IRPS BULLETIN

Newsletter of the International Radiation Physics Society

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Contents of this Journal

From the Editors

Dear Reader,

Welcome one and all to this final issue of volume 29 of the IRPS Bulletin and the end of a year in which outreach promoting radiation physics received special emphasis through activities both within the Society and without, as the world celebrated the International Year of Light.

Within the Society itself, 2015 witnessed the triennial election of the IRPS Executive Council and the 13th International Symposium on Radiation Physics (ISRP-13), in Beijing, PRC. The election results are summarized herein, and we at the Bulletin extend hearty congratulations to the new Executive Council, wishing them luck over the next three years. At the same time we bid a fond farewell to outgoing Executive Officers and Councillors, whom we thank for steadfast service over the past three years, with a special salute to departing IRPS President Ladislav Musilek, whose final President's Column in this issue reflects upon notable accomplishments during his administration, including the newly revised IRPS Constitution. Also within these pages you'll find an engaging summary of ISRP-13, contributed by Executive Councillors Richard Hugtenberg and Tomáš Trojek, and an item of historical interest on the contributions of Yvette Cauchois to x-ray spectroscopy, written by Francois J. Wuilleumier (Paris-Sud University) and reprinted here with the kind permission of the American Physical Society. Finally, we direct your attention to the events Calendar and other notices herein containing registration details, submission deadlines and other useful information related to upcoming meetings and conferences, such as the 2nd triennial International Conference on Dosimetry and its Applications (ICDA-2), to be held July 3-8, 2016 in Surrey, England.

While the International Year of Light has come to an end, we trust that other segments of the vast spectrum occupied by radiation physics will give fresh cause for celebration, with new developments and opportunities for research and collaboration. And so we appeal to you, our readers, to keep us informed in the coming year, to let us help you tell your stories of discovery and collaboration and outreach, as we extend to you our warmest wishes for the holiday season and hopes for a prosperous and busy 2016!

Ron Tosh and Larry Hudson

Election Form results on following page

Contacts

Items for the Bulletin : **Ron Tosh, Larry Hudson**

Membership Enquiries : **Elaine Ryan**

Layout and distribution of the Bulletin : **Shirley McKeown**

Web Pages : **Shirley McKeown**

Contact addresses for the above are listed in the IRPS information on page 2.

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The results of our recent, triennial election are in, and we congratulate all new officers and members of the Executive Council! We also acknowledge the efforts of the previous Council to revise the IRPS Constitution, which was formally ratified in the same election.

ELECTION BALLOT FORM

For all posts, except those of executive councillors, vote for one by marking the appropriate box.
For executive councillors, you may vote for up to five candidates who are running for the full six-year term.
For all positions you may write in names of other members of the Society and cast your ballot for them.

President (vote for one)
- Christopher Chantler (Australia) ☑
- ____________________ ☐

Secretary (vote for one)
- Jorge Fernandez (Italy) ☑
- ____________________ ☐

Treasurer (vote for one)
- William Dunn (USA) ☑
- ____________________ ☐

Vice Presidents:

Western Europe (vote for one)
- Jose Rodenas (Spain) ☑
- ____________________ ☐

Central & Eastern Europe (vote for one)
- Ines Krajcar Bronic (Croatia) ☑
- ____________________ ☐

F.S.U. (vote for one)
- Sultan Dabagov (FSU) ☑
- ____________________ ☐

North America (vote for one)
- Larry Hudson (USA) ☑
- ____________________ ☐

South & Central America (vote for one)
- Marcelo Rubio (Argentina) ☑
- ____________________ ☐

South East Asia (vote for one)
- Pradip Sarkar (India) ☑
- ____________________ ☐

Vice Presidents *(Continued)* :

North East Asia (vote for one)
- Dong Yu-Hui (P.R. China) ☑
- ____________________ ☐

Africa & Middle East (vote for one)
- Mohamed Gomaa (Egypt) ☑
- ____________________ ☐

Australasia and Oceania (vote for one)
- James Tickner (Australia) ☑
- ____________________ ☐

Industrial Applications (vote for one)
- Robin Gardner (USA) ☑
- ____________________ ☐

Membership Officer (vote for one)
- Elaine Ryan (Australia) ☑
- ____________________ ☐

Executive Councillors:

Six years term (vote for five)
- David Bradley (UK) ☑
- Odair Gonçalves (Brazil) ☑
- Esam Hussein (Canada) ☑
- Isabel Lopes (Portugal) ☑
- Tomáš Trojek (Czech R) ☑
- ____________________ ☐
- ____________________ ☐

IRPS

BALLOT PAPER

VOTE (X) ONCE ONLY

DO YOU AGREE TO THE ADOPTION OF THE REVISED IRPS CONSTITUTION?

YES	X
NO	

FROM THE PRESIDENT

Dear friends, dear colleagues, after three years as President of IRPS, I write my last President's Column. Therefore, though I am not a friend of evaluating reports, I feel that it should be useful to summarise briefly this last period in the life of our Society, to share with you my views, where we succeeded and those areas that we can work together to improve.

The previous Constitution of the Society was in some aspects a bit obsolete and did not correspond to the actual practice of the Society. The revision of the Constitution, which has been just approved by a correspondence voting, follows the main spirit and ideas of the original version, but specifies better some activities, rights and duties of the Society and its Council members, position and goals of the Advisory Board, the way of elections, and the organisation of the scientific conferences in which IRPS is involved. It does not further include the life-long membership in the Society, which has never been put into effect, and on the other hand, it endorses the awarding of honorary memberships. As you could notice, three of our colleagues, Professors Malcolm Cooper, Dudley Creagh and Richard Pratt, who have substantially contributed to the life of the Society, have been recognized in this way. It would be too long and boring to mention here all the amendments to the Constitution; you have the full text in the June 2015 issue of the IRPS Bulletin.

The other substantial contribution to the life of the Society has been the portfolio of scientific conferences that we endorse and organize. Our main scientific meeting, the International Symposium on Radiation Physics (ISRP), is no longer the only periodic conference co-organised by the Society. Close scientific and personal relations to the IRRMA group led to integrating the International Topical Meetings on Industrial Radiation and Radioisotope Measurement Applications (IRRMA) into the purview of the Society. Both of these series of meetings were triennial. A vacant year between these conferences, co-organised by IRPS, offered the possibility to start one more series of conferences to fill this gap. The 1st International Conference on Dosimetry and its Applications (ICDA), we hope, has started this new series of scientific events, in which our Society is engaged. ICDA-2 is currently being organized.

And, last but not least, I should like to mention our Bulletin, which has accompanied us for many years and which was years ago step-by-step transformed from the printed form to the electronic one. Let me express my thanks to its Editors, as I am convinced that they have been doing a great work; the quality and information value of this periodical has been therefore substantially increased. In this context, I should like to invite all of you to collaborate more actively with the Editors. Anytime, when you have some interesting information, news, or you feel competent to review some branch of radiation physics, do not hesitate to contact them, to send them an article, information or notice for publication.

Let us turn now to the parts of our activities that would benefit from more local engagement or collaborations among the membership. First of all, we have not steadily increased our membership and we can find regions and countries in which we have only a few or even no members. This should be one of our goals for the future development of the Society. The other issue is the membership fee payment. Though we keep the level of fee at the minimum possible level, some members do not pay it in time and some members even do not react when our Membership Officer sends a reminder. Because of the low level of the fee, I believe that this fact is caused by listlessness and not by thrift; indifferent members are probably even more dangerous for a Society than miserly ones.

And finally, we should address the question of the web page of the Society. We wanted to move the web page from the University of Canberra to an independent provider, but this effort has failed. Therefore, the old web site at the University of Canberra has helped for some time to bridge the

.../continued

.../President's column continued

gap. Let me express my thanks to our colleagues from this University both for their long lasting attentiveness to keep our web page and for willingness to keep it till the problem is solved. We are looking for a new provider, but this process is not yet finished and the new web presence of the Society is a task we shall have to address in the short term.

Dear colleagues, dear friends, I would like to thank all of you, who worked for the Society in the last period, and special thanks belong to those Council members and members of the Advisory Board, who contributed very much to our activities. I wish both to new and continuing Council members great success in their work for the Society and hope that I shall also be able to continue to contribute to this goal.

Ladislav Musilek

New Memberships, Membership Renewals

Membership form for new members, and details for payments by cheque for new and renewing members are on the last 2 pages of this journal and information for payment by credit card is below

If you are unsure when your renewal is due, contact

Elaine Ryan

email: **elaine.ryan@sydney.edu.au**

Membership Payments by Credit Card

Internet payments by credit card (Visa, Mastercard, AMEX, Discover) can be made via the IRPS website

http://www.canberra.edu.au/irps

You do not need a PayPal account to use this method of payment

Go to the Home Page on our website (as above)
click on Membership, scroll down to the selection of buttons and click on the one that suits your membership.

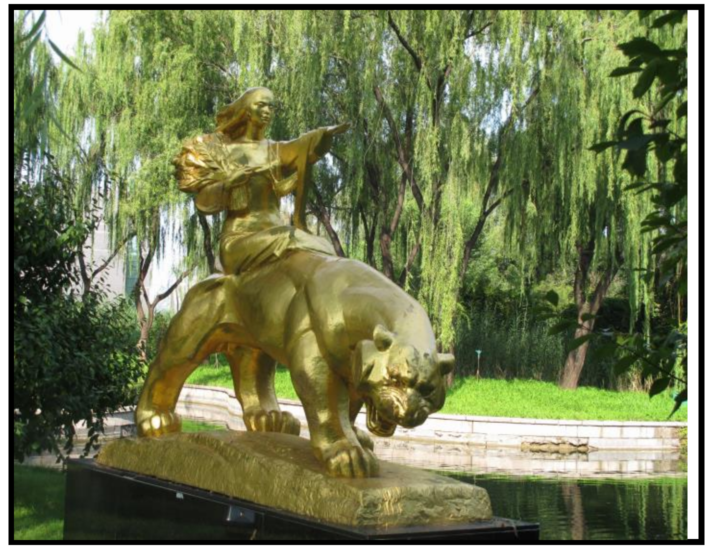
If you have any queries or problems contact :

Dr William L. Dunn
Department of Mechanical and Nuclear Engineering
Kansas State University
137 F Ward Hall, Manhattan, KS 66506, USA
Phone : 785 532 5628 ***email :*** **dunn@mne.ksu.edu**

Summary of Presentations made at ISRP-13

The 13th International Symposium on Radiation Physics (ISRP-13) was held in Beijing, China, in September, 2015, in the pleasant surrounds of the Beijing International Conference Centre. The Symposium was hosted by the Institute of High Energy Physics, Chinese Academy of Sciences and the University of Science and Technology of China, and attracted an international and, characteristically, broad range of presentations.

