The Centenary of Electron
(EL – 100)

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Uzhgorod, Ukraine
18–20 August 1997

Edited by: A. Zavilopulo,
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Інститут електронної фізики

ІЕФ УЖГОРОД

The Centenary of Electron (EL – 100)

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of the International Conference

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Наукові праці

Міжнародної конференції

Uzhgorod, Ukraine
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Сторіччя електрона. Наукові праці міжнародної конференції. Ужгород, 18–20 серпня 1997 року. Ювілейна міжнародна конференція була присвячена одному з найвидатніших відкрить кінця XIX сторіччя – експериментальному відкриттю Дж.Дж. Томсоном першої елементарної частинки – електрона. У цьому збірнику представлено результати експериментальних та теоретичних досліджень, в яких головну роль відіграють електрони. Значну увагу приділено впливу електрона на цілу низку наукових відкрить XX сторіччя та на світовий розвиток науково-технічного прогресу.

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Contents

Preface

The Jubilee International Conference was devoted to one of the greatest fundamental discoveries of the end of the 19th century — the experimental discovery of the first elementary particle — the electron.

The conference was held at the Institute of Electron Physics, Ukr. Nat. Acad. Sci. from 18 to 20 August 1997. The conference was organized by Institute of Electron Physics (Uzhgorod), Bogolyubov Institute for Theoretical Physics (Kiev), International Joint Institute for Nuclear Research (Dubna, Russia), Nyiregyháza Pedagogical University (Hungary), Debrecen Committee of the Academy of Sciences (Hungary), Szabolcs-Szatmár-Bereg Regional Scientific Association of the Hungarian Academy of Sciences

The leading specialists from Great Britain, France, Spain, Belgium, Austria, Hungary, Romania, Russia, Belarus, Japan, Germany, Slovakia, the Czech Republic, Egypt, Poland and Ukraine were invited to attend the conference and delivered lectures.

Plenary and section sessions of the conference dealt with the actual aspects of physics related to the discovery of electron. The modern state of the theory of electron and its applications were considered at the conference. The section sessions were devoted to the problems of nuclear physics, high-energy physics, solid-state physics, plasma physics, quantum electronics, physics of electronic and atomic collisions.

More than 110 scientists were the guests of the conference. The conference program included 38 plenary talks and 8 sessions (72 reports). A number of talks have initiated keen discussions.

The present book contains papers presented at the conference and received by the organizing committee. No grammar and style corrections in the papers submitted in English were made.

The organizing committee is grateful to the conference sponsors whose financial support is inestimable.

A. Zavilopulo
O. Shpenik

ПЕРЕДМОВА

Ювілейна міжнародна конференція була присвячена одному з найбільших відкрить кінця XIX сторіччя — експериментальному відкриттю першої елементарної частинки — електрона.

Конференція відбувалась в Інституті електронної фізики НАН України з 18 до 20 серпня 1997 року. Організаторами конференції були Інститут електронної фізики та Інститут теоретичної фізики ім. Боголюбова НАН України, Об'єднаний Інститут ядерних досліджень у Дубні (Росія), Ніредьгазький педагогічний університет (Угорщина), Дебреценський комітет Угорської академії наук, Саболч-Сатмар-Березька регіональна асоціація Угорської академії наук.

Були запрошені та виступили з доповідями провідні спеціалісти з Англії, Франції, Іспанії, Бельгії, Австрії, Угорщини, Румунії, Росії, Білорусі, Японії, Німеччини, Словаччини, Чехії, України, Польщі, Єгипту.

На пленарних та секційних засіданнях конференції було обговорено актуальні проблеми фізики, пов'язані з відкриттям електрона. Розглянуто сучасний стан питань теорії електрона та прикладних аспектів. Секційні засідання були присвячені ядерній фізиці та фізиці високих енергій, фізиці твердого тіла, фізиці плазми та квантовій електродинаміці, фізиці електронних та атомних зіткнень.

