Self-presentation

1. **Name and Surname:** **Mariusz Piwiński**

2. **Owned diplomas, degrees - with the name, place and year of obtaining:**
   - 1997 r., Nicolaus Copernicus University (NCU) in Toruń, Master in Physics, “Construction of a system for recording fluorescence spectra of laser-induced tissues”,
   - 1997 r., Nicolaus Copernicus University (NCU) in Toruń, Teachers Training Course, Pedagogical Studies, diploma of graduation,
   - 2004 r., Nicolaus Copernicus University (NCU) in Toruń, Doctor of Physical Sciences in Physics, “Studies on inelastic electron – cadmium atom collisions”,
   - 2014 r., Postgraduate Studies "R&D Project Manager", WSB Schools of Banking, Toruń, diploma of graduation.

2.1. Certificates:

- European Computer Driving Licence (ECDL) examiner: standard level (2002) advanced level (2006), WebStarter (2008),
- Certificate Cisco CCNA (Cisco Certified Network Associate, 2002) and Fundamentals of Wireless LANs (2005) instructor of the Regional Networking Academy Cisco NCU and Networking Academy Cisco WFAiIS,
- Certificate Fundamentals of Java Programming (2004),
- Expert Certificate of PIPS (No. 101), Member of the Experts Chamber of Polish Information Processing Society,
- Microsoft Technology Associate: Networking Fundamentals (2011)
- Microsoft Technology Associate: Security Fundamentals (2011)
- Microsoft IT Academy Program: HTML5/IE9 (2011)
- Meru Certified Engineer, MCE Course (2013)
- Certificate of Expert Level instructor excellence Cisco Networking Academy® program (2013)
- Certificate of Expert Level instructor excellence Cisco Networking Academy® program (2014)

- Certificate Cisco Networking Academy, Introduction to Cybersecurity course (2015)
- Certificate of Expert Level instructor excellence Cisco Networking Academy® program (2015)
- Cisco Networking Academy® Mobility Fundamentals Series: Wireless LAN Networks (2016)
- Cisco Networking Academy® Mobility Fundamentals Series: Wireless Technology and Standards (2016)
- Cisco Networking Academy® Mobility Fundamentals Series: Wireless Router and Clients Configuration (2016)
- Cisco Networking Academy® Mobility Fundamentals Series: Wireless LAN Security course (2016)
- Cisco Networking Academy® Mobility Fundamentals Series: Bring Your Own Device (BYOD) (2016)
- Cisco Networking Academy® Mobility Fundamentals Series: Troubleshooting Wireless LANs (2017)
- Cisco Networking Academy® Cybersecurity Essentials (2017)
- Cisco Networking Academy® Mobility Fundamentals (2017)
- Emerging Technologies Workshop: Network Programmability with Cisco APIC-EM (2018)

3. Information on previous employment in scientific institutions:

- 01.10.1996 – 31.07.1997, assistant – trainee at the Department of Gas Phase Spectroscopy, Institute of Physics, Nicolaus Copernicus University in Toruń,
- 01.10.2000 – 30.09.2004, assistant at the Department of Gas Phase Spectroscopy, Institute of Physics, Nicolaus Copernicus University in Toruń,
- 01.10.2004 – 30.09.2016, assistant professor, Department of Atomic, Molecular and Optical Physics, Institute of Physics, Faculty of Physics, Astronomy and Informatics, Nicolaus Copernicus University in Toruń,
- 2004, one month postdoctoral research, Department of Experimental Physics, National University of Ireland, Maynooth, working in the group of prof. Ray O'Neill,

- 2009, 4 – month postdoctoral research, Center for Atomic, Molecular and Surface Physics, ARC Center for Antimatter–Matter Studies, School of Physics, The University of Western Australia, Perth – working in the group of prof. Jim Williams
- 01.10.2016 – present, senior lecturer, Department of Atomic, Molecular and Optical Physics, Institute of Physics, Faculty of Physics, Astronomy and Informatics, Nicolaus Copernicus University in Toruń,

4. Display of achievements according to art. 16 ust. 2 of the act of 14 March 2003 on Academic Degrees and Title and on Degrees and Title in the field of art (Dz. U. 2016 r. poz. 882 ze zm. w Dz. U. z 2016 r. poz. 1311.):

4.1. Title of the achievement

Study of inelastic electron atom collisions

4.2. Publications that are part of the achievement

As indicated above under the Act for a scientific achievement, I chose a monothematic set of 7 publications on the study of inelastic electron atom collision I have been involved in the recent years. Impact factor of the journals from the year of publication, numbers of citations (according to the base Web of Science) and estimated percentage of my contribution are given for each of the publications listed below. A detailed discussion of my contribution and of the contributions of the co-authors is in the attached statements and in the list of my research activities beyond the scope of the presented achievement (Appendix No. 3).

H1. M. Piwiński, D. Dziczek, Ł. Kłosowski, R. Srivastava and S. Chwirot, 2006, „Coincidence study of excitation of cadmium atoms by electron impact”, Journal of Physics B: At. Mol. Opt. Phys., **39**, no. 8, p. 1945-1953,
IF: 2,024, minist. points:20, number of citation: 15, my contribution: 80%

H2. Ł. Kłosowski, M. Piwiński, D. Dziczek, K. Pleskacz and S. Chwirot, 2009, „Coincidence measurements of electron-impact coherence parameters for e-He scattering in the full range of scattering angles", Physical Review A **80**, no.6, p. 062709-1-4, DOI: 10.1103/PhysRevA.80.062709,

IF: 2,866, minist. points: 24, number of citation: 10, my contribution: 40%

H3. M. Piwiński, Ł. Kłosowski, D. Dziczek, S. Chwirot, T. Das, R. Srivastava, A. D. Stauffer, C. J. Bostock, D.V. Fursa, and I. Bray, 2012, „Electron excitation of the 4 $^1P_1$ state of a zinc atom", Physical Review A **86**, no. 5, 052706-1-5, DOI: 10.1103/PhysRevA.86.052706,

IF: 3,042, minist. points: 40, number of citation: 10, my contribution: 70%

H4. M. Piwiński, Ł. Kłosowski, D. Dziczek, S. Chwirot, D.V. Fursa, and I. Bray, 2015, „4 $^1P_1$ Zn excitation by 80-eV electrons", Physical Review A **91**, no. 6, 062704-1-5, DOI: 10.1103/PhysRevA.91.062704,

IF: 2,765, minist. points: 35, number of citation: 5, my contribution: 75%

H5. M. Piwiński, Ł. Kłosowski, S. Chwirot, D.V. Fursa, I. Bray, T. Das, R. Srivastava, 2018, „Electron-impact coherence parameters for 4 $^1P_1$ excitation of zinc", Journal of Physics B: At. Mol. Opt. Phys., **51**, no. 8, p. 085002-1-7, DOI: 10.1088/1361-6455/aab5cd,

IF: 2,119, minist. points: 25, number of citation: 2, my contribution: 70%

H6. M. Piwiński, Ł. Kłosowski, S. Chwirot, 2018, „Peculiar energy–scattering angle dependence of the alignment angle of atoms excited by electron impact", Acta Physica Polonica A, **134**, no. 2, p. RK.134.2.1-1-4,

IF: 0,857, minist. points: 15, number of citation: 0, my contribution: 80%

H7. M. Piwiński, Ł. Kłosowski, 2018, „An efficient high-vacuum thermoelectric cold trap for metal atomic vapours", Vacuum, **156**, p. 154-156, DOI: 10.1016/j.vacuum.2018.07.026

IF: 2,067, minist. points: 25, number of citation: 0, my contribution: 70%

Total values for publications comprising the scientific achievement
IF: 15,74, minist. points: 184, number of citation: 42

4.3. Discussion of the scientific goal of the work and results achieved, together with a discussion of their possible applications.

In this self-presentation, the references to the publications are consistent with the numbering of the papers included in the scientific achievement (**H1-H7**) and those not included in the achievement (**A1-A20, C1-C34**) listed in Appendix No. 3. Indices A1-A20 and C1-C34 are given in brackets with reference numbers, which is additional information for the reader.

I. Introduction and motivation of research

Present technological progress would not be possible without preceding development of science in the field of basic research. A more comprehensive understanding of the phenomena in the field of fundamental interactions, which include the collision of electrons with atoms is not only important for cognitive reasons, but also contributes to the increase in the number of practical applications. An example is the increased interest in zinc as an element, which together with its compounds is a potential candidate to replace mercury in commonly used discharge lamps. The application of such a solution would significantly reduce the degradation of the natural environment by abandoning the widespread use of mercury and its compounds [1].

Moreover, the obtained experimental data on collision processes play a significant role in studying atmospheres of planets, stars and clouds of interstellar matter, where the phenomena of electron collisions with atoms are one of the main mechanisms of energy transfer. For example a presence of cadmium in interstellar matter, provides information about the processes of catching neutrons in nearby stars [2]. Quantitative studies on the presence of zinc provide valuable information on the chemical evolution of the stars [3,4]. Helium, just after hydrogen, is the most common element in the Universe. It is also observed in the atmosphere of giant gas planets such as Jupiter or Saturn. Therefore, it was predicted that it should also be present in atmospheres of exoplanets observed outside the Solar System [5]. Finally, this fact was confirmed by observations using the Hubble telescope [6].

An even stronger motivation to conduct experimental research is obtaining results that do not agree with the current theoretical predictions. This was recently the case with electron-zinc atom collisions, which in recent years has become a subject of great interest due to unexpected experimental results published by the group of prof. Williams [7]. The authors investigated inelastic collisions of spin-polarized electrons with zinc atoms. As a result of this process, the zinc atom was excited from the ground state $(3d^{10}4s^2)4^1S_0$ to $(3d^{10}4s5s)5^3S_1$ state. During the study the fluorescence polarization was measured (Stokes Parameters P_1, P_2, P_3) related to the transition excited atoms to the $(3d^{10}4s4p)4^3P_{0,1,2}$ state. As it turned out, the values of the Stokes parameter P_2 measured below the cascading threshold were different from zero, which was in contradiction to the theoretical predictions. That fact led to a discussion of scientists involved in collision physics [8,9,10] trying to explain this discrepancy. However, the lack of other experimental data in this area, resulting from the use of a very sophisticated research technique (polarized electron beam) made it impossible to carry out effective verification of the obtained results. Clayburn and Gay attempted to resolve this controversy independently undertaking similar experimental research [11]. Obtained results on parameters P_1 and P_3 confirmed previous studies. However, in the case of the parameter P_2 measured below the cascade threshold, they received a zero value, which is fully consistent with theoretical predictions, but contradicting the data of the Australian group. Both the experimental groups reported that the experiments were repeated many times to rule out possible errors. Therefore, these discrepancies have not been definitively resolved and require a deeper analysis.

There are many different experiments involving studies of the collisional processes. In most of them, the obtained results are averaged over unobserved parameters. Such studies may include, for example, measurements of differential cross-sections determining the probability of the investigated physical process [12]. Due to the dynamic development of the experimental technique, it is possible to carry out more complex experiments that allow for a better understanding of the studied phenomena. This enables more accurate description of the observed processes. In 1969, Benjamin Bederson proposed the so-called “a complete scattering experiment” that would allow to determine all the scattering amplitudes, thus allowing to obtain a full (in the quantum-mechanical sense) information about the collision process [13,14]. The results of such studies would be the best source of data for testing the proposed theoretical models.