The pleasant and reflective surroundings at the Beijing International Conference Centre



The conference was opened by the Chairman of ISRP-13, Prof. Dr Yuhui Dong, of the Chinese Academy of Science. More than 100 topics were presented during the week, including invited speakers and poster presentations. This article summarises presentations delivered at the Symposium. Speakers presented on advances in fundamental radiation physics theory and its applications, with a focus for the meeting being the safe development and introduction of new radiation technologies, touching upon modern concerns in biology and medicine, cultural heritage and cosmology, energy and security.

Prof. Dr Yuhui Dong gives the opening address

/Presentations

Radiation Physics on Earth and in the Heavens

One of the first presentations of the meeting was given by **Larry Hudson** of NIST, where he discussed the evaluated compilations maintained by NIST, going well beyond the traditional radiation physics subject area in his explanations. A tour of the methods used in the standardisation of the time, length and mass standards was given, and efforts to link the three from the hyperfine atomic transitions in the ^{133}Cs time standard, through length standards, via visible HeNe lasers and X-ray and optical interferometry (XROI) in silicon diffraction, to the suggestion that the mass standard could be based on a perfect silicon sphere. The presentation was to set the tone for a symposium, literally looking to the stars.

Truong Nguyen of University of Melbourne, who later went on to be awarded the best student presentation, modelled green and ultraviolet emissions of oxygen generated in the aurora, as well as in the atmospheres of Venus and comets.

Truong Nguyen (left) of the University of Melbourne, just after receipt of the Didier Isabelle Award for Best Student Oral Presentation of ISRP-13. The award was presented by Larry Hudson (right).

Theoretical work in this area is powerfully motivated by differences in measurements and theory of as much as a factor-of-2 difference in the ratio of 557 and 297 nm emission lines.

Roger Hutton of Fudan University described experiments with an electron beam ion trap (EBIT) in order to understand magnetically induced light from highly ionised atoms, including the astrophysically important system Fe 9+, as well as discussing plasma diagnostics relevant to the ITER project.

Soo Hyun Byun of McMaster University described measurements of the radioactivity due to ^{60}Co in meteorite samples, requiring extremely low-level coincidence counting for activities of around 10 mBq. A large array of NaI scintillators was proposed, and optimisation of the array was performed using the EGS5 Monte Carlo code.

Behcet Alpat, from INFN, Perugia, Italy, described the AMS-02 experiment on the International Space Station, which detects predominantly protons and electrons in the spectrum of cosmic rays, but is also beginning to map positron and anti-protons contributions. When the protons and anti-protons are combined, the intensity distribution with energy appears to form a power law with an index in a narrow range of 2.6-2.7. The results provoke many questions. Is this evidence of some very high energy particle accelerator experiments somewhere in the universe, or is it just an invariant distribution under a boost, reminding us that the universe has no stationary frame? Do the results support the contention of Paul Dirac and others that we should expect to find antimatter stars and galaxies elsewhere in the universe? It is, however, noteworthy that although alpha particles are observed, AMS-02 has yet to detect anti-helium nuclei.

ISRP-13 Presentations Continued :

Theory and Applications of X-ray Spectrometry

Spectroscopic methods received much attention at the Symposium, from the development of theory to intriguing applications in material, environmental and biological sciences, and cultural heritage.
.

Newly elected Society President **Chris Chantler** of the University of Melbourne presented experimental studies of frozen dilute aqueous systems, in order to evaluate detailed models of X-ray absorption near-edge (XANES) and fine-structure (XAFS) spectra in environments more closely to applications, particularly in the biological sciences.

Jorge Fernandez, of the University of Bologna, described a highly efficient scheme for modelling the evolution of X-ray characteristic lines for the X-ray fluorescence (XRF) analysis of complex materials, within a framework of Boltzmann transport theory.

Several other talks featured the use of XAFS performed at X-ray synchrotron light sources. Wei Xu of the Institute of High Energy Physics, Chinese Academy of Sciences, described measurements in superconducting calcium, which is achieved under GPa pressures, and has been shown to be related to the coincidences in the energy levels of electron and phonon excitations. Failure of the traditional, muffin-tin model in EXAFS spectra was thought to be due to screening effects and changes in Fermi levels brought about by the superconducting state. The work suggested mixed electron modes should be considered, including the involvement of 3d level electrons, as is the case with the neighbouring atomic system of scandium.

Augusto Marcelli of the National Laboratory of Frascatti, Italy, used XAFS to examine how the bulk properties of materials are modified when they form nanoparticles, for example Au which forms a brittle and red nanoparticle and Co oxides that achieved a high magnetic saturation, with a size distribution dependent on plasma current. Particulates in the atmosphere, that have broad distribution of size averaging about 50 nm, were also briefly discussed.

Shiqiang Wei of the University of Science and Technology in Hefei showed how XAFS was used to correlate surface distortions in low-dimensional electrocatalysts. His work in vacancy-induced room-temperature ferro-magnetism in MoS_2 nanosheets has recently appeared in Nature Communications.

Marcelo Rubio of CEPROCOR, Cordoba, described the use of XRF in the study of phytoremediation. Dove hunting with lead shot made of lead-antimony alloys is responsible for poisoning pristine natural environments. The breakdown of shot by known hyper-accumulator plants, such as tagates minata and brassica napus, was studied, where antimony is also known to have an iron-like chemistry.

David Fleming of Mount Alison University in Canada used XRF analysis to study the effect of salinity levels on Sr-to-Ca ratios in the bony plates ('scutes') of sturgeon enabling study of migration patterns and preferred habitats. Patterns revealed in the growth of individual scutes reveals differing stages of ocean and fresh-water habitation across the species.

Martin de Jonge of the Australian Synchrotron described the Maia detector system, with its unique backscattering arrangement enabling high resolution XRF and XANES. Beamlines using the technology are able to answer questions about internalisation of nanoparticles, achieving sub-cellular resolutions in samples on the time-scale of a typical 8-hour shift.

ISRP-13 Presentations Continued

Zdravko Siketic of the Ruđer Bošković Institute, Zagreb, Croatia, introduced secondary-ion mass-spectrometry (SIMS) and his studies mapping elemental concentrations at cellular dimensions in the Caco-2 cell-line, as well as in paint materials in modern art.

Tomas Trojek of CTU Prague described the testing of a new portable confocal XRF setup, enabling the portability of the science needed to investigate immovable and immutable art-works, and helping to settle arguments in the art world about use of mercury and lead in pigments.

Outgoing Society President, **Ladislav Musilek**, also of CTU Prague, spoke of Good King Wenceslas, describing the study of a 10^{th} century helmet with metal and gilding that contained only traces of silver and gold. The symposium learned that he was really not an ostentatious king, as famously wrought in the popular Christmas carol. XRF was used to study Czech banknotes from 1949 and to examine pigments in beautiful 20^{th} century artworks by Karol Svolinsky.

Finally **Dudley Creagh**, of the University of Canberra, reminded the audience of the importance of cultural heritage, suggesting it as currency supported by cash-flow generated by tourism. He gave examples of his analysis of Australian indigenous art and iron-gall inks on parchment, describing how the measurements were often in conflict with the theories of provenance of art and artefacts.

Medical applications

The use of radiation is well established in diagnostic and therapeutic medicine, but a number of new developments were brought to the Symposium. **Iqbal Saripan** from the University of Putra in Malaysia showed how a machine learning approach could be taken to the detection of Alzheimer's from ^{18}F-FDG PET. The automated approach enabled diagnostics to incorporate a z-score analysis performed on a voxel-by-voxel basis.

Hao-Ting Chang of the National Tsing-Hua University in Taiwan described how a LYSO detector coupled with a multi-slit collimator was used for the verification of the range of protons in radiotherapy via their prompt emissions. Improvements in understanding of proton transport traversing complex and heterogeneous tissues structures is vital to their accurate use in radiotherapy. She discussed how the project made use of the GATE Monte Carlo package based on GEANT4, and widely used in PET and SPECT studies.

Tsi-Chian Chao of Chang Gung University, Taiwan, used both GEANT4 and MCNPX to reveal difference in lateral scattering of protons between codes and between measurements, examining variations in the energy-loss fractions. He found that the choice of energy loss parameter had little effect on the lateral distribution calculated for proton radiotherapy and work continues to improve agreement.

I-Chun Cho, also of Chang Gung University, described a miniature proportional counter for neutron therapy dosimetry. The device operates at three levels of gain and presents difficulties in merging data across the five orders of magnitude typical of neutron spectra. A replaceable plug provides interactions with boron, lithium and gadolinium, important materials in novel therapy avenues being developed with the use of neutrons.

ISRP-13 Presentations Continued

Gumersindo Verdu of ISIRYM, Valencia, spoke about neutron dosimetry, which needs to be considered when produced in high energy X-ray medical LINACs. The use of high-mass concrete in bunker design was described and interesting comments were made about the presence of thermal neutrons, post-treatment, in accordance with their ~10 minute half-life.

Jose Rodenas, of the Polytechnic University of Valencia, presented work originating from the doctoral studies of Isabelle Gerardy of the Institut Superieur in Brussels. They compared conventional planning of HDR treatments with Monte Carlo modelling and experimental measurements, finding that an accurate model of the elemental composition of tissue was necessary to achieve a high degree of dosimetric precision.

Andrew Stevenson spoke of his work at the Australian Synchrotron in Melbourne and characterisation of the imaging and medical beamline, which has a world-class 140 m baseline and Laue diffractometer. Undulator harmonics were chosen to give a boost at the Gd edge, useful in medical applications. He described the recombination corrections to standard ionisation chamber dosimeters needed to provide accurate dosimetry at high X-ray intensities. His techniques include current manipulation at the storage ring, and comparisons with the work of Nariyama and colleagues at the Japan Synchrotron Radiation Research Institute, where large voltages, of 20 kV or more, are used to suppress recombination.