Усього в роботі конференції взяли участь понад 110 вчених. Програма включала 38 пленарних доповідей і 72 доповіді на засіданнях 8 секцій. Багато доповідей викликали жваву дискусію.

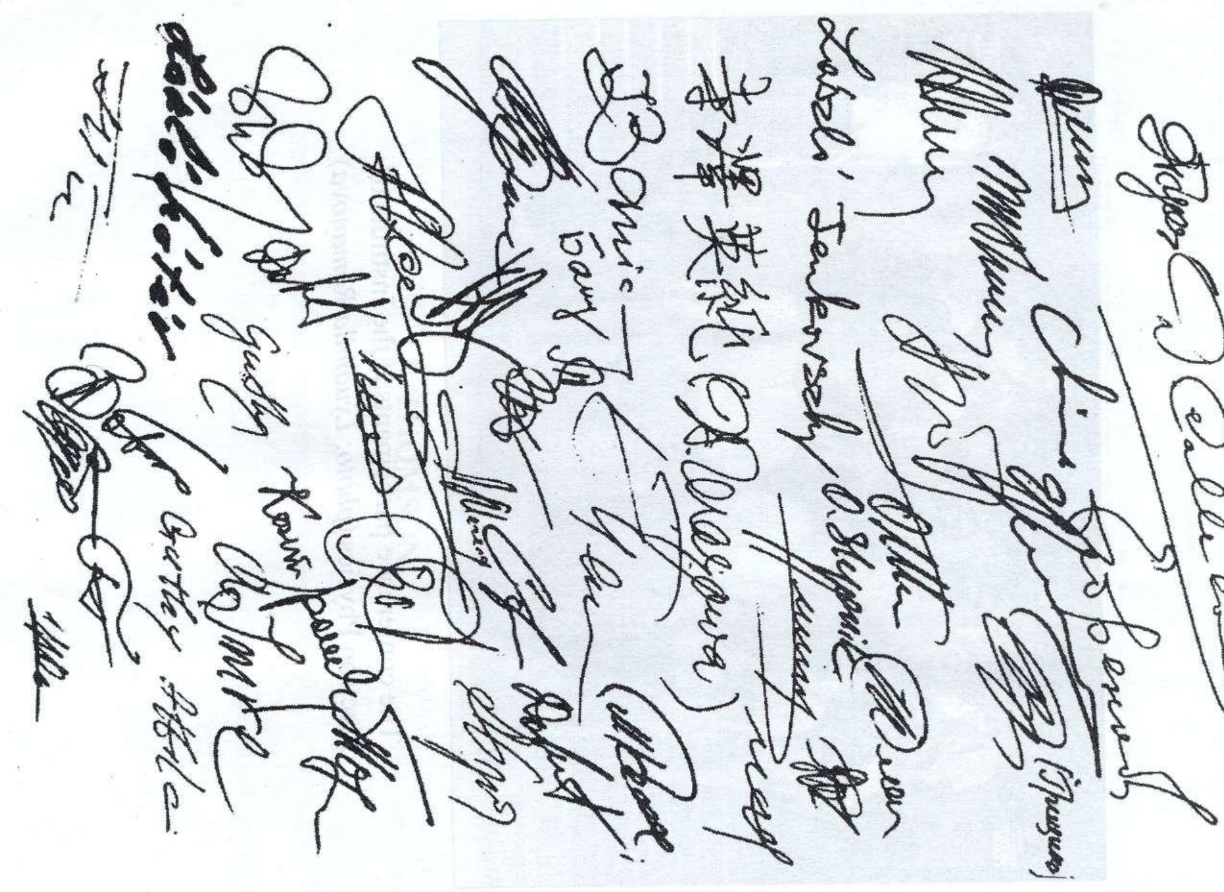
У даний збірник включено доповіді, автори яких виступили з ними та побажали надіслати їх у оргкомітет. Граматику і стилістику матеріалів, що надійшли англійською мовою, залишено без змін.

Оргкомітет щиро вдячний спонсорам конференції за неоціненну допомогу.

