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CONTENTS

The Nobel Prize in Physics 2005

"for his contribution to the quantum theory of optical coherence"

"for their contributions to the development of laser-based precision spectroscopy, including the optical frequency comb technique"

Roy J. Glauber

1/2 of the prize

USA
Harvard University
Cambridge, MA
USA

b. 1925

John L. Hall

1/4 of the prize

USA
University of Colorado, JILA;
National Institute of Standards and Technology
Boulder, CO, USA

b. 1934

Theodor W. Hänsch

1/4 of the prize

Germany
Max-Planck-Institut für Quantenoptik,
Garching, Germany;
Ludwig Maximilians -Universität
Munich, Germany

b. 1941

FROM THE EDITOR'S DESK

This issue of news letter carries an abstract on the fragmentation of molecules. In their work, Krishnakumar and coworkers have shown larger molecules retain the dissociative electron attachment of the precursor molecules. This inheritance of characters points to a way of interpreting dissociative electron attachment data from bigger biological molecules. An accompanying article in the news letter explores this phenomena in detail. An abstract in this issue is on work related to clusters, the photoexitation of Buckminster fullerene. The work is a culmination of combined efforts of experimental and theoretical physicists, as it is apparent from the authors list. The work is an endeavour of groups geographically separated, on different continents, belonging to different countries. A footprint of a globalized world, universality of science. Another abstract is on ultracold fermionic atoms. One of the research area in atomic physics that has experienced path breaking work in recent years. The mentioned work studies the superfluid state arising from pairing in two species ultracold fermionic cloud.

This month witnessed the announcement of the most coveted prize in natural sciences, Nobel prizes. The prize in physics has been awarded to Glauber, for his work on coherent light, and Hänsch and Hall for their work on optical frequency comb. Their works have pushed the frontiers of physics and uncovered new puzzles in their wake. An article in this edition of the news letter apprises the remarkable contributions of the awardees. The article traces the genesis of their work to the contributions of Maxwell and Einstein. Masters of eras, past, whose works continue to influence contemporary research. Coincidentally, this year marks a century of Einstein's revolutionary papers on photoelectric effect, Brownian motion and special theory of relativity. The coherence of light is perhaps a descendent of Einstein's work on photoelectric effect, which showed the quantum nature of light. The Nobel prize is a befitting closing of the centennial celebration of the year that shook the world of physics.

K.P. Subramanian
EDITOR, ISAMP Newsletter

Dilip Angom
Guest Editor

October 21, 2005

ABSTRACTS OF RECENTLY PUBLISHED PAPERS

Abstract#1

Photoexcitation of a volume plasmon in C_{60} ions

S. W. J. Scully, E. D. Emmons, M. F. Gharaibeh, and R. A. Phaneuf

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H. S. Chakraborty, M. E. Madjet, and J. M. Rost

Max Planck Institute for the Physics of Complex Systems, 01187 Dresden, Germany

Abstract: Neutral C_{60} is well known to exhibit a giant resonance in its photon absorption spectrum near 20 eV. This is associated with a surface plasmon, where delocalized electrons oscillate as a whole relative to the ionic cage. Absolute photoionization cross-section measurements for C_{60}^{+}, C_{60}^{2+}, and C_{60}^{3+} ions in the 1775 eV energy range show an additional resonance near 40 eV. Time-dependent density functional calculations confirm the collective nature of this feature, which is characterized as a dipole-excited volume plasmon made possible by the special fullerene geometry.

Phys. Rev. Letts 94, 065503 (2005)

URL: http://link.aps.org/abstract/PRL/v94/e065503

Abstract#2

On the effect of localized image states in resonant neutralization of hydrogen anions near Pd surfaces.

Himadri Chakraborty, Thomas Niederhausen, and Uwe Thumm

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By comparing the resonant charge transfer dynamics of hydrogen anions in front of the Pd(111) and Pd(100) surfaces with Ag(111) we directly asses the role of localized image states to influence the process. The eolution of the populated Rydberg series of image states on the vacuum side dominates the dynamics of Pd(111) by causing strong neutralization of the ion over the most part of incidence-angular range. For Pd(100), in addition to this effect, direct decay through the metal conduction band enhances the neutralization process.