Richard Hugtenburg of Swansea University in the UK also described dosimetry studies with synchrotron X-rays, in preparation for microbeam radiotherapy studies at the ESRF, making use of micron resolution and highly tissue-equivalent diamond detectors. The work explores the influence of bonding layers and density variations on detector response via Monte Carlo models.

Continuing the theme, demonstrating a novel X-ray source with potential applications in imaging and medicine, **Liming Chen** of the Institute of Physics, Chinese Academy of Sciences, described a laser-driven betatron which delivered in two electron bunches, with the second bunch injected directly into the wakefield. Peak brilliance was found to be beyond that of a 3rd generation synchrotron with a super-intense laser pulse being generated at a rate of one pulse per hour.

Ewa Stępień of Jagiellonian University in Poland discussed the use of micro-RNA as a biomarker of vascular damage in stressing conditions, including radiation damage. She suggested that micro- RNA may also have a role as a contributor to the bystander effect, where un-irradiated cells have been shown to exhibit radiation damage-like response in sympathy to neighbouring cells that have received damage.

Ashraf Almahwasi, also from Surrey University, talked about giant nucleated cells which have cross-sectional areas in excess of 125 micron square and are known to be induced by radiation. Doses in the 1-3 Gy range were used and showed large differences in the number of giant nucleated cells at the 14-day mark depending on whether protons or photons were used in the irradiations.

Literature was a theme of several talks, including that of **Roberto Amendolan**, of ENEA, Rome, who, in referring to the short story Two Kings and the Two Labyrinths, discussed how the seemingly labyrinthine theories in radiobiology continue to be ignored in favour of the simple physics models that

../Continued

Roberto Amendolan presentation continued

have been the basis of radiation dosimetry for more than a century. The work included the analysis of the up-regulation of keratin in the presence of radiation damage, which in itself regulates energy balance, stress metabolites, excretion and tissue repair. His studies have been applied to the dosimetry of cosmic rays, relevant to long-term space travel and new radiotherapies.

Yuelin Hua of Zhejiang University discussed progress in understanding the mechanisms underpinning deinococcus radiodurans' extraordinary ability to survive desiccation and doses in excess of 12000 Gy. The bacteria, reminiscent of the Tri-solarans in Cixin Liu's The Three Body Problem, achieve this feat by transporting damaged nucleotides out of the nucleosome and antioxidant production, utilising a unique repair system. She argued that a high Mn/Fe ratio present in the bacteria supported a Mn-based reactive oxide scavenging process also being involved, while Fe is known to be responsible for the formation of reactive oxygen species in more typical terrestrial species.

Environmental Radioactivity, Energy and Security

Francisco Da Silva from CNEN in Rio de Janeiro explained his work with technologically enhanced, naturally occurring radioactive materials (TENORM) in terms of their extraction from the lithosphere and introduction to the biosphere from human activity such as oil production, comparing also to the scale of natural occurring processes such as volcanism. Oil scale samples exhibited activity in excess of that predicted assuming secular equilibrium, suggesting unknown processes responsible for concentrating radioactive isotopes such as ^{226}Ra.

Growth in the use of biogenic fuels offers a potential mitigation to the production of TENORMs in the fuel cycle. **Ines Krajcar Bronic** also of the Ruđer Bošković Institute, described the investigation of biogenic fuel content at the pump, via ^{14}C analysis, where European rulings state that all liquid fuels must contain at least 10% bio-fuels by 2020. Difficulties in the methodology, including variation in colouration, due to the differing origins of bio-fuels, and their effect on measurement efficiency, were discussed.

A theme of a talk by **David Bradley** of the University of Surrey, was also concerned with dosimetry in technologically modified environments, where the durability and water resistance of optical-fibre dosimeters enable their use in the measurement of radioactivity, including alpha emitter ^{223}Ra, in environments saturated by ground water or dampness. The dosimeters showed better sensitivity than $CaSO_4$. Industrial suppliers produce fibres that have been extruded from glass disks with a carefully designed cross-section of dopant concentration (determining the profile of refractive index), and are many thousands of metres in length, suggesting the potential for improvements in inter-dosimeter variance, compared with other types of TL dosimeter. The influence of mechanical processes on the formation of luminescent centres was also discussed.

Jun Saegusa of the Japan Atomic Energy Agency discussed difficulties in monitoring radiation levels at the Fukushima Daiichi nuclear power plant, where summertime temperatures reach 40°C and winter

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Jun Saegusa presentation continued

temperatures reach -20°C. A range of portable radiation survey instruments were considered, including ionisation chambers and sodium iodide scintillation detectors. Details pertaining to temperature dependence were problematic when available, and depended greatly on the technical know-how of manufacturers.

Gumerisindo Verdu, also of the Polytechnic University of Valencia, presented work relating to safe handling of liquid radioactive wastes generated in the decommissioning of nuclear power plants, and their solution using semi-permeable membrane technologies. Permeates removed via reverse osmosis and evaporation were able to be declassified, with the associated reduction of volume of the radioactive waste simplifying handling.

One of the last talks of the conference was given by **William Dunn** of Kansas State University who described the use of tiered filters and Monte Carlo analysis to distinguish explosives from arbitrary 'clutter', used either as shrapnel or to disguise the explosive in an improvised device. Conversely, conventional explosives are characterised by a fixed ratio of the elements H, C, N and O. The approach was shown to achieve high detection rates for a variety of assumptions.

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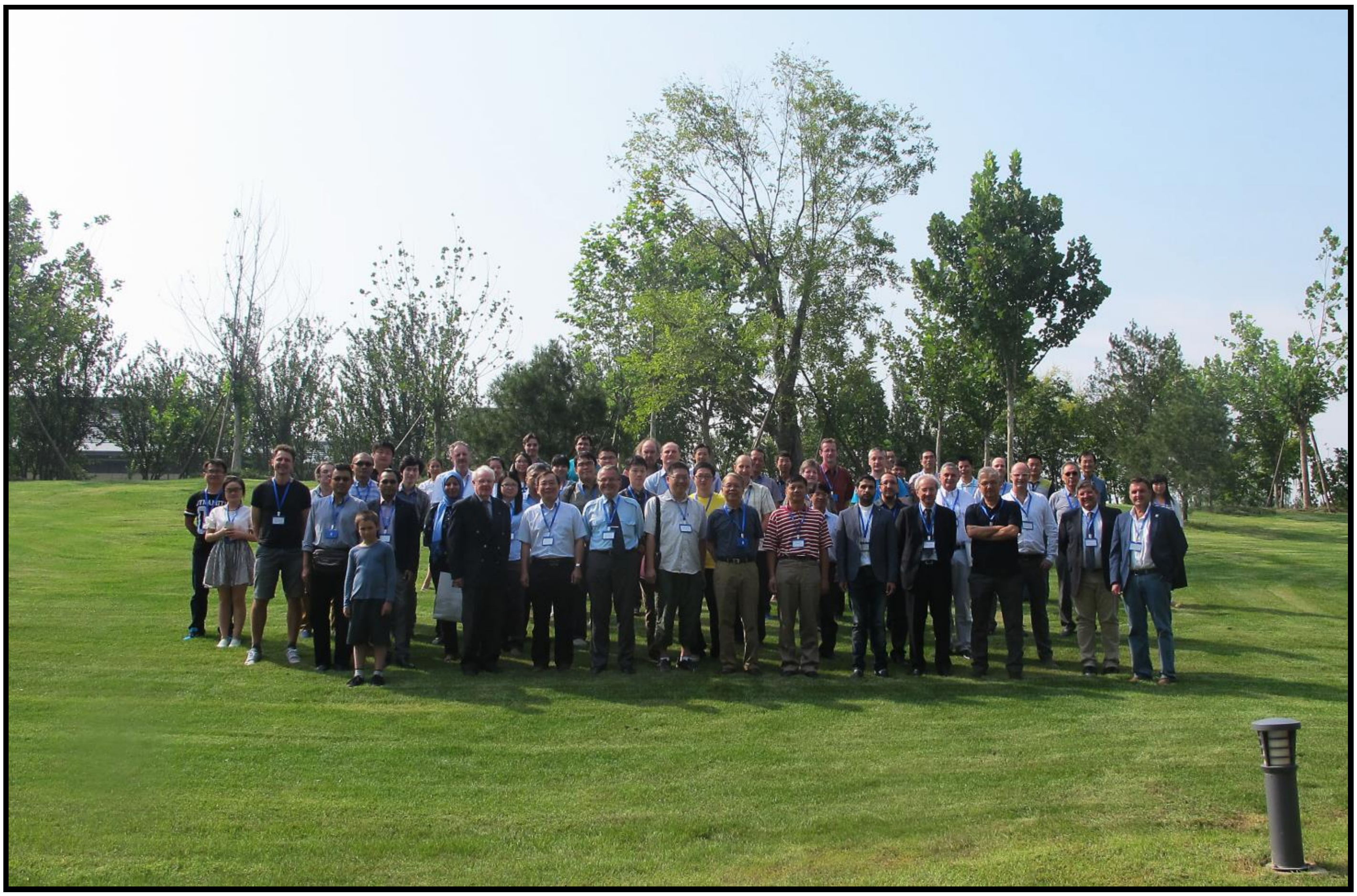


Delegates attending ISRP-13 were from across the Radiation Physics world.

…/ Beijing 2015 to Cordoba in 2018

Beijing 2015 to Cordoba in 2018

At the conclusion of the conference the hosting institution for ISRP 14 was announced as the National University of Cordoba, Argentina, virtually the antipode of Beijing. Chairman, Dr Marcelo Rubio, presented an invitation to attend this next symposium, to be held in 2018, giving delegates the opportunity to ponder their ideal route.

Beijing and Cordoba are virtually antipodes.
The hosting institution for ISRP in 2018 will be the National University of Cordoba, Argentina.

The proceedings of ISRP-13 will appear in Radiation Physics and Chemistry in 2016.

Assembly of the Proceedings of ISRP-13, to be published in 2016 by the Elsevier journal Radiation Physics and Chemistry, is being managed by Yanli Gao *(front/center)*, shown here with IRPS Council members who also have editorial duties with Elsevier journals *(left to right):* Bill Dunn, David Bradley, Ladislav Musilek, Chris Chantler, Richard Hugtenburg, Jorge Fernandez, Jose Rodenas.