The first realization of that postulate (although partial, because of the impossibility to determine the sign of the momentum transfer parameter) were measurements of the angular correlations using the electron-photon coincidence technique concerning the electron impact excitation of helium atoms to the 3^1P state [15,16]. These investigations allowed to determine the scattering amplitudes of electronic excitation of helium atoms to the 3^1P. Only the use of the electron-photon coincidence method in the coherence analysis version, consisting of coincidence measurements of the polarization state of the emitted radiation, allowed for a full description of the studied phenomenon [17].

Technological progress in research equipment, in particular fast pulse electronics and efficient detectors (for photons and electrons) working in the counting mode, has made the technique used (in the course of the following years) to conduct research on calcium [18], magnesium [19] and strontium [20]. All these elements have in the ground state two valence electrons outside completely closed shells, which makes research on them a natural extension of research on helium. However, much more interesting subject of research seem to be the atoms belonging to the 12th group (IIB), such as zinc and cadmium. Due to the fact that their electron configuration is similar to alkaline earth metals (group IIA, two valence electrons outside the completely closed shells), such studies give the possibility for observation increasing impact of the fine structure and the spin dependent interactions on the collision excitation process. This impact could be manifested, for example, by the lack of full coherence of the collision, which can be verified in this type of experiment. In addition, a comparison of the data for zinc and calcium as well as cadmium and strontium would allow obtaining information on the effect of a closed subshell $(n\text{-}1)d^{10}$ on the collision process.

The measurements on cadmium and zinc atoms lead to experimental difficulties resulting from the wavelength of the analysed radiation (228.8 nm for Cd 5^1P_1 and 213.9 nm for Zn 4^1P_1, respectively). Also, the study on helium atoms was not a simple task due to radiation with a wavelength of 58.4 nm, which forces detection inside the vacuum system using a channel electron multiplier. The cognitive aspect of the presented research is emphasized by the fact that the presented works are the first and still only experimental results describing collision parameters of cadmium and zinc atoms.

II. Electron Impact Coherence Parameters

The aim of the research was to determine the so-called Electron Impact Coherence Parameters (EICP) describing electron atom collision. These parameters, apart from differential cross-sections, are the fundamental physical quantities describing the process of an energetically degenerated collision. Depending on the approach presented over the years, these parameters were variously defined in the literature, however, they most often carry equivalent information, and therefore there is a methodology that allows for the mutual conversion of their values [21]. As already mentioned, the results of such measurements allow to determine the phase relations between scattering amplitudes for collision excitations of various atomic states. Furthermore, they allow the determination of the shape (P_L parameter) and the alignment angle (γ parameter) of the angular distribution of the electron charge cloud of the excited atom and information on the angular momentum transfer ($L_\perp$ parameter). The graphic interpretation of these parameters is presented in Figure 1.

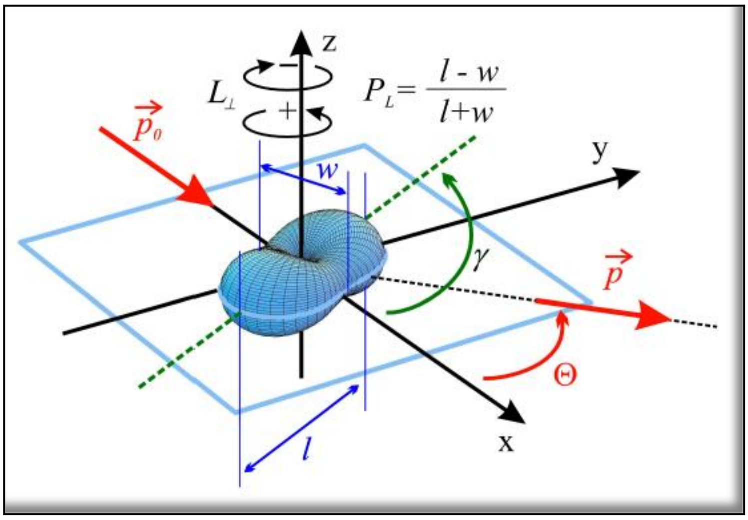

Figure 1 Example plot of the angular distribution of the electron charge cloud of excited atom to the *P* state.

Considering the collisional excitation of an atom from S_0 to P_1 state, the excited state is described as a coherent superposition of three magnetic sub-states. This phenomenon is described in a natural coordinate system for which the quantization axis is defined in a direction perpendicular to the collision plane (defined by the momentum vectors of the incident electron and scattered electron after the collision). With such assumptions, due to the reflective symmetry, only two sub-states make a non-zero contribution to this superposition. In this case, the excited *P* state can be expressed by their linear combination:

$$|P\rangle = a_{-1}|m_j = -1\rangle + a_{+1}|m_j = +1\rangle, \tag{1}$$

where a_{+1} and a_{-1} represents relevant excitation amplitudes.

The angular part of the electron charge cloud of the excited atom can be written in standard spherical coordinates as:

$$|\psi(\vartheta,\varphi)|^2 = \frac{3}{8\pi}\sin^2\vartheta\big(1 + P_L\cos(2\varphi - 2\gamma)\big), \tag{2}$$

where P_L is shape parameter and γ is alignment angle (Figure 1). The two parameters are related to the excitation amplitudes by following formulae:

$$\gamma = \frac{1}{2}\arg(-a_{-1}^* a_{+1}), \tag{3}$$

$$P_L = 2|a_{-1}^* a_{+1}|. \quad (4)$$

Another parameter needed for a complete description of the collision process is related to angular momentum transfer defined as:

$$L_\perp = |a_{+1}|^2 - |a_{-1}|^2. \quad (5)$$

In the case of a fully coherent scattering process the parameters P_L and $L_\perp$ fulfil equation:

$$L_\perp^2 + P_L^2 = 1. \quad (6)$$

In the so-called "fully complete experiments" there is the possibility of an experimental confirmation of the fulfilment of this condition, which is a very precise tool for studying the coherence of the observed process. In the case when the values obtained deviate significantly from unity, it may be an indication that the proposed model does not precisely describe the studied process. In some experimental realizations (electron-atom coincidence method in the angular correlation version) for technical reasons, it is not possible to directly measure the angular momentum transfer parameter. In such cases, if coherence of the process can be assumed, this value is calculated from the formula (6).

III. Experimental methods for determining EICP

There are several possible experimental implementations of the complete experiments postulated by Bederson:

a) superelastic collisions studies with optical pumping,

b) inelastic collision studies using electron-photon technique,

- angular correlation version,
- coherence analysis version.

a) Superelastic electron-atom collisions

In the case of superelastic research, the experiment is time reversed version of the analysed process. This means that in the first phase, the studied atoms should be prepared in a precisely defined (studied) quantum state. For this purpose, the atoms are illuminated by a suitably polarized laser beam propagating in the direction perpendicular to the scattering plane. Then such prepared atoms are bombarded by electrons of strictly defined energy. As a result of the collision, the atom may pass from the excited state to the ground state, and the surplus energy is transmitted to the scattered electron, which is observed at scattering angle Θ. Therefore, in the experiment the energy spectra of scattered electrons are observed (at the fixed scattering angles) for different polarization of the laser beam. As a result, differential cross-sections for superelastic collisions are obtained, which allow to determine the EICP values. However, this method has some very important limitations. The first of them results from the wavelength used. In the case when the excitation energy of the examined state is above 5 eV, the associated radiation will be in the UV range (wavelength shorter than 248 nm). In this case, it is not only problematic to find good quality polarisers and quarter-wave plates (with high extinction ratio and transmission), but above all, efficient and long-term stable lasers. At the current technological level, it is possible using laser systems equipped with non-linear frequency doubling systems. Due to the range of the fundamental wavelength obtained typically from solid-state lasers, in order to obtain, for example, radiation with a wavelength of 228.8 nm (state 5^1P_1 Cd), two such doubling systems should be used. Due to the non-linear nature of this phenomenon, each doubling is associated with a significant power loss (in the UV range, the efficiency is around 10%). As a result, commercially available solutions in the 213.9 nm range offer total power not exceeding 30 mW. Additionally, crystals working in the UV range are characterized by relatively rapid degradation during their work, which significantly increases experimental difficulties [22].

Due to the mentioned technical problems, this type of experiments were performed originally for calcium atoms. The relatively low excitation energy to the 4^1P_1 state (2.9 eV, 423 nm) allowed for use a commercially available laser system with relatively high power (150 mW), which was sufficient to excite about 45% of the population of calcium atoms in the interaction area [23]. In the following years, such experiments were also carried out for barium (554 nm) [24], ytterbium (556 nm) [25], silver (328.1 nm) [26] and magnesium (285 nm) [27].

The solution to the problem of providing sufficient UV radiation power may be to place the interaction area inside the optical resonance cavity. However, except the reports on the first apparatus test for calcium atoms (423 nm), no similar results for shorter wavelengths have been published so far [28].

Therefore, the described technique is very difficult to implement or even inaccessible to atoms such as cadmium (228.8 nm), zinc (213.9 nm) and helium (58.4 nm).

b) Inelastic electron-atom collisions (electron-photon coincidence technique)

In the case of coincidence electron-photon studies, the experiment involves the analysis of polarization of fluorescence from the excited state detected in coincidence with scattered electrons. In this type of experiments, the atoms are excited from the ground state to the investigated state as a result of a collision with electrons with strictly defined energy. Electrons

scattered
at a given angle Θ are analysed energetically in such a way that only the ones that excited the atom to the observed state reach the detector. At the same time, in the direction perpendicular to the collision plane, the polarization of the fluorescence emitted by the atom during the transition from the investigated state to the ground state is analysed. In this way, electron and photon signals are obtained, between which time correlation is measured. Signals coming from one collision act will appear in the coincidence spectrum as a peak (true coincidences). This peak will be visible above the background of the false coincidences, which are the result of stochastic time correlation between the electron and the photon, which did not come from one collision act. Due to technical reasons, in this type of experiments, the coincidence system is started by the electron signal and the photonic signal stops it. This requires the use of additional lines delaying the photonic signal. As a result, during the experiment, the so-called delayed coincidence spectra are determined for various positions of polarization analyser axis.

Finally, it allows to determine the number of true coincidences for each of the analyser positions, which leads to the calculation of the Stokes parameter values. Using the formulae below, they can be easily converted into EICP parameters.

$$P_L = \sqrt{P_1^2 + P_2^2}, \tag{7}$$

$$\gamma = \frac{1}{2}\arg(P_1 + iP_2), \tag{8}$$

$$L_\perp = -P_3. \tag{9}$$

Moreover, these data allows to determine the value of coherence parameter P^+ in accordance with the expression:

$$P^+ = \sqrt{P_1^2 + P_2^2 + P_3^2}, \tag{10}$$

resulting from equation (6). If the coherence condition of the examined process is fulfilled, the value of this parameter should be equal one.

