Engineering*), (2003-2006).

- *K. Pachucki, Precyzyjne policzenie poziomów energetycznych atomu helu w ramach elektrodynamiki kwantowej, 1999-2002.*
- *K. Pachucki, grant NATO: QED corrections to Parity Nonconservation in Heavy atoms, EST.CLG.979624, (2003-2004).*
- *K. Pachucki, grant EU: Novel Instrumentation for Precision Nuclear Experiments in Trap, HPRI-CT-2001-50034, (2002-2004).*
- *J. Kamiński, Control of quantum processes with external electromagnetic fields, (2000-2003).*

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