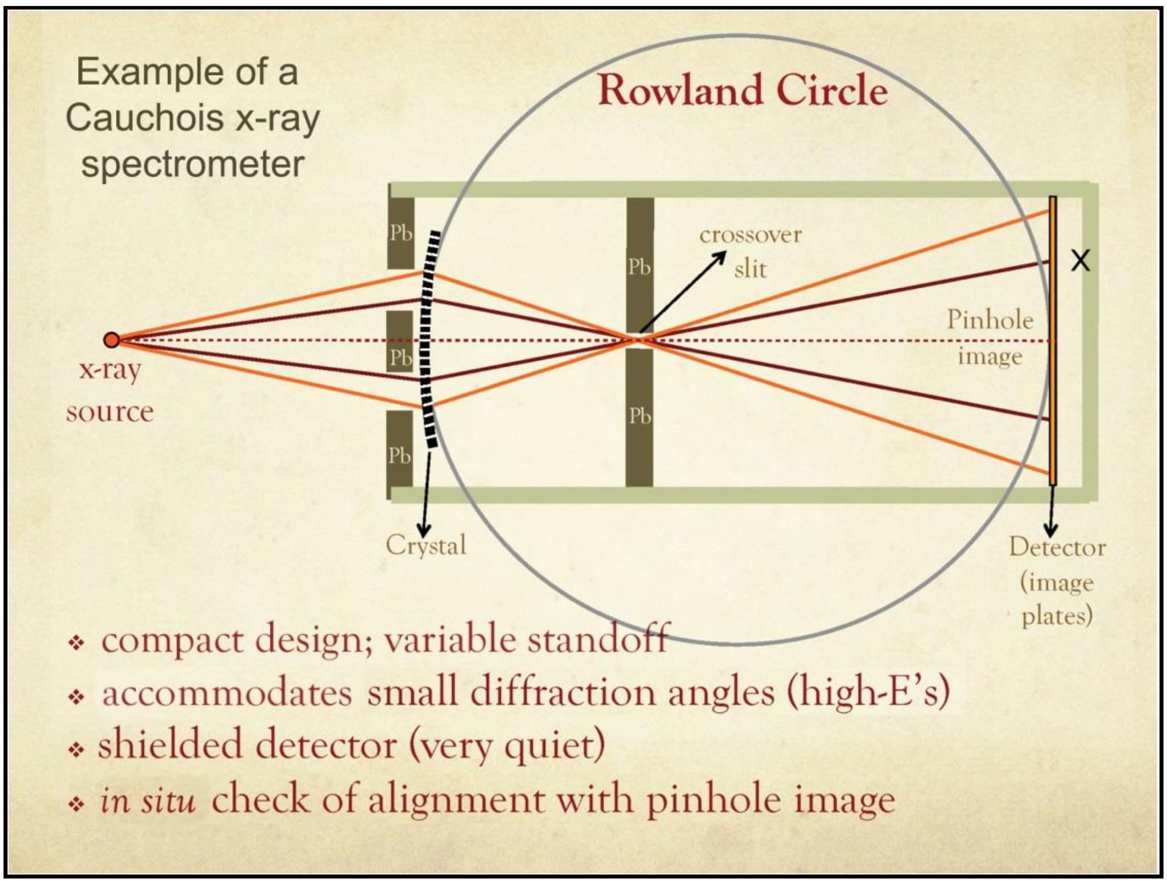
Yvette Cauchois and her contribution to X-ray and inner-shell ionization processes

François J. Wuilleumier

http://dx.doi.org/10.1063/1.1536359

***Editor's note*:**

For over a decade our group at NIST has been designing, building, and calibrating bent crystal spectrometers as plasma diagnostics in high-field and high-energy-density plasmas. Below is an example of a bent crystal being used in transmission, that is, the diffracting planes are perpendicular to the surface of the crystal. This is an example of "Cauchois" spectrometer geometry, in this case, with symmetric illumination and detection. So it was of great interest when chatting with Augusto Marcelli at ISRP-13, he mentioned an article by Wuillemieur on the life and contributions of Mademoiselle Yvette Cauchois. We reprint this article on the following pages with permission of the American Physical Society.



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Yvette Cauchois and her contribution to X-ray and inner-shell ionization processes

François J. Wuilleumier

Laboratoire d'Interaction du Rayonnement Avec la Matière (LIXAM, ex-LSAI), Paris-Sud University, B. 350, 91405-Orsay, France

Reprinted with permission of the American Physical Society from the proceedings of the 19th International Conference on X-Ray and Inner-Shell Processes editors: Bianconi, Antonio ; Marcelli, Augusto ; Saini, Naurang L (2003).

Abstract. At the end of 1999, Mademoiselle Yvette Cauchois passed away. For over 50 years, she has contributed in a profound way to our understanding of x-ray physics and chemistry. The main aspects of her accomplishments will be briefly outlined.

INTRODUCTION

Born on December 1908, Yvette Cauchois received her bachelor's degree in physics in 1928. Then she was admitted in the Physical Chemistry Laboratory of the Unversity of Paris "La Sorbonne", whose director was Jean Perrin, who had win the Nobel Prize in 1926. Her thesis was dedicated to the invention, the design and the use of a new type of x-ray spectrograh, i. e., the bent crystal transmission spectrograph. After having defended successfully her PhD in 1933, she became research associate at the Centre National de la Recherche Scientifique, a newly organization fonded by Jean Perrin. She dedicated the next ten years of her life to a thorough investigation of these x-ray emission lines whose energies did not fit into the energy diagram of x-ray levels, the so-called satellites or non-diagram lines. In 1947, together with H. Hulubei, she published an exhaustive table summarizing the status of the experimental data available on the wavelengths of X-ray emission lines and absorption edges. She became full professor at La Sorbonne in 1951, and was apppointed as Director of the Physical Chemistry Laboratory in 1953. At this position, she deeply influenced generations of young students and researchers. As the "grand patron", she was able to develop in many directions new program of research not only in x-ray physics but also in various fields of physical chemistry. She continued to be personnaly involded in research, especially in the studies of the influence of chemical bonds on photoabsorption and x-ray emission processes. Early in Europe, she was the first to understand that the newly discovered synchrotron radiation would become a major tool of investigation for fundamental and applied research. Under her vigorous leadership, several of her collaborators, such as Christiane Bonnelle and Pierre Jaegle, were among the first to begin to use, in 1963, the synchrotron light emitted by the Frascati electron synchrotron in Italy. She founded a new laboratory dedicated to physical chemistry in Orsay, twenty miles south of Paris, in a place that would become later the University Paris-Sud (Paris XI). She was involved in the organization of many scientific activities,such as X-70 in Paris in 1970.

She retired in 1978 and was appointed as emeritus professor. She died in Romania in 1999. Before trying to illustrate the various aspects of her scientific life, I would like to present a nice portrait, shown in Figure 1. It was taken in 1987, when she received the gold metal of University Paris VI. I think that many of her collaborators and students remember her exactly as she is looking in this picture.

FIGURE 1. A photograph of Yvette Cauchois taken when she received the Gold Medal of University Paris VI in 1987 ; on the wall, a painting of the Cardinal de Richelieu by Philippe de Champaigne (1602-1674).

THE FIRST YEARS: A NEW X-RAY SPECTROGRAPH

During the second decade of the twentieth century, x-ray spectroscopy was one of the major developing technique helping to better understand the atomic structure and the interaction processes occuring between radiation and atoms. Born in 1912 from the discoveries of Laue [1] and Bragg [2], the use of this new spectroscopic method grew rapidly in many laboratories, and was continuously improved by people such as Manne Siegbahn and L. G. Parratt. The first extensive x-ray data base was established by Siegbahn [3] in compiling all available measurements of absorption edges and X-ray emission lines. Owing to Bohr [4] atomic theory and further developments by Moseley [5], it was rapidly understood that characteristic X-ray emission lines originate from the radiative decay of electronically excited states in atomic inner-shells. The electronic states involved as initial and final states of a process, either absorption or emission process, were called X-ray levels. The X-ray lines emitted after the removal of a single electron from the electronic configuration of the neutral ground state were called X-ray diagram lines, while the term of satellite lines or non-diagram lines was reserved for any line that did not fit into the X-ray energy level. A quasi-universally adopted notation was proposed by Siegbahn. As an example, the diagram lines emitted in a transition of an atomic electron belonging to either the L_{III}- or M_V-subshells into a vacancy in the K- or L_{III} subshell were called $K\alpha_1$ and $L\alpha_1$ lines, respectively.

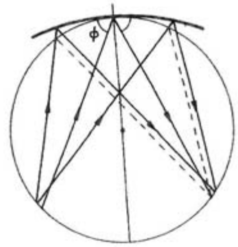
What was the status of the experimental techniques at the beginning of 1930? X-rays are produced by the interaction of charged particles with an electromagnetic field. At the time where our story begins, the almost exclusive way to produce X-rays on earth was to bombard a solid target by fast electrons, thus producing a continuous X-ray spectrum called bremsstrahlung, and a number of discrete emission lines characteristic of the target material. The decay of radioactive isotopes was, sometimes, used for the calibration of X-rays detectors. But X-rays from synchrotron radiation sources of from highly-charged laboratory plasmas were only part of a far and unknown future. The photon energy range accessible for spectrographic studies was the hard x-ray region, i.e., with x-ray wavelengths below 1500 xu or 1.5 angström. This wavelength border limits roughly the part of the spectrum which is not absorbed by the air. Above 2000 xu, the radiation is absorbed by the air and the study of these so-called soft x-rays necessitates the whole spectrograph, including the detector, to be placed in good vacuum.

The most simple spectrograph built for X-ray spectroscopy in this early stage was equipped with a plane crystal. Based on the well known relation nl = 2d sinθ established by Bragg [2], it makes use of a flat crystal to diffract the x-rays and of a photographic plate to record the monochromatized spectrum. The selective reflection of X-rays against the atomic planes of the crystal is comparable to the reflection of a beam of visible light at the surface of a plane mirror. It is possible to use this selective reflection without the help of any slit, but the resolution is very small in this case. Thus, it was soon realized that it was necessary to limit the size of the incident x-ray beam. In the first X-ray spectrographs [6], there was a fixed entrance slit. The crystal was rotated continuously about an axis parallel to the slit. During the rotation, the various monochromatic diffracted beams cross a definite point of a circle whose center coincides with the center of rotation of the crystal and which crosses the slit. Later instruments were derived from this system, making used of one or two slits to limit the X-ray beam. In fact, in a plane crystal spectrograph, only one slit is necessary to get a good as resolution as is possible. There are mainly two possible positions for this slit. It can either be placed in front, or behind the crystal. In case where an edge is placed in the middle of the crystal itself, the edge and its image in the crystal constitute the slit.