А. Завілопуло
О. Шпеник

J.J. THOMSON

The conference participants at the Institute of Electron Physics (*photo: Lyudmila Romanova*)



The conference participants at the Count Schenborn Castle not far from Uzhgorod (*photo: Bratislav Marinković*)

ON THE HISTORY OF DISCOVERY OF ELECTRON

A.A.Tyapkin

(JINR, Dubna, Russia)

The day of the 30th of April 1897 is officially considered the birthday of the first elementary particle – the electron. That day the head of the Cavendish laboratory and the member of the London Royal society Joseph John Thomson made his historical report "The Cathode Rays" at the British Royal institute in which he declared that his long-standing studies on the electric discharge in the low-pressure gas have met with the clarification of the nature of the cathode rays. Having placed the discharge tube in the crossed electric and magnetic fields and observing the compensating effect of these fields he succeeded to determine reliably the specific charge of the particles forming the cathode rays.

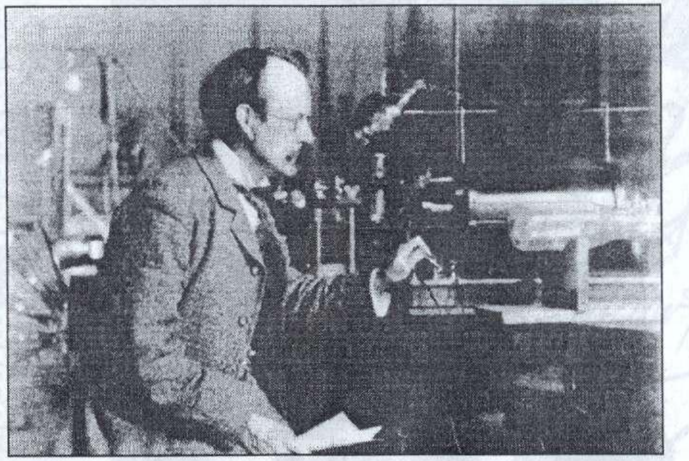


Fig.1 J.J.Thomson in his laboratory (1890).
(This picture from the Cavendish Laboratory archive was published in the European Journal of Physics. 1890. V.18. p.131)

It should be noted that the idea of the discrete nature of electric charge has been firmly established in science due to the preceding studies of the electric phenomena. Michael Faraday (1791–1867) in the first half of 30-s of last century when studying the transmission of electric current through the electrolites has found that the same amount of elecricity transmitted through the solution (now called the Faraday number) is required to produce at the electrode one gram-equivalent of any substance. He wrote in his work "Atoms... comprise equal amounts of electricity being naturally related to them". However, he had not concluded the existence of the minimal elementary charge. This was done in 1874 by the

Irish physicist G. Stoney (1826–1911) who in 1891 postulated the existence of the atom of charge having called it electron. However, these predictions assumed, of course, that the particle of matter like the ions in electrolite deposited at the positive electrode would be the negative-electricity carrier.

Note that the results obtained by J.J. Thomson appeared to be completely unexpected even for his contemporaries. First of all the series of experiments performed showed that the data on the cathode-ray measurements were completely independent of the type of gas in which the discharge occurred. Furthermore, the measured e/m ratio (i.e. the specific charge) was anomalously large: it appeared to be nearly 2 thousand times larger than that for the lightest hydrogen atom. In order to exclude the possibility to explain this result by the high charge concentration at the ceparate particle the researcher has made special control measurements of the absolute charge value. And only after this version being experimentally denied Thomson declared its strange discovery of negative particle with anomalously small mass. He also pointed out that the particles discovered by him constituted the basic part of the atoms of any gas. Let us cite here J.J. Thomson's words related to this fact: "It is obvious that we obtain the charge value not depending on the nature of gas, since the charge carriers are the same for any gas. Thus, the cathode rays are the new state of matter, the state in which the matter is splitted much more stronger than in the case of the common gaseous state,... this matter is the substance which all chemical elements are consructed from". (See S. Glesston. Atom, Atomic Nucleus, Atomic Energy. – IIL, Moscow, 1961, p.45).