To appear in Nuclear Instrumentation and Methods in Physics Research B

Abstract#3

Particle-induced x-ray emission investigation of eastern Indian ferromanganese oxide ores

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Ferromanganese oxide ore samples were studied from four different mines by Proton Induced X-ray Emission (PIXE) technique using 3 MeV proton beam obtained from a 3 MV pelletron accelerator at Institute of Physics, Bhubaneswar, India. After irradiation, the spectral data were analysed by using GUPIX-2000. Large number of major, minor and trace elements have been estimated in these samples. It has been observed that there is a positive correlation among manganese with several elements like Ca, Co, Pb, Zn and Se, whereas V and Mo well correlates with iron.

Submitted to: Journal of Radioanalytical & Nuclear Chemistry, Springer-Verlag

Abstract#4

Interior gap superfluidity in a two-component Fermi gas of atoms

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A new superfluid phase in Fermi matter, termed as "interior gap" (IG) or "breached pair", has been recently predicted by Liu and Wilczek. This results from pairing between fermions of two species having essentially different Fermi surfaces. Using a nonperturbative variational approach, we analyze the features, such as energy gap, momentum distributions, and elementary excitations, associated with the predicted phase. We discuss possible realization of this phase in two-component Fermi gases in an optical trap.

Phys. Rev. A 70, 011604-1-4(R) (2004)

Abstract#5

Electron impact total and ionization cross-sections for some hydrocarbon molecules and radicals

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Electron impact total (50 to 2000 eV) and ionization (threshold to 2000 eV) cross sections are calculated using the SCOP and CSP-ic methods [Phys. Rev A **69** 022705 (2004)] for the hydrocarbon molecules (CH_4, C_2H_2, C_2H_4, C_2H_6, C_3H_4, C_3H_6 and C_3H_8) and radicals (CH_x (x=1-3). Present method has already been tested successfully to many other aeronomic [Int. J. Mass Spectrum. **233,** 207 (2004)] and plasma molecules and radicals. Our results exhibited in this paper show good agreement with experimental results where available. For the radicals species, we have presently done a first estimate of the total cross-sections.

In press: Eur. J. Phys.-D

available online, http://dx.doi.org/10.1140/epjd/e2005-00257-7

PACS. 34.80.Bm Elastic scattering of electrons by atoms and molecules – 34.80.Gs

Abstract#6

Functional group dependent site specific fragmentation of molecules by low energy electrons

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Functional group dependence is observed in the dissociative electron attachment (DEA) to various organic molecules in which DEA features seen in the precursor molecules of the groups are retained in the bigger molecules. This functional group dependence is seen to lead in the site-selective fragmentation of the molecules at the hydrogen sites. The results are explained in terms of core-excited Fastback resonances. The results point to a simple way of controlling chemical reactions as well as interpreting DEA data from bigger biological molecules.

Physical Review Letters, 95, 143202 (2005)
DOI: 10.1103/PhysRevLett.95.143202
PACS numbers: 34.80.Ht, 82.30.Lp

Abstract#7

Mean kinetic energy of molecular fragment ions: time-of-flight vs. momentum analysis

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The mean kinetic energy of molecular ion fragments derived from the variance of their time-of-flight distribution is found to be in agreement with the values based on their momentum spectra, measured simultaneously. Electron impact on CO_2 is taken as a test case. The problem of estimation of mean kinetic energy of ions of a given species arising from differing precursor states is also addressed. This analysis verifies the proposition of von Busch [J Phys B **34** 431 (2001)], that the variance of the time-of-flight distribution is a robust estimate of the mean kinetic energy, as opposed to the commonly used estimate based on the square of the FWHM, which is an under-estimate. We also suggest a reliable method for determining the baseline and the extent of the time-of-flight peaks.