With a slit placed in front of the crystal, like in the case of the de Broglie spectrometer [7], an X-ray spectrum is registered all around the circle previously described. For this purpose, the crystal has to be rotated with its axis of rotation perpendicular to the plane of the circle and through its centre. Rays entering through the slit in a divergent beam strike the rotating crystal at the glancing angle corresponding to their wavelength. The use of the rotation was favorable also from the point of view that the crystals were not always of the highest quality. Spectrographs with a slit in front of the crystal have been used through the whole X-ray region [8]. When hard X-rays are concerned, the slit has to be made of a very absorbent material, such as gold or lead. One example of spectrograph often used over the world was designed by Siegbahn [9]. Photographic registration was used at the beginning rather than ionization chamber or counter detectors. Several methods were developed to measuring very accurately the Bragg angle, by reducing the adjustment errors. Errors due to the penetration of the radiation into a not perfect crystal, however, can never be completely eliminated, but at very long wavelengths. When the slit is placed behind the crystal, a diaphragm in front of the crystal limits the width of the beam from the X-ray tube, and the slit itself is placed on the other side of the crystal at the same distance from the crystal center. The diffracted spectrum is registered on a photographic plate far from the slit. Lead plates must be used to prevent the direct beam from penetrating the slit. A good example of this tube spectrometer was built by Siegbahn and Larsson [10] in 1925. The need to limit the incident x-ray beam by a slit reduces considerably the intensity available on the photographic plate. The experimentalists have always to find the best compromise between resolving power and intensity. Several new systems were proposed around 1930 to increase both factors. Higher resolution was needed to better resolve x-ray lines very close in energy, higher intensities were strongly required to study weak and unexplained lines appearing frequently on the high energy side of the diagram lines.

The principle of the two-crystal spectrometer was to use two consecutive crystals to diffract and measure the X-ray spectra. With such a device, photographic recording was excluded. In the early time, ionization chambers served to measure the intensity of the X-ray spectra, allowing in fact a better comparison of the relative intensities of weak and strong x-ray lines than the photographic plate. Counters were introduced later ad provided more reliable intensity data. First proposed by Ehrenberg and Mark [11] in 1927, the idea to have the X-ray beam reflected by two crystals raised may hopes. In the so-called antiparallel position, the dispersion and the resolving power was expected to be twice that of a single crystal instrument. The resolution does not depend anymore on the width of the slit, only the height of the slits plays a significant role. Even though this expected goal was never be reached because of the limiting factor introduced by the diffraction pattern of each crystal, the improved resolving power of this instrument helped greatly to determine, with a better accuracy, the energies of many x-ray lines, diagram or non-diagram lines, and to observe weak lines immerged in the tail of a neighborhood intense X-ray line. The price to pay for this improved resolution was the lost of intensity in the recorded diffracted spectrum and the difficulty to measure very weak lines. Early examples of two-crystal spectrometers were built by Du Mond [12], Allisson [13], and Parratt [14].

A fruitful idea to increase considerably the luminosity of x-ray spectrographs was to concentrate the X-ray beam in the direction perpendicular to that of the dispersion. Following an early suggestion by Gouy [15], Johann [16] was the first to build an instrument with a bent crystal to produce by reflection a monochromatic x-ray beams from widely divergent incident x-ray radiation. A scheme of his spectrograph is shown in the left part of Figure 2. The crystal is bent to a radius twice that of the focussing circle. A divergent X-ray beam is reflected by the system of atomic planes parallel to the curved surface. The X-rays originating from a focus spot placed on the circle are reflected into a fairly sharp line on the same circle. No slit is needed to reduce the divergence of the emitted X-ray beam. The focussing of the reflected beam is not perfect, however, since the image of the source formed by reflection on the surface of the crystal has some extension along the focussing circle. The focussing defect increases with the distance from the point of reflection to the center of the crystal. Thus, the line shape is asymetric and depends on the aperture of the crystal. It decreases with increasing values of the Bragg angle. For a given reticular distance of atomic planes, the highest is the Bragg angle, the highest is the wavelength of the reflected x-rays. The instrument is the most efficient for longer wavelengths, namely in the soft x-ray range. The luminosity is significantly enhanced because of the convergence of the reflected rays. Later, Johansson [17] improved the focussing of the instrument by grounding the crystal before curvature, making possible, at least theoretically, to get an exact focusing



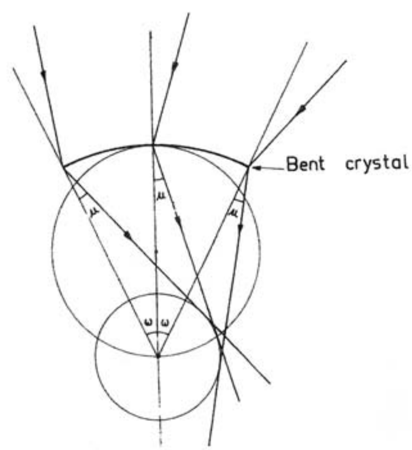


FIGURE 2. Schemes of the bent crystal spectrographs working by reflection (left part) and by transmission (right part) (from Ref. 20).

To work in the hard x-ray range, typically above 8 keV photon energy, Y. Cauchois [18, 19] proposed an alternative way to increase the luminosity of the spectrographs. She suggested to use the transmission of a widely divergent ray beam through a bent crystal. The scheme of this new instrument is shown in the right part of Figure 2. The rays are incident on the convex side of the crystal and are focussed, on the concave side. The selective reflection occurs on reticular planes whose orientation is perpendicular or oblique relative to the surface of the bent crystal. In the instrument built by Y. Cauchois, the diffracted x-ray spectrum was registered on a photographic plate placed along the focusing circle. In her thesis [19], she described in details the theory of the diffraction of the x-ray beams in this spectrograph in which all lines transmitted by the crystal are located on a circle which is tangent to the crystal circle and whose diameter is equal to the radius of the crystal. More exact formulae were derived later [20]

In her first spectrograph, Y. Cauchois chose R = 20 cm, with gypsum and mica crystals. Thus, the dispersion in first order was in the order of 25 xu/mm and the resolving power was better than 1 xu. The instrument could be used over the photon energy range extending above 6 keV. In practice, the resolving power of a bent crystal should be slightly inferior to that of a one crystal spectrometer, because of the mosaic effect [21], but the luminosity is considerably enhanced by a factor of about 100 as compared to a Bragg spectrometer [19]. Thus, the use of a bent crystal spectrometer is highly recommended to measure faint x-ray lines of very weak intensity.

Y. Cauchois made use of her instrument to study the x-ray emission lines for atoms in the gas phase, while most of the existing measurements had been made on solid target for evident reasons of intensity. She already had the idea that it should be possible to follow the influence of the chemical bond through a large number of various compounds of a given Z-element. To start with, she decided to measure the K-emission spectrum of krypton. To achieve her goal, she had a high-power fast-electron tube built in her laboratory. Combining its use with the high luminosity of her spectrograph, she succeeded to measure the diagram K-emission lines of krypton [19, 22], as shown in Figure 3.

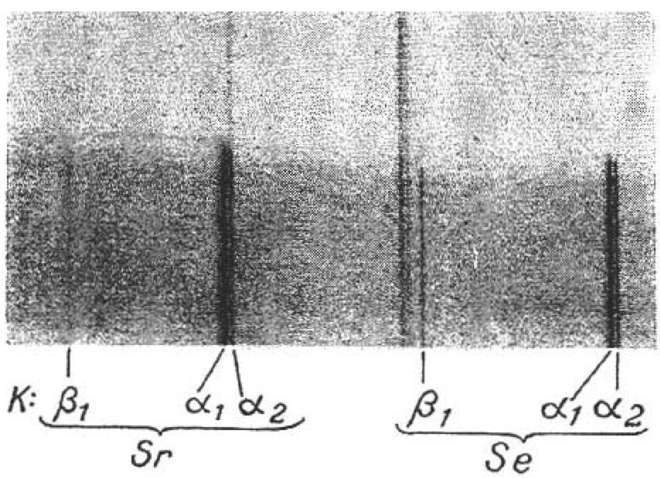


FIGURE 3. K-X-ray emission spectrum of krypton (from Ref. 22)

The geometrical width of the spectral line on the photographic plate was between 0.03 and 0.05 mm, providing an accuracy of ± 0. 25 xu. The Kβ_1 and K$\alpha_1\alpha_2$ lines of Sr and Se served as reference lines. In Table I are shown the results of her measurements. The values measured for Kr fit rather well within the Moseley diagram showing the square root of the energy linear as a function of the atomic number Z. In the last column of Table 1, I like to show also the results of the most recent and most accurate experiment carried out about 60 years later [23]. Since these new measurements were referred directly to the angström scale, I had to convert the values with the conversion factor taken equal to 1.00209(1) kxu/A according to the values quoted by R. D. Deslattes et al. [24]. In the latest experiment, only the Kβ_2 line was not re-measured. The accuracy is evidently greatly improved, by more than one order of magnitude, but the difference between the values measured by Y. Cauchois in 1932 and 1933 and the latest results are well within the error bars she quoted, demonstrating, if needed, the high quality of her early measurements.

Table I. Wavelengths of the diagram K-emission lines in krypton.

Transition	Cauchois kxu (1933)	1999 value [Ref.24] kxu
Kα_2	982.10 (25)	982.306 (14)
Kα_1	978.10 (25)	978.223 (14)
Kβ_1	876.70 (25)	876.690 (14)
Kβ_3	not resolved	877.178 (16)
Kβ_2	864.30 (25)	864.30 (16)

A PERIOD OF INTENSE RESEARCH ACTIVITY : THE SATELLITE STORY

During the 10-12 years following her PD, until 1945 when she became associate professor at La Sorbonne, Y. Cauchois was a full time research scientist, free of any teaching duty, thanks to her position at the Centre National de la Recherche Scientifique. She could then be fully dedicated to research. Having in hands the beautiful tool she has created, she could explore various aspects of x-ray physics and the application of x-ray spectroscopy in chemistry. A field which required as high as possible a luminosity was the study of non-diagram lines, also called satellite lines. Another goal she has in mind was the compilation of all data available for the x-ray emission lines and absorption edges, with the special care of defining as best as possible the chemical and physical states of the measured elements, as well as the accurate identification of the observed transitions.