The described measurement method is a very sensitive research tool due to taking measurements that do not require any additional normalization, or scaling based on other measurements, or theoretical data, as it is often the case for differential cross-sections. The possibility of a full description of the phenomenon (in the quantum-mechanical sense), is associated with a very long integration time of signals, resulting from the applied coincidence technique and relatively small counting rates of recorded signals. Moreover, with the increase of the scattering angle, the probability of an observed collision drops drastically. As a result, in the case of measurements for zinc atoms, the electron signal for the scattering angle 40° did not exceed 70 counts per second, with the photon signal at 1200 counts per second. It should be emphasized that the measurement concerns the timing coincidence between the two signals, for different polarization analyser axis settings (two for each of the Stokes parameters). Thus, for such experimental conditions, the measurement for one Stokes parameter (for one scattering angle) lasted continuously 27 days. This means that for the entire duration of the measurement (24 hours a day) it was necessary to ensure stable measurement conditions (stable electron and atomic beams). In addition, the electron energy loss spectrum was recorded periodically, making sure that the entire apparatus worked correctly. Due to the fact that the research concerned cadmium and zinc atoms, in order to avoid the deposition of metals on parts of the apparatus, an atomic trap had to be used. A typical problem in this type of beam experiments is the deposition of the studied atoms on different parts of the apparatus, which can lead to a change in the measurement conditions and even damage to the detectors. In the described experiments, the atomic trap used a reservoir with liquid nitrogen, which had to be periodically replenished.

In the case of measurements concerning helium atoms, the electron-photon coincidence method was used in the angular correlation version. In contrast to the coherence analysis method, it consists in coincidence registration of the angular distribution of emitted radiation in the scattering plane, because the photons emitted in this plane are linearly polarized. This technique allows obtaining equivalent information without the need to analyse the radiation polarization. In the case of the studied state of the helium atom (2^1P_1, excitation energy 22.4 eV), radiation with a wavelength of 58.4 nm was observed, for which the analysis of polarization causes technical problems. Therefore, using this method allowed to avoid these difficulties and to accomplish the assumed research goals. In conclusion, this method consists in registering the electron-photon coincidence for a specific scattering angle Θ and various angles ϕ at which photons are observed. Obtained results on the number of true coincidences as a function of the angle of photon observations allow to fit the curve determining the distribution of photon emission:

$$I(\phi) = \frac{1}{2\pi}[1 - P_L \cos(2\phi - 2\gamma)] \tag{11}$$

and determine the parameters γ and P_L. The disadvantage of this method is the inability to directly examine the $L_\perp$ parameter, which is calculated from equation (6) assuming complete coherence of the excitation process.

IV. Results obtained before PhD

A. Study on the 4^1P_1 calcium state

During the first phase of my research, I participated in conducting measurements on calcium atoms. The applied electron-photon coincidence technique in the coherence analysis version allowed obtaining EICP parameters concerning the 4^1P_1 calcium state for excitation energy 45 eV and 60 eV [29(A2)]. The experimental results agreed with the theoretical RDWA (Relativistic Distorted Wave Approximation) predictions. They also allowed to resolve the discrepancy between theoretical results [30] and existing experimental data for collision energy 45 eV [31], confirming the predicted character of functions describing the shape parameters P_L and alignment angle γ. The conducted research was not limited only to the EICP. As a result of the conducted experiments, it was also possible to determine the optical excitation function for $4\,^1P_1$ calcium state and polarization function of the emitted fluorescence (423 nm) [32(A1)].

B. Study on the 5^1P_1 cadmium state

After finishing the work on calcium, the subject of my further research became cadmium, which is much more interesting and more difficult to interpret due to a presence of the hyperfine structure. This element had not been systematically studied yet. The main experimental difficulty associated with these research was the analysis of radiation polarization with a wavelength of 228.8 nm. Commercially available polarizers working in this range are characterized by low transmission, which would significantly reduce the number of photon counts. Considering the fact that the applied technique concerns the registration of time coincidences between the electron and photon signals, it would mean a significant extension of the measurement time. This problem was solved by building a transmission type pile of plates polarizer that met the imposed requirements. In addition, the change in the wavelength required the optimization of the entire photon detection channel, including the use of a photomultiplier working in the ultraviolet radiation range. Due to the change of the studied element, a new source of the atomic beam was built equipped with a special set of collimators ensuring atomic beam divergence at the level of 5°. As a result of long-lasting measurements, EICP values for 5^1P_1 of cadmium state for 100 eV impact energy were obtained. They became a direct stimulus for the group of prof. Srivastava to carry out a series of new calculations using the RDWA approximation. The significance of the measurements carried out is evidenced by the fact that it was the first experimental complete set of EICP values for cadmium atoms. The obtained results show good agreement with theoretical predictions [33(A3)].

After receiving the first set of data for one electron energy, a decision was made to continue the research for lower collision energy (80 eV). The obtained data became the basis of my doctoral dissertation titled "Studies on inelastic electron – cadmium atom collisions". These results have been extended with polarization and optical excitation function study for the excitation of 5^1P_1 cadmium state [34(A4)]. In the case of the polarization function, they were the first experimental set of such data in the world, and in the case of the optical excitation function, significantly expanded the existing data in the higher energy range (up to 500 eV).

V. Description and motivation of achievement

The lack of experimental results describing the electronic excitation of the cadmium atom, suggested the need to carry out such measurements both in the wide range of collision energy and scattering angles. In addition, the analysis of the available literature data showed a complete lack of experimental results on the EICP data for the zinc atom, despite the large interest in this element, as the subject of electron-atom collision studies [35]. The main reason for this situation were already described experimental difficulties (radiation 213.9 nm). Moreover, the lack of experimental data used to verify the proposed models caused that the theoretical groups did not undertake research with zinc either.

Therefore, the long-range goal of further investigations was to measure the EICP values for cadmium and zinc in the wide range of energy and scattering angles. The comparison of several sets of experimental and theoretical data obtained for various collision energies for the same element made it possible to draw conclusions about the impact of incident electron energy on the observed process. Moreover, the comparison of cadmium and zinc data allowed to draw more general conclusions, and in the future perhaps even for the entire 12th group. Furthermore, moving to heavier elements one can expect an increase in the impact of the fine structure and spin effects on the collision process. This can be experimentally followed by examining the degree of coherence of the observed process (P^+ coherence parameter). In addition, the final comparison of the data obtained for zinc and calcium as well as cadmium and strontium will allow to obtain information on the effect of a closed subshell $(n\text{-}1)d^{10}$ on the investigated collision process.

The execution of the above described long-term research program requires obtaining EICP values for cadmium, zinc, calcium and strontium atoms in the possible wide range of impact energy and scattering angles. The obtained experimental results are a strong motivation for theoretical groups to develop and compare different theoretical approaches, thus such data have big influence on the development of models describing the electron-atom collisions. As already mentioned at the current technical stage, such studies on cadmium and zinc atoms are possible only using the electron-photon coincidence method. This means that it is the most time-consuming (several weeks of continuous measurements for one experimental point) and the most difficult (detection in UV radiation) phase of the planned research.

The situation is quite different for calcium atoms (423 nm). For this element there are several sets of EICP values for different collision energies, obtained by electron-photon coincidence (by our research group) [29] and using a much faster superelastic method with optical pumping technique [36]. In the case of strontium atoms (461 nm) there are three sets of EICP data obtained using the electron-photon coincidence method [20, 37]. Due to the fact that studies on calcium and strontium atoms were carried out by various research groups, over a different period of time, they relate to various collision energies. This can make direct comparison difficult. However, in case of doubt it will be possible to carry out additional measurements using the fast superelastic method.

The increasing computing power of computers causes that numerical calculations for one collision energy do not take weeks, but rather days or hours. Thus, it became possible to generate EICP values not for a few selected energies, but for a wide range of collision energy (e.g. with a resolution of 1 eV). Such data will create EICP maps, which will allow for better comparison of the data between the proposed models and will help to find more general trends and differences between the examined elements. In this case, the obtained experimental data for different energies will be control points on a multidimensional EICP map. Moreover, such data will be a kind of signpost, indicating the experimental groups interesting structures that can become the object of new precise research. Therefore the comparison of EICP values between different elements does not necessarily require obtaining experimental results for exactly the same impact energy.

Analysing the available experimental data on the various atoms that are subject of this type of research, one can see that there are no results regarding large scattering angles. On the other hand, the data presented in the theoretical papers contain graphs for the full range of scattering angles, while showing a rich structure for their larger values. Thus, this region is very interesting area for experimental research. The problem of their implementation results from the fact that for increasing scattering angle the differential cross-section of the studied process decreases drastically, which leads to an unacceptable increase in the duration of measurements. Therefore the interesting range of scattering angle seems at least at present to be beyond the scope of experimental research.

However, analysing data on differential cross-sections for electronic excitation of atoms to a specific state, it can be seen that the probability of excitation increases again for large scattering angles. Therefore, there is a chance of doing this type of experiments at very large scattering angles. Unfortunately, the geometry of the typical experimental systems used, due to the finite dimensions of both the electron gun and the electron energy analyser, makes it impossible to carry out measurements for such large scattering angles. It should be noted that this problem does not only concern the coincidence method, but also occurs in studies related to the determination of differential cross-sections. The solution may be the application of the local magnetic field method, which allows for conducting measurements in the full range of scattering angles. It involves the use of a Magnetic Angle Changer (MAC), which is a special system of solenoids, generating a localized static magnetic field with cylindrical symmetry relative to the propagation direction of the atomic beam [38,39]. This technique is being developed, which enabled to used it (for example) in differential cross sections measurements [40,41,42]. The sources of static magnetic field used so far were designed for electrons with energies not exceeding 75 eV. Their application to experiments with electrons with energy 100 eV was completely impossible due to the need to apply too high values of currents in order to obtain sufficiently strong magnetic fields. Moreover, due to the character of the carried out experiments, very often in the area of electron-atom collisions nonzero magnetic field was generated, and at most it was ensured that its value was constant in the largest possible area. In practice, this means that the field affects the observed process, which must be taken into account when analysing the obtained data. Therefore, constructing a source of a local magnetic field suitable for EICP measurements (zero magnetic field value in the impact area) would develop completely new experimental possibilities not only for the coincidence, but also for the superelastic collision method.

The scientific achievement of the habilitation was preparing and conducting of long-term coincidence EICP measurements (giving a complete description of the process) for cadmium and zinc atoms. It was the first (the most arduous) part of the described broad research

program. In the case of cadmium and zinc atoms, it was the first systematic analysis of the obtained EICP data for various collision energies. In addition, due to the complete lack of data on EICP parameters for zinc, it was a completely new research topic. The obtained results allowed
the theoretical groups to develop applied models by verifying theoretical predictions. This was especially applied to CCC (Convergent Close Coupling) approximation, where both databases of used functions describing states and applied relativistic corrections were verified.