The discovery of the electron was highly favoured by the preceding development of technique and methods of the electric discharges in gases. The phenomenon of gas luminescence under the electric current transmission has been discovered and first studied by M. Faraday in 1838. 20 years after the German physicist and inventor H. Geissler (1815–1879) mounted two metal electrodes inside the discharge tube and studied the gas luminescence having shown that the color of the luminescence depends on the gas nature. The invention of manometer for measuring low gas pressures (G. McLeod) had played a vital role in studying the discharge in rarefied gases. W. Crookes (1832–1919) had made a series of modifiations of discharge tubes. His studies have proved that the cathode rays transfer both energy and momentum (1879). "Crookes' tubes" have found a wide utility in various laboratories. Just prior to the discovery of electron J.J. Thomson has proved plausibly the corpuscular nature of the cathode rays which were treated by a number of famous scientists (H. Hertz, P. Leonard and others) as the electromagnetic waves.

Later (in 1903) J.J. Thomson suggested the model of atom in which electrons have a form of separate point particles floating in the continuous positively charged medium of the atom. It should be noted that it was extremely difficult to imagine the atom as an empty space where the positive charges are also concentrated inside the small bulk central nucleus. (A similar pranetary model was, however, suggested earlier by a French scientist J. Perrin in 1901 and then in 1904 by the Japanese physicist H. Nagaoka who compared the atomic electrons with the Saturn rings). J.J. Thomson aslo introduced in 1904 the idea that electrons in atoms are grouped in such a manner that they define the periodicity of the properties of chemical elements. Small electron mass was perceived as the measure of inertia inherent in the electric field of the particle. {Yet at the beginning of his scientific activities (1881) J.J. Thomson showed that electrically charged sphere increases its inert mass by a certain quantity depending on the charge and radius of sphere and, thus, introduced the notion of electromagnetic mass}. The obtained ratio was used to estimate the size of electron witin the assumption that this size is hundred thousand times smaller than that of the atom.

It is of interest that the discovery of electron was done prior to that of proton which resulted from the channel-rays studies in the Crookes' tube. These rays were discovered in 1886 by the German physicist E. Goldstein (1850-1930) by the luminescence produced in the channel made inside the cathode. In 1895 J. Perrin determined the positive charge carried by the channel particles. German physicist W. Wien (1864–1928) continued these investigations and in 1902 by crossed magnetic and eletric fields measurement determined the specific charge of the particles which in the case of filling the tube by hydrogen cooresponded to the weight of the hydrogen atom positive ion.

The discovery of electron has influenced greatly the whole development of physics. In 1898 several scientists (C. Riecke, P. Drude and J. Thomson) independently elaborated the concept of free electrons in metals. This concept was later used as the basis of the Drude-Lorentz theory. H. Lorentz who was developing the Maxwell's theory on the base of atomistic ideas introduced point electrons into his theory. W. Kauffmann when studying the electron deflection confirmed the increase of mass with electron velocity (1902). H. Poincare's fundamental work on the relativistic theory was entitled "On the Dynamics of Electron". However, all this became not only the start of an explosive development of the physics of electrons, but also the beginning of a revolutionary transformation of basic physical principles. The discovery of electron destroyed the concept of indivisibility of atom and, hence, the starting ideas of completely non-classic theory of electron behaviour in atoms began to be formed.

Thus, at the end of last century one of the greatest discoveries occurred and its consequences are impossible to overestimate. And the fact that now we are celebrating the centenary of this disovery in Uzhgorod, in the Institute of Electron physics established only five years ago in the Transcarpathian centre, is quite symptomatic testifying to the development of electron physics which is still in progress now.

Let us remind in conclusion some additional data on the scientific biography of the discovere of electron.

THOMSON Joseph John (18.12.1856–30.08.1940) – a member of the London Royal society since 1884, its president in 1916–1920.

In 1880 he graduated the Cambridge University, in 1884 – a professor of Cambridge University and a director of the Cavendish Laboratory (till 1919). In 1905–1918 – a professor of Royal Institute, since 1918 – a head of the Trinity College in Cambridge.