What was, known about x-ray satellite lines in 1935 ? They had been discovered by Siegbahn and Stenstrom [25] in 1916 when they observed, on the high-energy side of the $K\alpha_{1,2}$ doublet of Zn (Z = 30), a weak line whose energy did not fit into the X-ray energy level diagram. This faint x-ray emission line was becoming more prominent for elements of lower Z, until Na (Z = 11). It was perhaps fortunate, as mentioned by Richtmeyer [26] years after, that the spectrographs available in this early time did not have high sensitivity and resolving power. The diagram x-ray lines were the most intense and the most easily resolved lines in the x-ray spectra. These lines were well represented by the energy level diagram of singly ionized atoms and constituted a firm basis to go further into the interpretation of additional emission lines. Thanks to the improvements in instrumental techniques, many more faint lines were subsequently discovered, and did not fit into this diagram. Thus, they were called non-diagram or, preferably, satellite lines.

Within a few years, it became evident that the more experiments were performed, the more was the number of discovered lines which were not diagram lines. Wentzel [27-29] proposed a theory of the origin of satellite lines, suggesting that they were originating from transitions in multiply-ionized atoms. As an example, the $K\alpha_4$ satellite line was supposed to arise from a KK $\rightarrow$ KL transition where KK refers to a doubly ionized atomic state in which the two K-electrons are missing. The probability of having two electrons ejected from an atom by successive impacts of the electrons in the target of an x-ray tube was much too low to account for the observed satellite intensities [30]. The double ionization process had to occur by a single impact, i. e., by simultaneous ionization of two electrons. The original Wentzel theory was questioned by the determinations of the excitation voltages of satellites [31, 32]. The measured values for the K-satellite lines gave values considerably less than twice that of the parent diagram lines. With a wealth of new data becoming available, Druyvesteyn [33-35] modified the Wenzel's theory by proposing that the initial state of the atom giving rise to satellite lines is one in which the double ionization never refers to the same atomic shell. In the now so-called Wentzel-Druyvesteyn theory, the main satellite lines of the $K\alpha_1$ diagram line are produced by radiative decay in a KL $\rightarrow$ LL transition. The excitation potential should be approximately equivalent to the total energy required to remove the K-electron of the atom Z plus the energy required to remove an L-electron of atom (Z + 1). The x-ray transition producing the emission of the satellites is a single-jump transition. (We know now that, in the double ionization process, two electrons can be ejected simultaneously from the same shell, according the shake off theory which was developed 30 years after the time where the case of satellite lines was a hot topic. Even double K-electron ejection is possible and gives rise to the hyper-satellite lines, a subject well documented by recent theoretical and experimental works [36]). Further improved studies [37, 38] of the excitation potential needed to produce satellite lines of either the parent K- or L- diagram lines were in good agreement with the Wentzel-Druyvesteyn theory.

Keeping the idea that x-ray satellites have their origin in x-ray transitions within multiply-ionized atoms, Richtmeyer [39] proposed that the satellite emission were resulting from a two-electron transition. Assuming that the initial doubly ionized state is a type in which one of the initial ionizations occurs in an inner shell, and the other not far from the outermost filled shell, he suggested that the two electrons jumping simultaneously into the two vacancies produce the emission of one satellite whose frequency should be equal to the sum of the frequencies of the two transitions taken separately. This two-jump theory explained the low excitation potentials of the satellite lines, while the variation of the relative intensities of the most intense K-satellites were found in agreement with the one jump theory. Both theories were able to explain the measured energies of the satellite lines. The key point, however, was the comparison of the intensities of the satellites relative to the parent lines and their variation with the atomic number Z.

At the end of 1934, the number of discovered satellites was still increasing rapidly, to the point that the number of known satellites was exceeding the total number of diagram lines. Most of the data available to date had been obtained using the Siegbahn vacuum type spectrometer and photographic detection. The use of the high luminosity Cauchois spectrometer and of the two-crystal spectrometer with ionization chambers or counters was barely starting and many more data were still to come. With the low luminosity Siegbahn spectrograph and the photographic detection, only rough estimates of the intensities of satellites had been made. To bring out the satellites on a photographic plate required that the parent lines were usually much overexposed, so that the direct comparison of intensities was difficult. In addition, many of the satellites were lying in the shadow of the parent line, the shape of which had to be estimated in order to make an even semi-quantitative determination of the relative intensities. In summary, the relative intensities of the most intense Ka satellites had been measured for Z between 13 and 29. Calculations of the K-L ionization probability, based on the Born approximation of collision theory, and using self-consistent-field wave functions for sodium [40] and potassium [41] atoms predicted variation of the relative intensities for Ka satellites in good agreement with the measurements. Extension of these calculations from Z = 17 to Z = 29 gave relative intensities whose Z-dependence was in excellent agreement with the measured data. These results supported the Wentzel-Druyvesteyn interpretation of the Ka satellites. For the Lα and Lβ satellites the answer was raising puzzling questions. In the low and intermediate Z-range (37 to 52), the ratio of the intensities of the satellites to that of the parent line was shown [42, 43) to rise from a few percent for Z = 40 to a large maximum (nearly 50 percent) in the neighbourhood of Z = 45 (for Lα) and 47 (for Lβ), and to fall rapidly to zero for Z = 52. For Z = 53 and above, no satellites could be observed until they reappear for Z = 73 to 90, with a significant intensity of 5 to 6 percent [44]. The L-satellites observed for the heavy elements seemed also to be different from the ones measured below Z = 52. These results were in full disagreement with the one jump theory which predicted a continuous decrease in satellite intensities with increasing Z atomic number. It seemed impossible to correlate these rapid changes of the relative intensities with any know change in the atomic electron configuration .

Seen from far away in the future, it is surprizing that it took so much time to understand the behavior of the L-satellite lines. Ten years before, Auger [45, 46] had discovered the non-radiative decay of core-hole ionized atomic states by observing

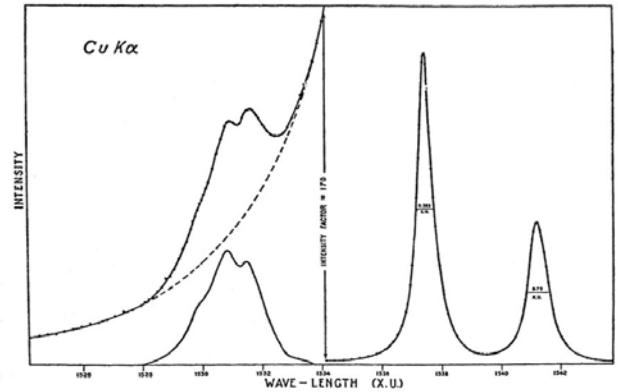


FIGURE 4. The Kα doublet of Cu (right part) with accompanying satellites (left part, intensity scale increased 170 times) as measured with a two-crystal spectrometer (from Ref. 50).

short tracks in a Wilson cloud chamber ionized by X-rays. Coster and Kronig [47] established that some doubly ionized atomic states were arising from a so-called internal photoelectric effect, redistributing the vacancies within the L-subshells. Assuming that an L_I electron is missing, a L_{III}-electron can drop into the vacancy, freeing an energy equal to the differences between both binding energies. This energy is then used to ionize an outer electron provided that the energy released is higher than the binding energy of this electron. Between Z = 52 and Z = 73, the energy released by Coster Kronig transitions was not sufficient to expel M_{IV} or M_V electrons. This interpretation was in complete agreement with all experimental results and brought a strong support to the Wentzel-Druyvesteyn theory. The puzzling problem risen by the widths of K-, L-, and M-x-ray lines was also illuminated by consideration of the Coster-Kronig transitions. From 1935, the way was then paved for an accurate interpretation of more and more experimental data.

To make the results on x-ray satellites fully quantitative, more accurate data were needed. Some people, such as Paratt [48, 49], chose to use systematically the two-crystal spectrometer to make profit of the high-resolving power of the instrument and of the linearity in the dynamical response of the detection system. Soon new satellites were measured. It was noted [26] that and atom, which is capable of being singly ionized in 16 different ways (K to N shells), can be doubly ionized in 120 different ways. As an example of the high quality of the data obtained with the two-crystal spectrometer, I show in Figures 4 and 5 the K$\alpha_{3,4}$ satellites of copper and the Lα satellites of silver, respectively. In the Kα spectrum, there appear to be at least four components in the satellite group. In the La spectrum recorded with a resolving power of 11 000, the group of satellites near the Lα_1 diagram line is made of at least five components (21 satellite lines were measured in total). The difficulty in tracing accurately the background on the tail of the parent line, still maintains some significant uncertainties on the relative intensity of the satellites, even with such a high resolution instrument.

Cauchois decided to use her high luminosity apparatus in order to explore known and unknown K- and L-satellites. During the 10 following years, her activity was mainly devoted to measurements and identifications of L-satellite spectra in heavy

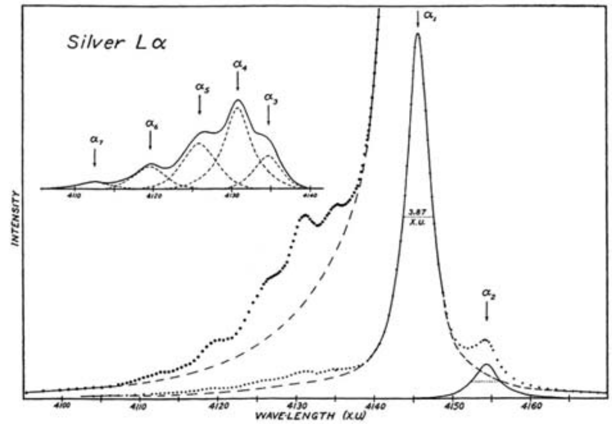


FIGURE 5. Intensity curve of the Ag Lα region. Five component satellites lines are sketched in the left upper part of the figure with the intensity scale increased 6 times (from Ref. 51).

elements [52], from W (Z = 74) to thorium (Z = 90), including some radiactive elements : As [53], Po [54] and Np [55]. She also studied in details the K-absorption spectrum of lighter elements [56], below Se (Z = 34). Over a period of ten years, she published not less than forty papers. To illustrate the results she obtained, I show in Figure 6 the L-x-ray emission spectra of gold (Z = 79) and W. (Z = 74), registered with a mica (201) crystal bent under a radius of 40 cm . The plates were overexposed to bring out the faintest L-satellites. She found many new lines in the Lα and Lβ spectra, with some of them being possibly attributed to a double electron jump (such as Lα_a and Lα_s). In particular, she demonstrated the existence of a new series of satellites correlated with the Lβ_5 diagram lines ($L_{III} \rightarrow O_{IV, V}$), made at least of two components and relatively intense in lead and gold. A comprehensive summary of her results was published in 1944 [52]. From the data she accumulated, she was able to propose the first table of the energy levels of doubly ionized atoms.