In particular, for cadmium atoms, the models were used: RDWA (Relativistic Distorted Wave Approximation)[33(A3)] **[H1]**, RCCC(200) (Relativistic Convergent Close Coupling), CCC(183) (Convergent Close Coupling) and RDW (Relativistic Distorted Wave) [43]. The results for zinc atoms were used to create and verify models CCC(206) and RDWA for 100 eV **[H3]**, CCC(206), SC RDWA (Single Configuration Dirac-Fock Wave Function Fully Relativistic Distorted Wave Approximation) and MC RDWA (Multi Configuration Dirac-Fock Wave Function Fully Relativistic Distorted Wave Approximation)[44] **[H4]** for 80 eV, and CCC(206) with RDWA for 60 eV and 40 eV **[H5]**. By comparing the obtained experimental data and theoretical curves for the first time, general conclusions were drawn regarding the dependence of the variability of EICP parameters in the function of collision energy. Moreover, comparison of the results provided by various models (mainly RDWA and CCC (206)) allows for observation the characteristic differences in predictions provided by both approximations.

Obtaining a large amount of experimental data and their detailed analysis allowed us to observe characteristic 2-dimensional structures in the surface describing alignment angle of the electron charge cloud γ presented in the function of the scattering angle and impact energy. According to the theory, in the centre of such a structure, the γ parameter is undefined due to zero value of the shape parameter P_L (case of rotational symmetry). The narrow local character of these structures causes that they can be a very sensitive tool for comparing different results, including those provided by different theoretical models. Analysis of the available EICP data for other elements indicated a presence of such structures also for the following atoms: magnesium, calcium, strontium and barium **[H6]**. Therefore this work provides a very precise tool for comparing the EICP values predicted by different models, which can be tested in the vicinity of such structures. Moreover, such defined impact conditions (scattering angles and impact energies) due to the definition of the alignment angle γ and the shape parameter P_L (equations (3) and (4)) are an interesting place to conduct experimental research in order to better understand mutual relations between scattering amplitudes.

In order to carry out the EICP measurements in the full range of scattering angles, a new experimental technique using the local magnetic field together with the electron-photon coincidence technique was developed. A source of a local magnetic field has been designed and made, characterized by a zero magnetic field in the area of electron-atom interaction. This geometry ensures that the produced field has no influence on evolution of the observed state, while effectively changing the direction of incident and scattered electrons [45(A6),46(A7)]. As a result, for the first time in the world, the technique of the local magnetic field was used with the electron-photon coincidence method to carry out EICP measurements. The experiment was conducted for the 2^1P_1 helium state with excitation energy of 100 eV, for which no measurements for large scattering angles had been carried out until then. In particular, it was also possible to obtain data for 0° and 180° scattering angles **[H2]**. The described MAC can be used in all methods of EICP measurements and differential cross-sections studies, which significantly increases the potential of other experiments in the field of electron-atom collisions.

An important improvement of the research equipment was the design and construction of a new cold atomic trap used to capture the examined metal vapours (due to similarity of names, it should not be confused with the optical dipole trap or MOT trap). This trap uses thermoelectric modules placed in high vacuum conditions. Thanks to a special design allowing a significant reduction of the cooled volume, these modules maintain the atomic trap at -20°C with a consumed power of 3 W. This solution ensures that the magnetic field from the modules and supply wires in the collision area does not exceed 1 mGs, which does not affect practically the collision process **[H7]**. The presented solution is very universal and can be used for various metal beams such as calcium, zinc, cadmium, magnesium, strontium or barium.

Conducting long-term coincidence studies also entails significant costs resulting from the operation of the experimental apparatus. One of the significant cost is to maintain a working cold atomic trap that uses liquid nitrogen as a reservoir stabilizing its temperature. In the case of measurements lasting many months, the price of liquid nitrogen consumed (about 30 litters per day) is a significant cost of running the entire experiment. Therefore, the new thermoelectric cold atom trap used will solve this problem. The universality of the proposed solution causes that the described atomic trap can be used in various beam experiments influencing the development of this research field.

VI. Detailed description of the obtained results – the habilitation achievement

A. Study on the 5^1P_1 cadmium state

To execute the planned research goal, an experimental setup for measurements for lower energy collisions (60 eV) was prepared, which was associated with a significant increase in the difficulty of experimental work. For this purpose, the stability of the electron gun power supply system and the power supply of the electron energy analyser were increased. Moreover, due to the planned long-term measurements, a new atomic trap was designed and made, using an enlarged reservoir of liquid nitrogen (30 litters) with an external copper rod connected to the vacuum feedthrough (presented in **[H7]** as a liquid nitrogen trap). After modification of the apparatus, a short series of test measurements was carried out for previously obtained EICP values for 100 eV and 80 eV. The results confirmed previous data within experimental uncertainties. During the new measurements, Stokes parameters were obtained for 60 eV collision energy, which allowed for determination EICP values. The comparison of the received data with the theoretical predictions of RDWA revealed discrepancies, visible especially at the scattering angle 5° and 10° for the parameters P_2 and P_3. Thus, to verify the received data, the experiment was repeated for scattering angle 10°. The results obtained in independent measurement fully confirmed the previous data. The obtained experimentally parameter P^+ allows to check the coherence of the examined process. In the case of deviation from unity, it may also indicate systematic experimental errors (for example associated with the radiation trapping) resulting in lowering the value of the observed polarization. In this case, the P^+ parameter for all scattering angles in accordance with the theoretical predictions has the value of 1, thus the source of discrepancy remains unexplained. Preliminary results obtained for impact energy 60 eV were presented in the postconference paper [47(C7)]. Complete data sets (experimental with the First Born Approximation (FBA)) were published in a joint paper with prof. Srivastava (Indian Institute of Technology, Uttranchal) responsible for the theoretical RDWA model **[H1]**.

The obtained data contributed to establishing cooperation with the theoretical group (Prof. Fursa and Prof. Bray, Curtin University, Perth) and encouraged them to propose their theoretical description using CCC (Convergent Close Coupling) model. Finally, the experimentally obtained set of EICP values for three excitation energies (100 eV, 80 eV and 60 eV), together with previously published data on differential cross-sections [48], became the motivation for initiating new work of theoretical groups. In the joint publication of two theoretical groups [43] not only the CCC results were presented, but also RDW (Relativistic Distorted Wave) predictions, developed by prof. Stauffer (York University, Toronto) and prof. McEachran (Australian National University, Canberra). In particular, the results obtained in the RCCC (200) (Relative Convergent Close Coupling) approximation, CCC (183) (Convergent Close Coupling) and RDW (Relativistic Distorted Wave) were compared. It allowed to study the impact on the results of the number of considered states (given in brackets) and taking into account relativistic corrections. In their work, the authors used experimental data to verify the proposed models, not referring to the theoretical data of RDWA prof. Srivastava, which gave slightly different results than the results obtained by them at RDW approximation. In the conclusion of the work, it was written that the relativistic corrections included in the RCCC method only slightly improve the results in relation to the CCC predictions. Moreover, it was found that the RDW method gives better results for lower energy, which is in contradiction with the general intuition that this model should better describe the collision process for higher energies. However, the problem that remains unresolved is the discrepancy between experimental and theoretical results for small scattering angles for 60 eV collision energy.

The presented experimental results of EICP parameters for cadmium atoms are the only such results in the world.

B. Study on the 4^1P_1 zinc state

After the completion of a series of studies related to cadmium atoms, preparations were made to study electron-zinc collisions using the electron-photon coincidence method in the coherence analysis version. Due to the new research object and significantly higher melting temperatures of zinc (419.5°C) in relation to cadmium (321°C), the new source of the atomic beam together with the system of cold collimators forming the beam with a divergence not exceeding 4° was reconstructed. The execution of a series of measurement tests allowed to determine the appropriate operating conditions of the oven, ensuring the density of the atomic beam in the area of interaction at the level of 10^{10} atoms/cm^3. Such level of density ensures no radiation trapping effect, which was confirmed experimentally during non-coincidence fluorescence polarization measurements for various collision energies. The change in the analysed wavelength forced the need to modify the entire photon channel together with the change of high transmission broadband filter and optimization of the polarization analyser (quarter wave plate). The first preliminary results on the zinc atom EICP values were presented at the 63rd Annual Gaseous Electronics Conference and 7th International Conference on Reactive Plasmas conference in Paris (France) in 2010 and published in the postconference publication [49(C10)]. After the publication of cadmium and the GEC conference, closer cooperation was established with theoretical groups that were waiting for the end of the long-term measurement cycle. Finally, a full set of experimental data was published along with the predictions of three theoretical groups: prof. Srivastava together with prof. Stauffer preparing the description using RDWA model and prof. Fursa and prof. Bray responsible for CCC model **[H3]**. Due to the fact that the results for parameter P_2 (obtained for the scattering angle 15°) and P_1 (obtained for the scattering angle 25°) differed from the theoretical predictions, it was decided to repeat these measurements. Their results fully confirmed previous values.

In the case of CCC calculations the experimental results were used to test the relativistic effects included in the RCCC model. Therefore, two versions of calculations were made: for nonrelativistic approach (CCC (206)) and relativistic approach (RCCC). Although zinc is a relatively heavy atom, it was found that the obtained results do not differ significantly from each other, and therefore the results obtained in CCC (206) approximation were presented in the paper. This situation is interesting because in other papers concerning collisions of electrons with zinc atoms, the authors pointed to the existence of relativistic effects visible in the Sherman function measurement [50,51]. The best way to resolve these doubts would be to validate new calculations with experimental data for other excitation energies. Moreover, the theoretical curves obtained in CCC approximation seemed to better reflect the experimental results rather than the RDWA approximation. Thus, this work demonstrated the need for further experiments for lower collision energy.

During further work, we started measurements with electrons with energy of 80 eV. The first results were presented at the VIIth Workshop on Atomic and Molecular Physics conference in Jurata (Poland) in 2012, after which the postconference paper was published [52(A13)]. Due to technical problems with equipment and prolonged measurements, the group of prof. Srivastava decided to publish new theoretical data by comparing them to our published preliminary experimental results [53]. This paper presents two theoretical approaches RDWA in the SC (Single Configuration) and MC (Multi Configuration Wave Functions) versions. Due to the small amount of experimental data, it is difficult to refer to the correctness of the presented predictions. The final set of measurements for 80 eV was presented together with the results of CCC(206) model and earlier SC RDWA and MC RDWA data **[H4]**. The obtained theoretical CCC(206) results reflect the main trends visible in the experimental data. Much larger deviations from experimental results are visible for RDWA approximations, especially in the SC RDWA approach.

Due to interpretation, when comparing the results against each other, all EICP values obtained for a given scattering angle should be analysed at the same time. Theoretically, this can be done by defining a polarisation vector $\boldsymbol{P} = (P_1, P_2, P_3)$ and plotting it in a 3-dimensional coordinate system. This means that, in the case of a fully coherent process, all the vectors will lie on the Poincare sphere of unit radius. The lack of coherence will be visible by vectors lying inside this sphere. In practice, this way of presenting data is unfortunately illegible. Therefore, in a situation where one wants to observe general trends, the data are plotted on the graph, where P_1 and P_2 parameters are presented as a function of the scattering angle

$$P_1 + iP_2 = P_L \exp(2i\gamma) \; [21]. \tag{12}$$

In the above equation (12), P_L represents the length of the polarisation vector defined by P_1 and P_2, and 2γ is the angle between the P_1 axis and its direction. As a result, this graph can be treated as a projection 3-dimensional graph on a plane (P_1, P_2). In paper **[H4]**, due to the lucidity of the graph, the results presented in this form were limited to the scattering angles in the range from 0° to 45°. This graph allows to observe differences between data sets in a slightly different view.