His works are devoted to the investigation of electron current transmission through rarefied gases, studies of the cathode rays and X-rays, atomic physics. He had also developed the theory of electron motion in magnetic and electric fields, and suggested in 1907 the principle of mass-spectrometer. For his works on the cathode rays and the discovery of electron he was awarded a Nobel Prize in 1906.

Note one more original Thomson's work. In 1907 he showed that a flexible conductor with current immersed into the magnetic field takes an equlibrium postion which coincides with the trajectory of the charged particle with the momentum equal to 2.94 T/I MeV/s, where T is the conductor tension (grams) and I is the electric current (amperes). This method of determinating the trajectories appeared to be quite convenient for the direct

determination of the meson trajectories in the real space at the constant magnetic field accelerators (see M.S. Kozodayev, A.A. Tyapkin// Prib.Tehn.Eksp. 1956, No1. p.21).

AFTERWORD

It should be noted that at the end of the last century a surprising concentration of three unexpected discoveries related directly or indirectly to the Croocks'tube studies took place. These discoveries were awarded the Noble Prizes early in the 20th century.

1. At the very end of 1895 the German physicist W.K. Roentgen (1845–1923) discovered the radiation which arises in the discharge tube under the influence of cathode rays.

2. Then on March 1, 1896 A.H. Becquerel (1852–1908) at the session of the Academy of Sciences in Paris reported the discovery of the uranium radioactivity. The most unexpected discovery in the history of physics has been induced by a false hypothesis introduced by H. Poincare (see A. Tyapkin, A. Shibanov – POINCARE – M.:ZhZL, 1979. p.250).

3. The next great event at the end of the 19th century was the discovery of electron in spring 1897, the centenary of which we celebrate now.

ELECTRON SCATTERING BY ATOMS AND STEPWISE ELECTRON LASER EXCITATION

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1. INTRODUCTION

This conference marks the centenary of the discovery of the electron by J.J.Thomson, an event that turns to be one of crucial points in the history of science. In 1897, J.J.Thomson showed that cathode rays are composed of electrons, the particles of big charge and small mass. The experiments on electron binary scattering by atomic species have been developed since early 1930's. The physical observable that is standardly obtained in such experiments is differential cross section (DCS). On the other hand, a new kind of spectroscopy, i.e. electron energy loss spectroscopy, is invented. It is comparative to the optical absorption spectroscopy. Although its energy resolution is much less than in the optical measurements, its great advantage lays in wide range of accessible energies with almost constant efficiency. From the discovery of lasers, a new powerful tool has been added in electron scattering experiments. New techniques have been developed such as laser assisted electron scattering or stepwise electron laser excitations. They enabled investigation of even finer details of scattering processes such as investigation of atomic sublevel excitations.

In this short review, two experimental set-ups designed at the Institute of Physics, Belgrade, are covered: **ESMA** (Electron Spectrometer for Molecules and Atoms) and **SELE** (Stepwise Electron Laser Excitation). The focus of interest are investigations of elastic scattering, excitation processes, resonances, autoionizing states, energy loss spectroscopy, differential cross sections measurements, integrated (integral, momentum transfer, viscosity) cross sections and critical minima. The targets used to investigate such processes include rare gas atoms (Ne, Ar, Kr, Xe), metal vapours (Na, Zn, Cd, Hg) and small molecules (N_2O, H_2S). Some details of elastic electron scattering by argon atoms and resonances in electron - cadmium atom scattering are presented. Also, a new design of an apparatus for stepwise electron laser excitation based on a trochoidal electron monochromator is presented.