One of her goal was to compile and publish the results of all wave lengths measurements for diagram and satellite x-ray lines in a widely available table. She wanted also to include the values of the x-ray absorption edges in order to have a consistent set of data for the binding energies of all atomic electrons. To select the data, she took a great care of the physical and chemical state in which was the measured elements. The completion of this additional part rose additional problems. The main question was, at a time where there did not exist accurate data from low-energy electron spectrometry, what does one actually measure when studying an X-ray absorption edge? The answer is quite different, depending on the status of the element under investigation. For an atomic gas (rare gases, metallic vapors), the answer is relatively simple. It is well illustrated by the X-ray absorption spectrum of argon measured by Parratt at the K-absorption edge [57] which is shown in Figure 7. Recorded with a two-crystal spectrometer, the measured absorption curve was analyzed in terms of the resonant 1s $\rightarrow$ np (n > 3) absorption lines. The data were corrected for the finite resolving power of he spectrometer. The resonant structures observed below

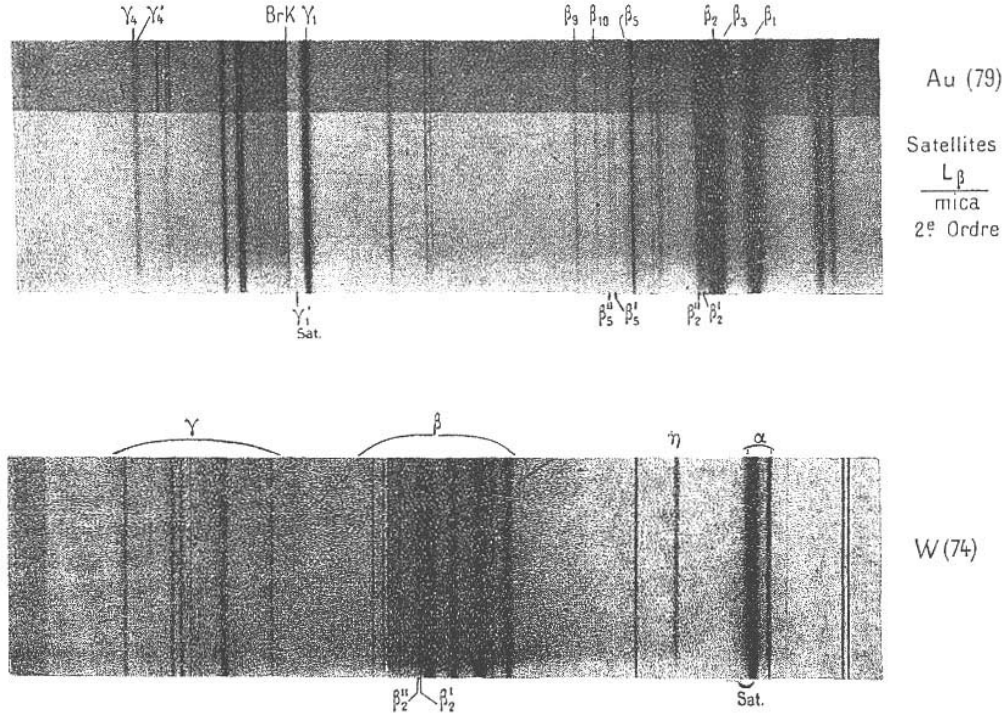


FIGURE 6. L spectrum of gold (upper panel) and tungsten (lower panel) showing the overexposed diagram lines and many of the weaker satellites (from Ref. 52]

the K-edge (located at 3866 kxu) were supposed to be of equal width (0.58 eV, equal to the natural width of the K-hole state) as given by the width of the fully resolved first resonant line. The data were analyzed assuming that the splitting between the np levels is equal to the separation of the optical terms of potassium. The theoretical shape of the main edge is represented by an arctangent curve. The analysis places the main edge (transfer of the 1s-electron to infinity with zero energy) at 3.5 to 4 xu below the wavelength of the maximum absorption. Nothing is remarkable in the spectrum at this wavelength of the true edge value which it would not be possible to determine without being able to decompose the structure of the absorption edge. The situation would then be more difficult to analyze if the resolving power would be worse.

In the case of a metal, shown in Figure 8, the lowest energy transition in the photoabsorption process corresponds to the transfer of the K-electron to the bottom of the empty part of the conduction band. Thus, there is no narrow absorption line, but a broad absorption band at the K-edge. How to compare the energy of the electron excited in the conduction band with the binding energy as defined above? If the elements under investigation are available only in different chemical states, the actually measured binding energy of the electrons can be spread over several electron volts.

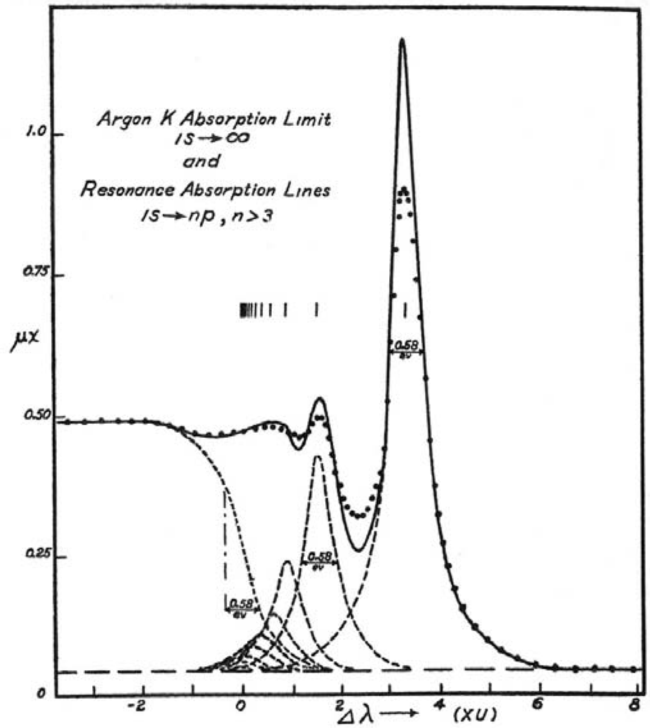


FIGURE 7. The K-absorption edge of argon. The broken curves represent the main edge and resonance absorption lines (from Ref. 57).

Finally, Cauchois published, together with H. Hulubei, their Table des Longueurs d'Onde des Emissions X et des Discontinuités d’Absorption X [58]. When available, the selected values were chosen from the works carried out in her laboratory. This table was the first one available. Let's mention that a new edition was published in 1978 with the help of Christiane Senemaud.

Cauchois established later reliable data for the binding energies of most elements. She published two separate Tables of these energy levels [59, 60] covering a large part of the Mendeliev Table.

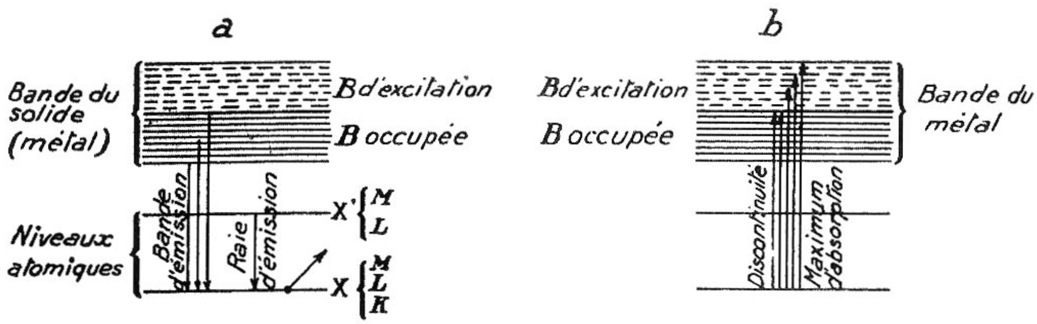


FIGURE 8. Scheme of absorption and emission processes occurring in a metal.

THE PROFESSOR AND THE DIRECTOR OF A LABORATORY

Y. Cauchois was appointed at the University of Paris "La Sorbonne" as an associate professor in 1945, and as a full professor in 1953. She became the director of the Physical Chemistry Laboratory of the University of Paris in 1953. She was succeeding Edmond Bauer who was the director of this laboratory after the death of his founder Jean Përrin in 1926. In such a position, she had to considerably diversify her activities as it is the duty of the director of any laboratory of significant size, and as a worldwide recognized leader in X-ray spectroscopy. As a professor she was teaching undergraduate and graduate students. Her graduate school was well attended by many students who prepared their PhD in her laboratory or in an associate institution. To help the students, she wrote various university books dedicated to X-ray scattering, X-ray spectroscopy, X-rays in Chemistry, X-ray absorption elementary particles, all of them being published by the Centre de Documentation Universitaire de Paris [61]. She wrote several books for researchers and students such as "Les spectres de rayons X et la structure électronique de la matière [62], Atomes, Spectres, Matière [63], Cheminement des particules chargées [64] ".