Comparing the theoretical predictions obtained with the RDWA and CCC(206) models, one could notice differences that seemed to be more and more significant for lower collision energies. Therefore, experimental studies for lower electron energy (60 eV) were continued. Due to the observed increasing discrepancies between the obtained data sets, it was decided to carry out an unplanned series of measurements for 40 eV. Experimental and theoretical results (CCC(206) and RDWA) were presented in the publication **[H5]**.

In this work, in addition to the presentation of new data sets, for the first time, an attempt was made to draw broader conclusions on general trends and differences between theoretical and experimental results. As a result of the data analysis, the following conclusions were drawn:

- Discrepancies between theoretical and experimental data become greater as the collision energy decreases,

- For all energies, the characteristic structures of parameters P_L, γ and $L_\perp$ move towards higher scattering angles with the reduction of collision energy. This phenomenon can be intuitively explained as a manifestation of a longer interaction time of the electron with the atom during an impact. As shown in the paper, this conclusion fully agrees with the FBA theory, for which calculations were also carried out. This effect should be visible also in the case of other elements.
- In the case of the CCC model, the characteristic structures of the γ parameter are visible for slightly larger values of the scattering angle than for the RDWA model (approximately 5°).
- For all the examined collision energies, in the range of the scattering angle between 15° and 40° experimental data for the shape parameter P_L show two minima reproduced by the CCC(206) model. The RDWA model provides only one minimum around 35°. Analogous structures (two maxima for CCC(206) and one maximum for RDWA) are visible for the angular momentum transfer parameter $L_\perp$.
- In the case of all impact energies, there was no significant deviation of the P^+ parameter value from unity, which indicates that the examined collision process is coherent.
- It appears that the CCC(206) model reproduces experimental results better than the RDWA model.

The obtained data is the only set of EICP values for zinc atoms in the world and this is the first broader analysis of the EICP. This work completes the first (experimental) stage of a long-term research project. Over the years, theoretical models have undergone constant modifications and improvements, so a direct comparison of available theoretical data (old and new) may lead to false conclusions. Thus, at this stage talks with theoretical groups are conducted to generate new theoretical data for the calcium and strontium atoms, and also in the case of RDWA to verify them for cadmium.

Independently, a preliminary comparison was made for cadmium atoms (Figure 2-4). Due to the small differences between the results obtained for the RCCC(200) model and CCC(183), for simplicity, only CCC(183) data were used for comparison. The presented results of the RDWA model concern calculations for different energies that were performed in different years. This means that the model used has undergone some modifications and optimizations. In the case of the alignment angle parameter γ, the CCC(183) data are significantly different from the RDWA predictions, which may be surprising in view of the high consistency in the case of zinc atoms. On closer examination, it can be seen that this applies to 100 eV and

80 eV energy (older data), while the results for 60 eV (newer data) show a much greater similarity to the CCC(183) data. Therefore, it seems justified to re-verify the RDWA theoretical data. Nevertheless while waiting for new theoretical data, several general conclusions can be drawn at this stage:

- In contrast to the case of zinc atoms, the agreement between the theoretical and experimental data remains at a similar level for different collision energies.
- According to earlier conclusions for zinc, for all energies the characteristic structures of parameters P_L, γ and $L_\perp$ move towards higher scattering angles with decreasing impact energy, which agrees with FBA predictions.
- In contrast to the zinc atoms in the case of the CCC(183) model, the characteristic structures of the γ parameter are visible for slightly smaller values of the scattering angle than for the RDWA predictions (approximately 1°).
- In the structure of the shape parameter P_L in the range of the scattering angle between 15° and 40°, all data show only one minimum. Similarly, in the case of the angular momentum transfer parameter $L_\perp$ one maximum is visible.
- In the case of all impact energies, there was no significant deviation of the P^+ parameter value from unity, which indicates that the examined collision process is coherent.
- Both the CCC(183) and RDWA models reproduce all the structures visible in the experimental data, although in the case of RDWA they show much smaller amplitudes.

Final confirmation of these conclusions can be made after obtaining verified RDWA data.

Independently, theoretical groups are to provide theoretical data for a wide range of energy that will allow the creation of EICP maps. Thanks to this, it will be possible to better compare individual elements and draw more general conclusions. An example of colour EICP map for zinc atoms, generated from existing CCC(206) data is presented in Figure 5.

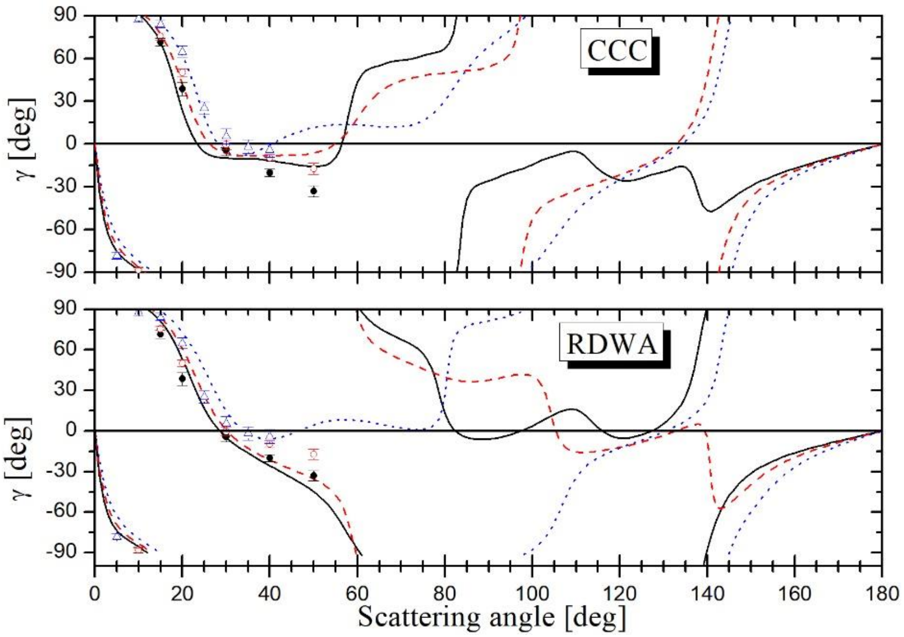

Figure 2 Alignment angle parameter for electronic excitation 5^1P_1 cadmium state. Experimental data: (●) 100 eV, (○) 80 eV, (△) 60 eV. Theoretical predictions: (CCC(183) i RDWA): (—)100 eV, (– –) 80 eV, (····) 60 eV **[H1]**.

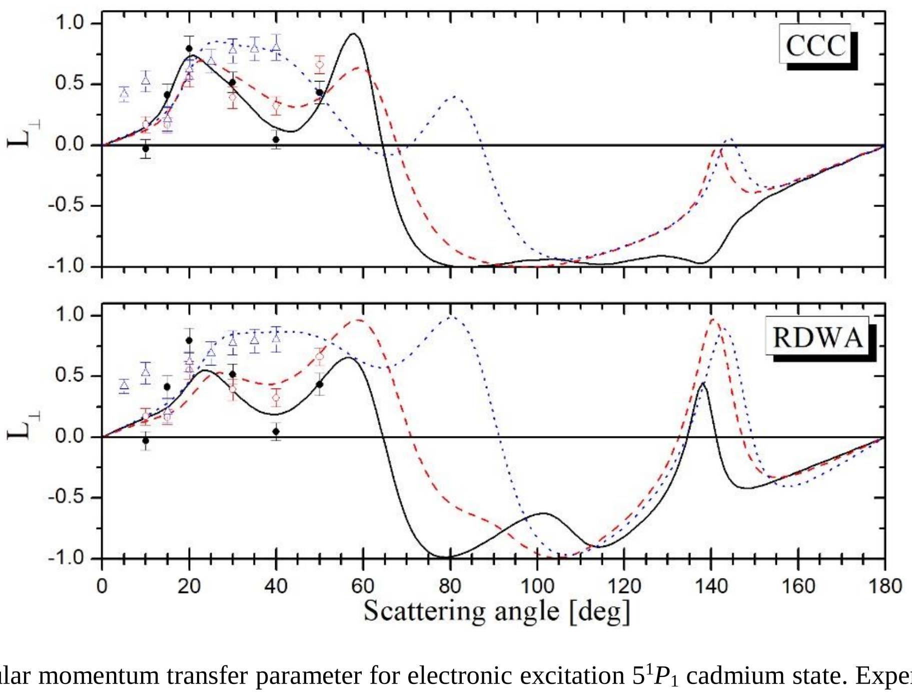

Figure 3 Angular momentum transfer parameter for electronic excitation 5^1P_1 cadmium state. Experimental data: (●) 100 eV, (○) 80 eV, (△) 60 eV. Theoretical predictions: (CCC(183) i RDWA): (—)100 eV, (– –) 80 eV, (····) 60 eV **[H1]**.

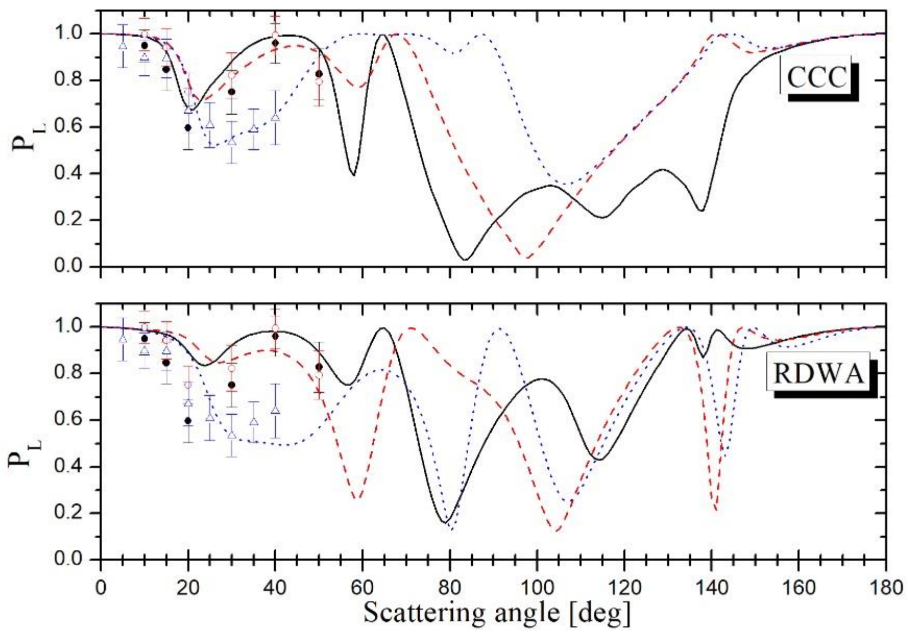

Figure 4 Shape parameter for electronic excitation 5^1P_1 cadmium state. Experimental data: (●) 100 eV, (○) 80 eV, (△) 60 eV. Theoretical predictions: (CCC(183) i RDWA): (—)100 eV, (– –) 80 eV,(····) 60 eV **[H1]**.