2. ELASTIC ELECTRON SCATTERING BY ATOMS

2.1. Elastic electron scattering by argon atoms

Elastic electron scattering by argon atoms has been extensively examined since the first electron scattering experiments performed in a wider angular range [1]. Absolute DCS values has been obtained in low, intermediate and high impact energies. Our goal was to reinvestigate intermediate energy range from 10 to 100 eV and to determine the exact position of critical minima in this region. Critical minima are points in which DCS attains its smallest values. In

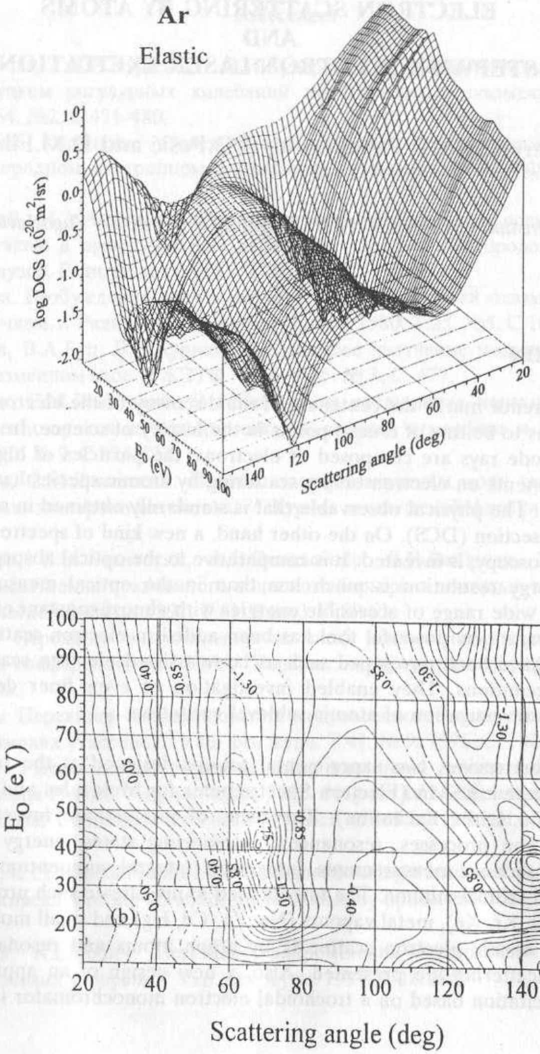

Figure 1. Differential cross sections for elastic electron scattering by argon atom in the angular range from 20° to 150° at incident energies from 10 to 100 eV: *a)* Three-dimensional representation of the DCS (E_o, θ) surface on a logarithmic scale, *b)* Projection of the DCS (E_o, θ) surface on the horizontal plane. Numbers correspond to the logarithm of the DCS values in units of 10^{-20} m^2/sr.

Fig.1(a) is shown a three-dimensional representation of the DCS (E_o, θ) surface on a logarithmic scale, while the projection on the horizontal plane is shown in Fig.1(b).

Relative DCS values have been obtained by using ESMA electron spectrometer described elsewhere [2]. The typical energy resolution of the spectrometer was 50 meV and the angular resolution was ±1.5°. Energy calibration was done by comparing the energy scale with the position of the 29.0 eV resonance in elastic channel. Absolute DCS values have been obtained by normalization to results of Srivastava *et al* [3]. Two areas of deep DCS minima existing in the considered energy domain can be identified in Fig.1(b). These areas ranges from 36.3 to 44.3 eV impact energies and from 64° to 74° as well as from 135° to 150° scattering angles. These areas are closely investigated in 1 eV and 0.5° increments. We have determined two critical points, the first at 68.5° ± 0.3°, 41.30 ± 0.02 eV, and the second at 143.5° ± 0.3°, 37.30 ± 0.02 eV. The DCS value at the first minimum is (6.1 ± 1.3) x 10^{-23} m^2/sr and in the second one is (6.8 ± 1.2) x 10^{-23} m^2/sr.

2.2. Resonances in elastic electron scattering by cadmium atoms

The first elastic electron DCS have been measured by Childs and Massey [4] in the energy and angular ranges 4 - 48 eV and 25° - 130°, respectively. The systematic study of resonances near threshold region in optical excitation functions have been obtained by Шпеник *et al* [5]. The first resonances in elastic channel have been observed by Marinković *et al* [6]. The comprehensive review on electron impact cross section data for cadmium atom have been reported by Marinković [7].