As the leader of a scientific school, she continued to push the development of x-ray studies into new directions. One important new field was the exploration of the soft and ultra-soft photon energy ranges. Emission and absorption processes in atomic gases as well as in many chemical compounds were among her favored studies. She had built in 1945 a so-called universal spectrometer [65] which could be used either in transmission or in reflection. Several other instruments were developed and built in her laboratory by collaborators such as C. Bonnelle and P. Jaeglé, to continuously cover the range between the hard X-rays and the VUV region. She was personally involved in several areas: the chemical shift in X-ray absorption and emission processes, the transuranium elements, the extraterrestrial X-ray radiation, together with many people who became her collaborators after having been his students. I would like to recall here the names of C. Bonnelle and Y. Héno, who were her main collaborators (C. Bonnelle succeeded her as the director of the Physical Chemistry Laboratory when she retired in 1978), P. Jaeglé who became the first director of the Laboratoire de Spectroscopie Atomique et Ionique in Orsay at the University Paris XI, the X-UV part of the laboratory founded by Y. Cauchois in Orsay, C. Senemaud, a bright scientist, director of research in her laboratory who died prematurely in 1997, A. Maquet and C. Hague two very active scientists who are presently director and deputy director of the Physical Chemistry Laboratory after C. Bonnelle retired, R. Barchewitz who was professor at Paris VI University, and some well known theoreticians such as F. Combet Farnoux and A. Sureau, who were developing sophisticated multi-configuration codes to treat photo-absorption processes in atoms and plasmas.

Y. Cauchois was also deeply involved in many national and international organizations. In particular, she was active in creating the series of International Conferences dedicated to X-ray processes. It might be interesting for the jung newcomers in the field and for the participants to X-ray-2002 in Roma to know that she

FIGURE 9. Photograph of Y. Cauchois and H. Curien at the opening ceremony of X-70 at the CNRS in Paris

was the chaiman of X-1970 in Paris, called "Processus électroniques simples et multiples des domaines X et X-UV" (I helped her to organize this 4th edition of the series) after Gatlinburg (1962), Leipzig (1965) and Kiev (1968). I like to show in Figure 9 a photograph of the chairs at the opening ceremony of X-70. Hubert Curien, seated on the right side, was the General Director of the CNRS before becoming later Minister of Research in the Government.

The people who would like to know more about the life of Y. Cauchois, will read with interest the bibliography published by C. Bonnelle in Physics Today [66].

FIRST EXPERIMENTS USING SYNCHROTRON RADIATION

Y. Cauchois was interested quite early in the perspective open by the possible use of synchrotron radiation. In one of her book, she wrote a long chapter on the characteristics of synchrotron radiation [64]. Since the discovery of the existence of this radiation in 1947, and the first characterization of this new source in 1956 by Tomboulian [67], the National Bureau of Standards in Washington, USA, was the first center to develop some programs to use the radiation emitted by the 180 MeV-SURF synchrotron in the VUV range. The first major physics result using synchrotron radiation was obtained by Madden and Codling, when they discovered the famous doubly-excited states in helium [68]. Predicted by Fano, the existence and properties of the newly observed autoionizing states were soon interpreted. I remember that we had

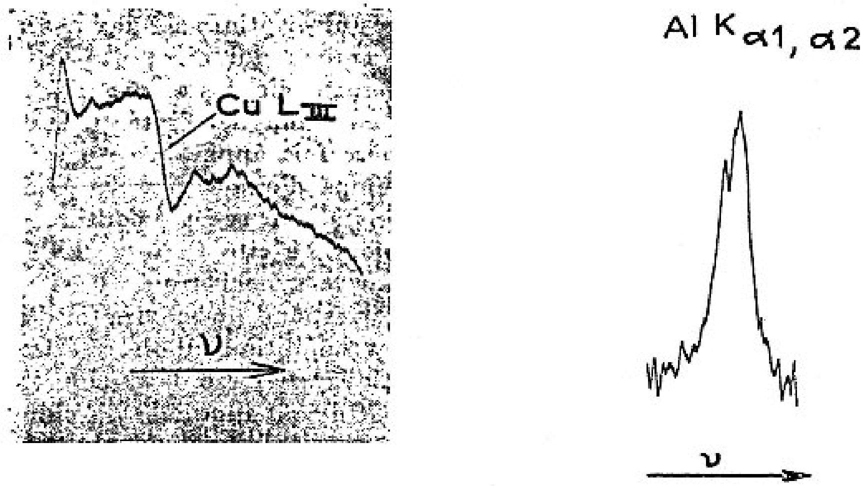


FIGURE 10. The L_{III} absorption edge of Cu (left part, from Ref. 68) and the fluorescent Ka emission line of Al (right part, from Ref. 69) measured with the synchrotron radiation emitted by the 1.1 GeV electron synchrotron in Frascati.

the visit of Cooper and Fano in her laboratory in 1962 or 1963. We were all excited by the lively discussion she organized with them, and I was particularly impressed when she invited a graduate student like me to participate to the working lunch.

Together with C. Bonnelle and P. Jaeglé, she established a long term collaboration with the Istituto di Sanitaria di Roma to prepare a program using the radiation emitted by the Frascati electron synchrotron. In 1963 was published [69] the first observation of x-ray processes due to interaction of this radiation with various targets. Figure 10 shows examples of the spectra obtained with a soft x-ray spectrometer at the L_{III} absorption edge of Cu, and the $K\alpha_{1,2}$ emission lines of Al produced by fluorescence of an irradiated target. Even though the experimental conditions were not yet fully optimized during these first experiments, the comparison of the exposure time to record these spectra with the time needed to obtain equivalent spectra with the bremsstrahlung emitted by an x-ray tube shows that the gain in effective intensity was already several thousands at the Al K-edge, suggesting very exciting developments in the future.

A little later, P. Jaeglé and his collaborators installed a grazing incidence spectrograph in Frascati to work in the vacuum ultraviolet range. Soon they discovered a new effect in photoabsorption [70] as shown in Figure 11. The photoabsorption spectra of some heavy elements (from Ta to Bi) show an unexpected behavior over the 200 eV photon energy range. When the energy of incident photons increased, the absorption coefficient show large variations well away from any ionization threshold, passing through a deep minimum before reaching a weaker maximum, and then followed by a slower decrease towards high photon energies. Photoionization cross sections performed in the central field approximation explained these results by the combined effects of the 4f- and 5d subshells.

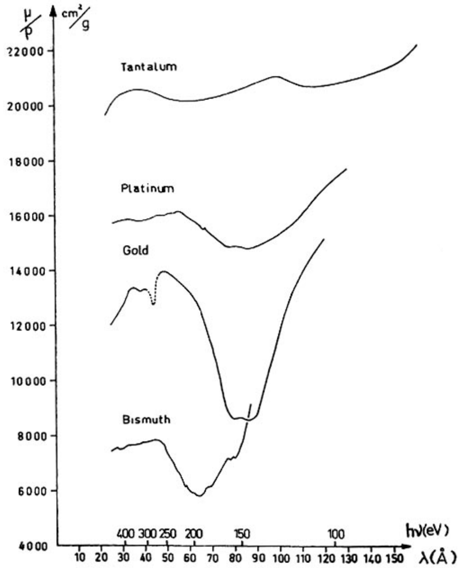


FIGURE 11. Mass absorption coefficients measurements for tantalum, platinum, gold, and bismuth recorded with the synchrotron radiation available for the Frascati synchrotron (from Ref. 70).

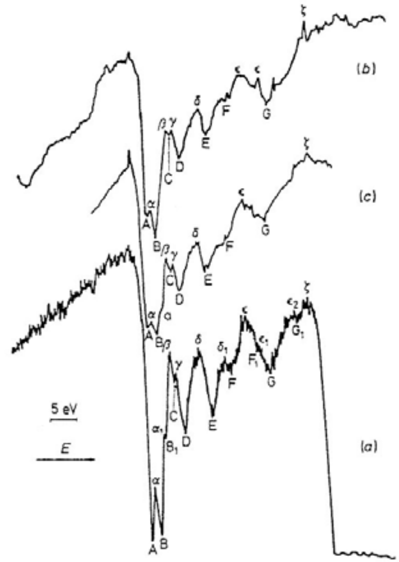


FIGURE 12. Comparison between the specular reflection at 8 mrad (a), and the photoabsorption spectra obtained by Barchewitz (b) and Rule (c) for Na K-absorption (from Ref. 72).

Finally, I would like to show as a third example of studies achieved at Frascati, some results obtained by R. Barchewitz and co-workers [71, 72]. They developed a new method to determine photoabsorption spectra of a bulk sample from the measurements of the specular reflection of continuous radiation on its surface. The apparatus used in Frascati consisted of two plane parallel mirrors placed in the path of the beam so that the axis of rotation of the first mirror was in the orbital plane and perpendicular to the beam direction. The second mirror was located so that its edge lies on a line passing through the center of the first mirror. The reflected radiation was analyzed by means of a bent crystal spectrograph using a mica crystal. Sodium was evaporated under vacuum onto the mirrors to give a film of nearly uniform thickness. Figure 12 presents a comparison between the specular reflection spectrum measured for a glancing angle of 8 mrad (curve a), the photoabsorption spectrum measured also in this work (curve b) and the Na K absorption spectrum measured previously by Rule (curve c, Ref. 73). The dispersion between the values deduced from reflection and absorption curves is of the order of the experimental errors, showing that reflection measurements are a good alternative to absorption measurements when a solid of convenient thickness cannot be prepared. Moreover, under equivalent resolution, some features are better seen in the reflected than in the transmitted spectrum or are observable only in the reflected spectrum (they are noted by the suffixed letters).

In 1968, Y. Cauchois and myself wrote a report on the use of synchrotron radiation to be included in the "Rapport de Prospective du CNRS". It was suggested to use the newly built storage ring in Orsay ACO for synchrotron radiation experiments. At this time the proposal was turned down by the particle physicists. A few years later, however, another attempt made by a group of atomic and molecular scientists, several of them from her laboratory, was successful, opening the way to the creation of the LURE laboratory [74]. People working since years at the french synchrotron radiation center owe some credit to Yvette Cauchois, a great pioneer in the field.

CONCLUSION

The end of the life of this outstanding scientist occurs in Romania where she had kept many friends, when she died of pneumonia during a short visit in 1999. I show in Figure 13 the place where she was buried in the country side, not far from the monastery of Barsana. The stone on her tomb was engraved with the following dedication :

OUTSTANDING SCIENTIST
FAITHFUL AND JOYFUL FRIEND
LOVING ALL GREAT AND BEAUTIFUL THINGS
REST IN THE PEACE AND LOVE OF GOD

FIGURE 13. Photograph of the grave of Yvette Cauchois in Romania (courtesy of Viorica Florescu)

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