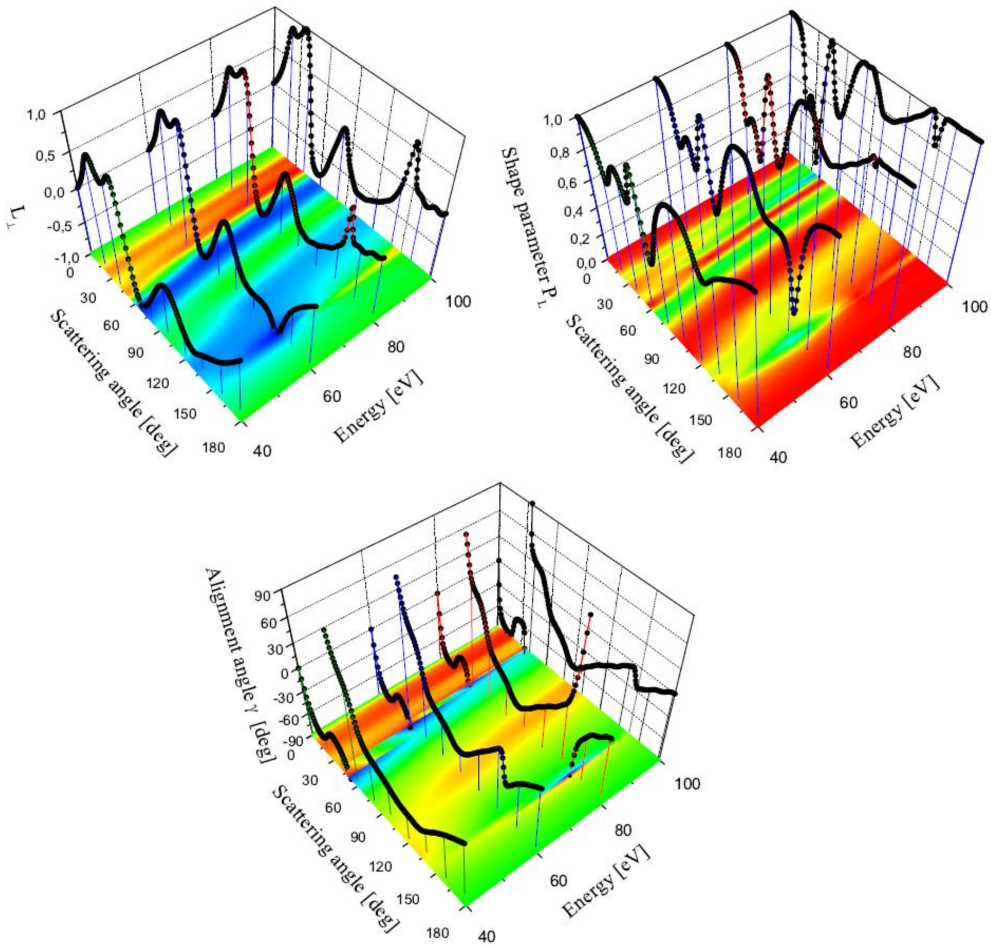

Figure 5 An example of the colour map of EICP extrapolated from CCC(206) for 4^1P_1 zinc state. Black curves show existing theoretical data. The red–blue colour palette was used for mapping EICP as follows: P_L (blue colour correspond to value of 0, and red value of 1), γ (blue colour correspond to value of -90°, and red value of +90°), $L_\perp$(blue colour is coding -1 value, and red +1 value) **[H5]**.

C. Peculiar structures in the alignment angle γ

Analysis of the obtained data as a function of the collision energy and the scattering angle allowed to observe the characteristic behaviour of the function of the alignment angle γ (Figure 6). This structure results directly from the definition of γ parameter (equation (3)), however, it is difficult (without additional data) to predict the experimental conditions for which it can be observed. This structure, due to its very rapid character, can be used to verify theoretical models. Moreover, this issue is a very interesting physical situation, because for such collision conditions one of the scattering channel is completely closed. It is manifested by reaching the maximum value of the parameter determining total angular momentum transfer $L_{\perp}$ during the collision and zeroing the shape parameter P_L. Ultimately, these structures were observed for zinc and cadmium atoms.

The conducted analysis indicated that such structures should appear also for other atoms. Unfortunately, due to the limited amount of systematic data on EICP, wider research in this area was difficult. Nevertheless, it was possible to indicate for several atoms the ranges of collision energy and the scattering angles for which this structure should be observed. Thus, these results may be stimulating also for other research groups. The described results were presented in the paper **[H6]**.

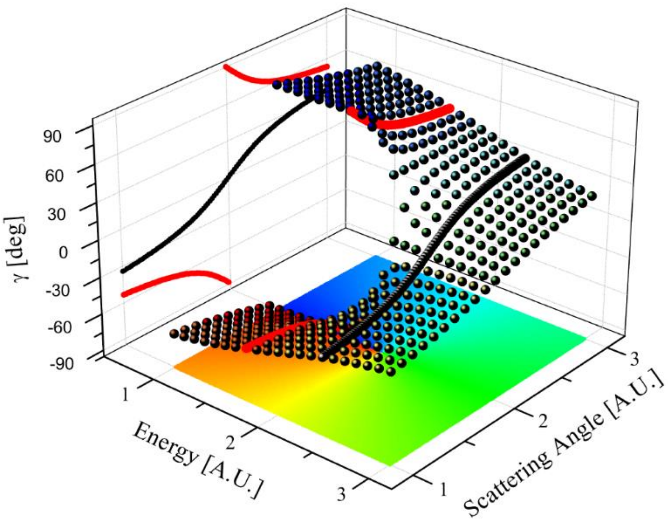

Figure 6 Illustration of the predicted behaviour of the alignment angle for the impact energy and the scattering angle in the neighbourhood of arbitrarily chosen values of these parameters. The 2D colour map represents the same function (from -90° red to +90° blue). Additionally 2D projections on the plane (γ, Θ) are presented for two values of the impact energy corresponding to two different modes in changes of the alignment angle with the scattering angle.

D. The local magnetic field method - 2^1P_1 helium state studies

Improving the research technique for the collisional experiments in the full range of scattering angles, the local magnetic field method was used. For this purpose, a magnetic angle changer was designed and built, which is a system of solenoids, generating a localized static magnetic field with cylindrical symmetry relative to the propagation direction of the atomic beam. Its very specific configuration ensures no impact on the examined collision process, while curving the paths of moving electrons, which effectively changes the angle at which they are observed. It means that the generated magnetic field should quickly vanish outside the coil (the zeroing condition of the magnetic dipole moment), and also has a zero value in the area of electron-atom collisions. A nonzero magnetic field in this area would result in an evolution of the excited state, which would modify the observed EICP values. Moreover, the whole device had to be adapted to the experimental conditions for the typical electron-photon coincidence measurements, associated with using photon and electron detectors, as well as the characteristic long-term conducting measurements. Therefore, care was taken to ensure a high stability of the source supplying the device to minimize the possibility of changes its value during a long measuring cycle. The constructed device enables electron-atom collision measurements
for electron energy up to 100 eV in the range of the full scattering angle using relatively small values of current (3A). This property is very important due to the fact that the described device works in high vacuum conditions. The first, test results of the device were presented at the conference VI Workshop on Atomic and Molecular Physics FAMO in Jurata (Poland) in 2006 and published in the reviewed postconference paper [54(A6)]. Optimized device was used for the test measurement of the EICP for the helium at 100 eV collision energy and scattering angles 23° and 33°. The obtained results (with the device turned on and off) showed full agreement and confirmed its effectiveness and lack of apparatus effects [55(A7)]. As a result, for the first time in the world, the technique of the local magnetic field was used with the electron-photon coincidence method to carry out EICP measurements.

After the test phase, EICP measurements were taken using electron-photon coincidence technique in the angular correlations version for the 2^1P_1 helium state (58.4 nm) with excitation energy 100 eV, for which there were no data in the range of large scattering angles. The first results of the work were presented at the 61st Annual Gaseous Electronics Conference in Dallas (Texas, USA) in 2008 and published in a short postconference paper [56(C8)]. The final full set of EICP data with results for scattering angles 0° and 180° were published in **[H2]**. The obtained experimental data on electronic excitation of 2^1P_1 helium state completed the results of the existing complete quantum-mechanical measurements with the values for large scattering angles, which are particularly important for the modelling of electron-atom interaction potentials. They allowed to shed a light on available theoretical data, however, they did not resolve which of the presented approaches is appropriate. The latest of the presented theoretical results were published in 1995 [57]. Due to the continuous development of theoretical models, new experimental data may be the motivation to carry out the new theoretical analysis of the studied process.

Independently to our work, experiments with the local magnetic field were conducted by a group using superelastic approach. However, the device they designed does not provide a zero magnetic field in the impact area. As a result, it leads to the evolution of the excited state by disturbing the measured parameters P_L and γ [58]. The analysis of this effect was carried out in detail in our publication [56(C8)]. Only taking this effect into account during the conducted research in the magnetic field allows to obtain complete information about the collision process [59]. The source of the local magnetic field designed by our group is devoid of this disadvantage and could be successfully used during superelastic and differential cross-sectional studies.

E. The atomic trap using thermoelectric modules

Effective atomic traps are a key element of the apparatus in research using atomic beams [60,61]. In the case of working with metals, the lack of an efficient device may result in the deposition of vapours on different parts of the apparatus, which contributes to various technical problems. Sometimes this can also lead to damage sensitive detectors, such as the channel electron multiplier. Therefore, in this type of research, cold atomic traps are most often used, in which the catching surface has a significantly lower temperature than other parts of the apparatus. As a result, atoms from the beam deposit on its surface, and not on other elements inside the vacuum chamber. Typical experimental devices use liquid nitrogen or dry ice as a cold medium that has a contact (direct or indirect) with the catching surface.

In the case of coincidence studies, their long-term nature also entails significant costs associated with the replenishment of this medium (e.g. 30 litters of liquid nitrogen per day).

In order to solve this problem, a cold atomic trap was designed and made using thermoelectric modules placed inside the vacuum chamber. The power of the modules used and the volume of the cooled element have a direct impact on the performance of such device. Placing this construction inside the vacuum optimized the entire system. Finally, it allows to maintain the surface catching atoms at a temperature of -20°C at the consumed power of only 3 W. Thus, the magnetic field coming from the modules and power wires in the collision area does not exceed 1 mGs, which is practically negligible **[H7]**.

The presented device can be successfully used in various beam experiments using such atoms as calcium, zinc, cadmium, magnesium, strontium and barium. Its simple design and low operating costs cause that such solutions will be widely used in research regarding not only EICP parameters but also differential cross sections.