Differential cross sections for elastic electron scattering have been obtained at 3.4, 6.4, 10, 15, 20, 40, 60 and 85 eV impact energies. The angular distributions were recorded 6° to 150° scattering angles. The impact energy scale was calibrated by measuring elastic scattering intensity as a function of the electron energy at different scattering angles. Results are shown in Fig.2 for three different angles. The curves show the appearance of resonances in the elastic channel. The position of the first , the most pronounced one, is attributable to the threshold energy of the 5^3P_0 excitation at 3.737 eV. The curves in Fig.2 do not represent relative elastic cross sections as a function of energy at the particular angle since transmission effect corrections are not included.

The atom beam source as well as electron optics with the energy selectors hidden into aluminum boxes, were designed to ensure reliable work for extended periods of time. The effusive atom beam was produced in stainless-steel crucible with the tube 11 mm long and 1.5 mm in diameter.

Cadmium atom does not have stable negative ions, but it shows interesting structures in elastic DCS, due to temporary negative ions. Within the observed energy range, from 2 to 10 eV, several resonances have been recognized by different authors: d-resonance just below the threshold for the 5^3P_0 excitation (E = 3.0 to 3.5 eV) [8] and two at 6.75 eV and 7.24 eV [9]. If the curves from Fig.2 are corrected for the transmission function and fitted to the Fano profile resonances, the position of the first resonance is found to be at 3.23 eV ± 0.20 eV and its width is 310 meV. This result was obtained with the 50 meV energy resolution of electron spectrometer [10].

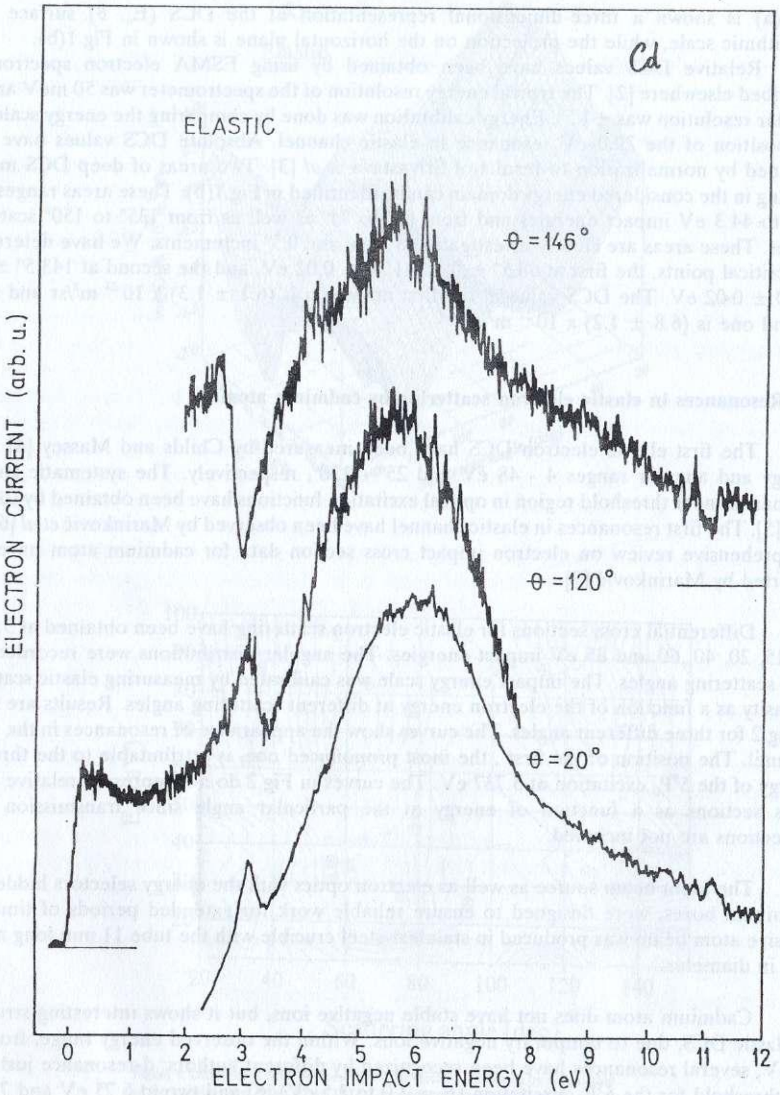

Figure 2. Intensity of electrons elastically scattered by cadmium as a function of impact energy at scattering angles of 20°, 120° and 148°. The energy scale is not corrected. The transmission effects are superimposed.