VII. Summary of the achievement and its importance

As a result of the research carried out indicated in the scientific achievement:

A. The quantum mechanical data for the inelastic electron-atom collision process were obtained. In particular, they concerned:

- extension of the set of previously obtained data on EICP values for the 5^1P_1 cadmium state, (electron-photon coincidence method in the coherence analysis version, impact energy: 60 eV) ,**[H1]**
- obtaining new data on EICP values for the 4^1P_1 zinc state, (electron-photon coincidence method in the coherence analysis version, impact energy: 100 eV, 80 eV, 60 eV, 40 eV). **[H3, H4, H5]**

B. Experimental and theoretical data (models: CCC(206), SC RDWA and MC RDWA, RDWA, FBA) were compared for zinc atoms and the following conclusions were obtained:

- discrepancies between theoretical predictions and experimental results increase with the decrease of collision energy,
- there are differences between the results provided by the CCC(206) and RDWA model (in the case of parameter P_L two minima for CCC(206) and one for RDWA, in the case of the γ parameter, the structures for CCC(206) are visible for slightly larger values of the scattering angle than for the RDWA - the difference is around 5°),

- characteristic structures in the EICP move towards higher scattering angles with the reduction of collision energy - agreement with the FBA theory,
- for all collision energies, the values of parameter P^+ are not less than one, so the collision process is coherent,
- experimental results are better reproduced by the CCC(206) model than the RDWA. **[H3, H4, H5]**

C. Experimental and theoretical data (models RDWA, RDW, RCCC(200), CCC(183), FBA) for cadmium atoms were compared and the following conclusions were obtained:

- discrepancies between theoretical predictions and experimental results do not increase with the decrease of collision energy (no dependence of the magnitude of discrepancies on the collision energy),
- there are differences between the results provided by the CCC(183) model and RDWA (in the case of the γ parameter, the structures for CCC(183) are visible for slightly smaller values of the scattering angle than for the RDWA - the difference is around 1°),
- characteristic structures in the EICP are moving towards higher scattering angles with decreasing collision energy – agreement with FBA theory and conclusions for zinc,
- for all collision energies, the values of parameter P^+ are not less than one, so the collision process is coherent,
- both CCC(186) model and RDWA reproduce all structures visible in experimental data, however in the case of RDWA they show much smaller amplitudes. **[H1]**

D. In the obtained data for zinc and cadmium atoms specific structures appear in the alignment angle γ, which are predicted by theory. These structures are also indicated in the data on the atoms: magnesium, calcium, strontium and barium. **[H6]**

The importance of the results listed in points A, B, C and D

Obtained results are the only sets of EICP parameters for cadmium and zinc atoms in the world describing collisional excitation of atoms to the first P state. Completed measurements led to the development of theoretical descriptions modelling the electron-atom collision process studied (RDWA, RCCC(200), CCC(183), RDW, CCC(206), SC RDWA, MC

RDWA). In addition, they allowed to verify individual models and to study the impact of including relativistic effects on the quality of reproducing experimental results.

The conducted research is the first (experimental) part of a long-term project aimed at finding the characteristic features of EICP parameters for zinc and cadmium, as well as features common for the 12th group. Moreover, thanks to the comparison with the data for calcium and strontium, it will be possible to examine the effect of a fully closed subshell $(n-1)d^{10}$ on the investigated collision process. Thus, the obtained results became the motivation for theoretical groups to prepare EICP maps. This stage is currently in progress. **[H1, H3, H4, H5]**

The found peculiar structures in the alignment angle parameter can be used as a very sensitive tool for comparing different sets of data. In addition, a more accurate study of such areas will allow for better understanding of the phase relations between the scattering amplitudes. **[H6]**

E. The first in the world coincidence electron-photon measurements were performed using a local magnetic field source. The constructed device is characterized by a zero magnetic field in the area of electron-atom interaction. Helium results were obtained for 100 eV collision energy in the full range of scattering angle. In particular, measurements were made for the scattering angle 0° and 180°. **[H2]**

The importance of the results listed in point E

The obtained results completed data on the excitation of helium atoms to the 2^1P_1 state. They allowed to shade a light on available theoretical data, however, they did not resolve which of the presented approaches is appropriate. New experimental data may be the motivation to carry out the new theoretical analysis of the studied process.

The source of the local magnetic field designed by our group ensures zero magnetic field in the area of impact, so its use does not affect the investigated collision process. Therefore, it can be successfully used during electron-photon coincidence studies, superelastic scattering as well as differential cross sections measurements. **[H2]**

F. A cold atomic trap was designed and made using thermoelectric modules placed in the vacuum chamber. The device allows to maintain the surface catching atoms at -20°C using very low power (3 W), without disturbing the observed process of electron-atom collisions. **[H7]**

The importance of the results listed in point F

The trap can be used in various experiments with metal beams as: cadmium, zinc, barium, calcium or strontium. It is an ideal alternative to expensive traps using liquid nitrogen. In the case of long-term measurements (e.g. coincidence), its use will significantly reduce the total cost of conducting measurements.

5. Other scientific and research achievements

My other scientific achievements can be divided into three groups:

- **A.** Collisions between polarized electrons and atoms,
- **B.** Research in National Laboratory of Atomic, Molecular and Optical Physics (KL FAMO),
  - **B.1** Studies on ions in the ion traps,
  - **B.2** Construction of the Polish Optical Atomic Clock,
  - **B.3** Studies on the shapes of the spectral lines of the oxygen B-band,
  - **B.4** Construction of cryogenic system for line shape investigation,
- **C.** Research on the detection of neoplastic lesion in the Interdisciplinary Group of Optical Methods of Early Cancer Detection (IZOMWN) UMK.

A. Collisions between polarized electrons and atoms

During the postdoctoral training as part of the Australian Government's Endeavor Research Fellowship scholarship, I started working in the group of prof. Williams (Perth, Australia) conducting electron-atom collisions experiments using polarized electrons. Their goal is to obtain information on the impact of spin-orbit interactions on the collision process. The implementation of that research consists in the use of spin-polarized electrons, which allows control of spin momentum in the collision process. During experiments, the energy loss spectra of scattered electrons are analysed and fluorescence detected, which allows identification of excited states. Additionally, the measurement of its polarization makes it possible to draw conclusions about the angular momentum transfer in the scattering process and the spin-orbit interaction. This group was also famous for collision experiments using the triple coincidence (electron-photon-photon) technique in collision studies of 3^1D helium state (667.8 nm $3^1D \rightarrow 2^1P$, 58.4 nm $2^1P \rightarrow 1^1S$) [62]. So far, this is the only example of this type of measurements.

Research methods using polarized electrons entail many experimental difficulties. The main problem is the generation of a polarized electron beam. Its source is a GaAs crystal, which is heated under ultrahigh vacuum conditions (on the order of 10^{-10} mbar), and then exposed to cesium and oxygen to create a surface with Negative Electron Affinity (NEA). This surface is illuminated by a laser beam (830 nm) with variable circular polarization, which causes emission of electrons with different spin orientation (up or down). The electrons are collimated by the 23 electrodes to form an electron beam with the desired geometry and energy. An electron gun with a length of over 1 meter is connected to an experimental collision chamber. Systems of this type (there are only a few of them in the world) are used to study zinc atoms (an oven placed inside a collision chamber), gases (a nozzle with a precise gas dosing system), as well as surface measurements [63(C12)].

The motivation of my work was new theoretical results provided by prof. McEachran (Australian National University, Canbera) indicating the existence of very narrow resonances (as a function of collision energy - about 10 eV and scattering angle - about 5°) regarding asymmetry functions describing elastic electron-atom collisions (xenon and krypton). An experimental confirmation of these data would prove the correctness of the proposed theoretical description. As a result of my work, a new source of polarized electrons was launched and tested. The experimental setup was adapted for xenon studies. Finally, after the test phase, measurements were carried out for the asymmetry function (Sherman function) for elastic electron-xenon collisions. The obtained results confirmed theoretical predictions, however, with slightly different values of the scattering angle and collision energy, which is a further motivation to develop the theoretical description [64(A9)].

The importance of the results

The obtained results were used to confirm resonances in a Sherman functions predicted by the theoretical model. Moreover, experimental data allowed to prove that the use of imaginary absorption potential as a perturbation in the description of the process can sometimes lead to significant errors in obtained results. The extension of experimental investigations in the wide range of collision energy and scattering angles will enable verification of other effects predicted by the theoretical models.

B.1 Studies on ions in the ion traps

- Research in National Laboratory of Atomic, Molecular and Optical Physics

This work is carried out as part of the NCN OPUS project research led by dr. inż. Łukasz Kłosowski. The aim of the project was to implement a new method of ion production for the experiments with molecular ions in traps. For many kinds of molecular ions, the use of existing methods of their production such as photoionization, photoassociation or photoablation can be very difficult or even impossible. An example may be the production of CO_2^+, which due to the high ionization energy (13.8 eV), using optical methods would require the use of synchrotron radiation or (in the case of multiphoton processes) complex laser systems. The aim of the experiment is to apply the electron-molecule collision technique as an alternative mechanism for the production of molecular ions. As a test object, carbon dioxide ions will be used. The experiment will be carried out in a quadrupole ion trap in the configuration of a linear segment trap. At the first stage of the experiment an ensemble of Ca^+ will be prepared. Doppler cooled Ca^+ ions can be observed using a CCD camera (397 nm fluorescence). Its role will be indirect cooling and indirect detection of the studied molecular ions. As a result, it will enable the observation of large molecular ion ensembles in Coulomb crystals, as well as conducting experiments with a single molecular ion.

As a result of the project, the experimental system (ion trap, laser optical system, detection system with CCD camera) was designed, built and tested, which enabled catching and optical cooling of the Ca^+ ions [65(A17)]. Moreover, for the first time, the phenomenon of nonlinear resonances in a linear trap with short central electrodes was experimentally studied [66(A18)]. As a next step, the cross sections for electronic ionization of calcium atoms were measured for various impact energies [67(A19)]. The interaction of electrons with trapped calcium ions was also investigated. Theoretical description of the observed energy transfer process was proposed based on the Rutherford scattering model. It allowed for conducting a series of simulations, which results reproduced experimental data [68(A20)]. During the work, electron-ion collisions leading to annihilation of the ion and collision with the charge transfer between the molecular ion and the atom were also observed. These processes will be the subject of further research.

Current work aimed at improvement the cooling of the ion cloud to obtain the Ca^+ Coulomb crystal, and then a multicomponent crystal composed of Ca^+ and CO_2^+ ions.

The importance of the results

The conducted work showed the existence of nonlinear resonances, which can be used to identify the mass of ions caught in the trap. This technique can be used in the study of chemical reaction products. Cross sections for the electronic ionization of calcium atoms were measured, which completed the existing results in terms of higher collision energy. The process of interaction of ions with the electron beam was also described. Special features of the ion crystals could be studied using nonlinear resonances. The tentative hypothesis is that such crystals due to the constraint in relative motion resulting from the Coulomb interaction would have different lifetime than a single ion. Moreover, cooled ions to the crystal should behave differently in conditions of such a resonance than a warmer ion cloud. In such case the nonlinear resonances could be used as an indirect probe of the structure (also temperature) of the trapped ions. This technique could be also used as a precise tool in cold plasma studies. New attempts are also made to construct a very precise atomic clock (much more accurate than an optical clock) using ions in a trap. Recent reports about $^{40}Ca^{+}$ ions shows stability at the level 2.2×10^{-17} [69].

B.2 Construction of the Polish Optical Atomic Clock

- Research in National Laboratory of Atomic, Molecular and Optical Physics

As part of projects carried out in the National Laboratory of Atomic, Molecular and Optical Physics, a system of ultra-narrow tuneable diode lasers with the spectral line width a few Hz was built. This system consists of laser stabilised using ultra-stable optical resonance cavity using Pound Drever Hall technique and second laser stabilised to the first one using fast feedback phase loop with the 2 MHz band. The relative stability of the frequency of two lasers is below 150 mHz. The possibility of tuning the laser was demonstrated on measurement of 20-kilohertz resonance of the ultra-stable optical cavity. In order to ensure stable working conditions, the cavity was put in the vacuum chamber (vacuum better than 1×10^{-7} mbar), which was placed on the mechanical insulator system (Minus K Technology platform , Sorbothane insulators) [70(A11), 71(A12), 72(A14)]. Based on the earlier experience, a second system of ultra-stable cavity placed in ultra-high vacuum conditions was built. The work carried out was aimed at preparing for the construction of an optical atomic clock. Finally, as part of the MNISW project for the Construction of the Polish Optical Atomic Clock (POZA), a system of two independent optical atomic clocks using strontium atoms was built. The system consists of two atomic frequency standards, ultra-narrow laser (spectral line width less than 10 Hz), ultra-stable optical cavity with very high finesse and optical frequency comb [73(A15)]. The relative stability of the clock after 5 minutes is 2×10^{-15}. The fibre-optic link used for sending signals over long distances enables the obtained results to be compared to the UTC (AOS) and UTC (PL) scales. The results of the work were also presented at international conferences and published in reviewed postconference publications [74(C15), 75(C19)].

The importance of the results

In 2015, our achievement was awarded with prizes:

- The team award of the Marshal of the Kuyavian-Pomeranian Voivodeship in the category of Science, Research and Technical Progress for the construction of the Polish Optical Atomic Clock (2015),
- Certificate of the Innovative Brand of the Region Made in Kujawsko-Pomorskie InnoMaRe Science awarded by the Marshal of the Kuyavian-Pomeranian Voivodeship for the project of the Polish Optical Atomic Clock (2015)

The built system of two atomic clocks is used in conducted spectroscopic measurements, providing a reference signal to various research laboratories. The optical clock has been used, among others, for the most accurate measurements in the world of the frequency of optical transitions in the oxygen molecule [76]. It has also been used to develop a new method of searching for dark matter [77], which is currently used by an international research consortium that brings together the most accurate optical clocks in the world [78].

B.3 Studies on the shapes of the spectral lines of the oxygen B-band

- Research in National Laboratory of Atomic, Molecular and Optical Physics

During my research work I also cooperate with a group studying molecular gas spectroscopy. The aim of the research is the high resolution spectroscopy of oxygen perturbed by gases, such as nitrogen and argon. The conducted experiments enable obtaining very precise data on the shapes of the spectral lines of the oxygen B-band located near 689 nm, which provide information on molecular interactions and dynamics of collisions.

Parameters describing the shape of the spectral line can be used in many applications, such as detection of trace amounts of gases, temperature and pressure measurements, or monitoring the condition of the Earth's atmosphere. In addition, project results can be used to complement existing spectroscopic databases such as HITRAN [79].

The measurements are carried out using a frequency-stabilized cavity ring-down spectrometer (FS-CRDS). The high-quality optical cavity used is stabilized to the reference helium-neon laser. In addition, the use of the Pound-Drever-Hall technique (PDH) to establish the frequency of the laser to the mode of the optical cavity of high finesse, which makes the spectrometer system very sensitive tool. Coupling the spectrometer with the optical frequency comb allows measuring the absolute frequency of the sampling laser at each measuring point, which eliminates the influence of helium-neon fluctuations (± 1.5 MHz) on the frequency axis of the measured spectra. Additionally, in order to improve the accuracy of the obtained results, a system of active thermal stabilization of the optical cavity of the spectrometer was built (level of 30 mK). The use of optical frequency comb has allowed the determination of the positions of the spectral lines with an accuracy better than 200 kHz. In addition, the use of the PDH technique enabled the recording of spectra with a high signal to noise ratio coefficient (up to 10000). This allowed to determine the value of the most important parameters describing the shape of the spectral lines (e.g. intensity or pressure broadening coefficient) with a relative uncertainty below 0.3%. During the research, the spectral lines of the oxygen B-band were perturbed by nitrogen. These measurements were made for a mixture prepared with a special system containing 3% oxygen in the pressure range up to 400 Torr. The analysis of the spectral lines shape showed that the narrowing of the line is for the most part due to the presence of effects dependent on the speed of the absorber. In addition, an asymmetry related to the dependence of pressure shift on velocity was observed. In the case of the studied spectral lines from the P branch of the oxygen B band, the experimental data obtained by us (especially regarding the position of the line) are currently the most accurate available results in the world [80(A8), 81(A16)].

The importance of the results

Parameters describing the shape of the spectral line can be used in many applications, such as detection of trace amounts of gases, temperature and pressure measurements, or monitoring the state of the earth's atmosphere and climate change. Project results were included in the HITRAN spectroscopic database. The research on the positions, intensities and shapes of the oxygen line contributed to the development of a new spectrum model of the B-band, based on the so-called speed dependent Voigt profile [82]. It allows the real spectrum to be reproduced in near atmospheric conditions with sub-percent accuracy, which could not be previously obtained using the Voigt profile used in all spectroscopic databases. These works have opened the way to the use of oxygen B-band in precise atmospheric studies.

In addition, project results can be used to complement existing spectroscopic databases such as HITRAN.

B.4 Cryogenic system for line shape investigation

- Research in National Laboratory of Atomic, Molecular and Optical Physics

Currently, I participate in the work under the project "Cryogenic system for developing new optical quantum technologies" (MNISW grant for large research infrastructure 2018-2019), aimed at building a system enabling the measurements (including measurements of line shapes) in cryogenic temperatures. This system will be a unique device on a global scale and will allow to obtain very interesting data in the field of atomic and molecular spectroscopy. In addition, it will enable start new research in the field of atomic and molecular physics, quantum cryptography, simple molecules chemistry and van der Waals complexes and the search for new physics beyond the Standard Model, among others by measuring the frequency of optical transitions in cold hydrogen molecules and their comparison with ab initio calculation of the Standard Model. In the course of the work, a vacuum system was built, in which a two-stage cryogenic head (CRYOMECH PT420 MR) connected to the helium compressor was placed. Currently, tests and optimization work on the cooling system, designing experimental chamber are in progress.

C. Research on the detection of neoplastic lesion in the Interdisciplinary Group of Optical Methods of Early Cancer Detection (IZOMWN) UMK

In 1995, during my studies at the Faculty of Physics and Astronomy of the Nicolaus Copernicus University, I began working in the Interdisciplinary Group of Optical Methods of Early Cancer Detection, managed by prof. Barbara Chwirot. Its main research goal is to develop a non-invasive method for diagnosing early stages of neoplastic lesions. The conducted research concerns both the skin and the human gastrointestinal tract. Such a specific topic requires both the construction of specialized apparatus and extensive knowledge about the processes taking place in the tissues, individual cells and the entire human body. Therefore, the team operating as part of the Nicolaus Copernicus University includes both doctors and biologists as well as physicists. In 1997 as a member of this team under the supervision of prof. Stanisław Chwirot I completed my master's thesis entitled "Construction of a system for recording fluorescence spectra of laser-induced tissues". The built apparatus made it possible to carry out numerous in vitro and in vivo measurements, which are necessary in determining an effective diagnostic method[, 83(C1), 84(C2), 85(C3), 86(C6)].

In 2000, cooperation was established with prof. Shen from Beijing (Institute of Biophysics, Chinese Academy of Science) as a result of which we have started research on neutrophils isolated from pig's blood. Neutrophils are the main defenders of the body against bacterial infections. They are responsible for the so-called an oxidative burst that produces toxic highly reactive oxygen species such as hydrogen peroxide and hypochlorite ion. The excited molecules going to the ground state emit photons (chemiluminescence), the observation of which allows to draw conclusions about the oxidoreductive state of cells, which can ultimately be an indicator of their physiological state. In the conducted research, the main cognitive aspect was an attempt to verify the thesis that between the two neutrophil populations, information is transmitted via the optical path. Explanation of this aspect would allow a much more comprehensive description of how the body's defence system works. In order to increase reliability and check the repeatability of the obtained results, independent research was carried out in Beijing and Toruń. The results obtained did not give a definite solution to this problem, but they pointed to interesting relationships that were presented at the 9th International Symposium "Molecular and physiological aspects of regulatory processes of the organism" in Krakow in 2000.

In addition, research on the content of collagen in human skin was conducted. The deficiency of collagen in the skin may indicate occurring adverse changes in it. Due to its linear structure, collagen fibres are characterized by birefringence, which allows their relatively easy observation, using a system of two "crossed polarizers". In this measurement system, bright luminescence of collagen fibres is visible, against the background of the remaining (dark) part of the tissue that does not show birefringence. This naturally occurring effect can be enhanced by staining the slides with picrosyrius red. During the staining process of slides, collagen molecules that are rich in amino acids react strongly with the acid dye. The elongated dye molecules surround the fibre so that their long axes are parallel to each other. Such a parallel alignment of the dye and collagen molecules is manifested by increased birefringence, which allows us to observe even small amounts of collagen in the examined tissues. In such slides, various colours of collagen can be observed, resulting both from the type of protein observed, as well as its structure, thickness and orientation.

Determination of the orientation of collagen fibres in the slide requires the use of polarizing microscopy. Thus, I designed a universal adapter enabling the recording of images of microscope slides in polarized light. The main advantage of the device is its universality (easy mounting on each of the available optical Olympus microscopes) and the ability to precisely align the axis of the polarizers. The use of the described device made it possible to propose together with prof. Stanisław Chwirot, a methodology enabling the quantitative determination of the collagen fibre content in the microscopic specimens. The obtained results were the basis for the master's thesis of Ida Jurczyk (Department of Medical Biology, Faculty of Biology and Environmental Protection, Nicolaus Copernicus University), pt. "Quantitative assessment of the content of collagen fibres in benign and malignant pigmented skin lesions of the human skin" (2003).

In the course of work on the optimization of the fluorescent method of in situ detection of melanoma, I designed systems cooperating with any optical Olympus microscope enabling excitation of standard microscopic slides using laser beam and recording fluorescence spectra with fibre optic spectrometer from selected fragments of tissue. The described devices were used during further studies on the quantitative analysis of fluorescence microscopic images for the detection of specific tumour antigens in histopathological slides. The apparatus enabled also conducting quantitative measurements of formalin-induced fluorescence intensity for the detection of melanoma cells [87]. The advantage of the proposed method is the fact that it does not require special sample preparation and can be used for paraffin slides normally prepared for histopathological examination.

As a result of the work carried out in the Patent Office of the Republic of Poland, a patent application was filed for a diagnostic algorithm concerning the detection of melanoma cells at the level of histopathological examinations.

The importance of the results

The presented works allowed for the development of diagnostic methods for the early detection of tumours. In addition, as a result, several research systems were built and measurement procedures were developed and used in the work of the IZOMWN team, which ended with diploma theses and scientific publications. The proposed diagnostic method for the detection of melanoma cells at the level of histopathological examination can easily support histopathological examination, due to the use of standard paraffin preparations.

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