3. STEPWISE ELECTRON LASER EXCITATION

A stepwise electron laser excitation technique is a new developed technique in which a combination of electron beams and laser beams are used to excite target of atomic species. MacGillivray and Standage [11] have categorized the experiments using this technique according to whether laser excitation is used in the first or second excitation step. In the former case, information can be obtained about electron scattering from the excited species, while the latter case provides detailed information of magnetic sublevel excitation by electrons. These two types of situations are represented in Fig.3.

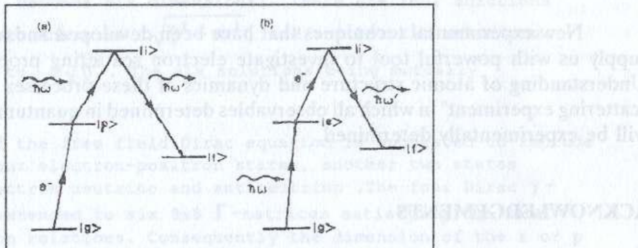

Figure 3. Two different schemes of electron laser excitations: *a)* Electron excitation in the first and laser excitation in the second step, *b)* Laser excitation in the first and electron excitation in the second step.

An example of the type of experiment in which laser excitation was in the first step and the electron excitation in the second step is the experiment performed by Stumpf and Gallagher [12]. They have determined electron excitation cross sections of Na(3S) and Na(3P) atoms to the Na(3D) state. They found that the excitation near the threshold from the 3P excited state to the 3D state is about ten times larger than the excitation from the ground state.

Another recent example of this kind of measurements are experiments performed by Dorn *et al* [13]. They have investigated experimentally and theoretically Auger and autoionization spectra for electron impact on laser-excited sodium atom.

An example of the type of experiment in which electron excitation was in the first step and the laser excitation in the second step is the experiment performed by Добрышин *et al* [14]. They have measured absolute cross sections for the electron excitation of the $4^3P_{0,1,2}$ magnetic sublevels of calcium atom. Using dye laser tuned to the transition $4^3P_{0,1,2}$ - 5^3S_1 and monitoring the 616.2 nm florescence, they found experimentally that the cross sections for electron impact excitation of magnetic levels are proportional to their statistical weights.

An experimental apparatus SELE is designed in Institute of Physics, Belgrade, to investigate stepwise electron laser excitations. It consists of the cylindrical trochoidal electron monochromator as source of monochromatic electrons. This kind of monochromator is designed in JILA Institute. Optical excitation function near threshold are measured on sodium atom [15] and is shown in Fig.4. Independently, this cylindrical monochromator was used by group from Uzhgorod [16] in order to investigate threshold spectra of Mg and Ca atoms [17].

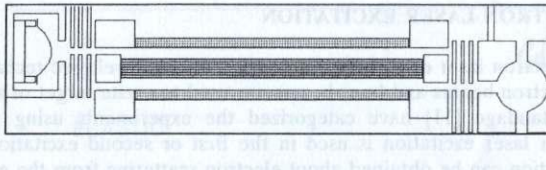

Figure 4. Schematic of cylindrical trochoidal monochromator

4. CONCLUSIONS

New experimental techniques that have been developed and applied since last decade, supply us with powerful tool to investigate electron scattering processes by atomic species. Understanding of atomic structure and dynamics of these processes leads us toward "perfect scattering experiment" in which all observables determined in quantum-mechanical calculations will be experimentally determined.

ACKNOWLEDGEMENTS

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