Submitted to: J. Phys. B

Nobel Prizes in Physics for year 2005

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This year's Nobel Prize in Physics has been awarded to two US scientists Roy J. Glauber and John L. Hall and a German physicist Theodor W. Hänsch. Half of the prize money is won by Glauber for his contributions in the development of the field, now known as Quantum Optics, whereas Hall and Hänsch share equally the other half for developing spectroscopic techniques with unprecedented accuracy. The quantum nature of electromagnetic radiation was hypothesized by Einstein exactly a century before, and thus recognition of quantum optics for award of Nobel Prize is befitting to the Centenary Year of Physics Celebrations.

In October 1900, Planck obtained the correct empirical relation for the frequency distribution of light emitted by a black body. By applying Boltzmann's probabilistic approach to entropy to particle-like energy packets, he could solve the problem of *"ultraviolet catastrophe"* in the energy distribution of black body radiation. Though Planck himself did not believe in *"quantized energy packets"*, he explained his results in terms of quantized *"Hertzian oscillators"* of the black body exchanging fixed quanta of energy with the radiation field. Einstein soon realized that the algebraic expression used by Planck allowed interpretation of quantized nature of the radiation field itself. He extended this proposition to explain the photoelectric effect (1905) which was verified in Millikan's experiment. These radical changes in concepts about the nature of light came face to face with the most celebrated theory of previous century, *viz.* Maxwell's theory of electromagnetic radiation. Soon both the *"lumpy"* and *"classical field"* nature of light was accommodated together under the term now known as *"complementarity in quantum theory"*. However, quantization of electromagnetic field, an extension of quantum theory to classical fields introduced a series of problems in the form of a number of singularities in theory, first realized by Igor Tamm. The success of the renormalization procedure introduced by S. Tomonaga, J. Schwinger and R.P. Feynman formed the basis of quantum electro dynamics (QED). Owing its heavy lenience to relativistic theory, QED was largely applied to the then new areas of high energy physics. It was still naively assumed that the conflict between Maxwell's and Planck's treatments would be of no significance in optical observations. However, an unexpected observation in astrophysics suggested that this blissful indifference is not to last.

In 1954-56, Hanbury Brown and R.Q. Twiss investigated an interferometric method to determine the angular extension of distant stellar objects, and also made field measurements. They found that the intensity-intensity correlation between photocurrents recorded in two separated detectors displayed a bump when the difference in optical path lengths between the signals was zero. This is clearly far away from the regime of interference effects of electromagnetic waves. The individual photon had entered the realm of observational optics, where effects due to coherence is manifested.

In the early 1960s, Harvard University's Roy Glauber tackled a fundamental problem with the quantum theory of light: A randomly produced bunch of photons behaves more like a shower of bullets than a graceful carpet of classical light wave. Electromagnetic energy is transmitted in patterns determined by classical optics. Energy distributions

of this kind form the landscape into which the photons can be distributed. These are separate individuals, but they have to follow the paths prescribed by optics. This explains the term Quantum Optics. To appear more wavelike, the individual photons must be coordinated or synchronized to create a so-called *"coherent state"*, in somewhat the same way that a painter organizes colored dots into a complete image. That much was already known. Glauber studied in detail the properties of such coherent states and their interactions with detectors. His work explained surprising phenomena that occur only in experiments that probe the quantum nature of light, such as the tendency for individual photons to clump together or avoid each other depending on the circumstances.

In the 1963 publication, Glauber made the following points: Detection in photon correlation experiments must be based on a consistent application of quantum electrodynamics. Thus all multi-photon experiments must be based on the fact that, once a photon has been absorbed, the state of the field has been changed so that the next absorption event occurs against a different initial state than the previous one. In particular, a state with only n photons, can only have correlations up to n:th order. This implies the use of normally ordered expectation values for the optical detection processes. As the consecutive absorption processes are based on different states of the field, its state ought to be characterized by correlations to all possible orders, and the description in terms of classical noise is not sufficient. In particular, experiments like those by Hanbury Brown andTwiss are described by a consistent calculation of two-photon interference effects.

The mathematical formalism of quantized fields was developed in parallel with Glauber's work on their applications. E.C.G. Sudarshan drew attention to the use of coherent state representations for the approach to classical physics; at this point he refers to Glauber's work. Together with J.R. Klauder he proceeded to develop the mathematical formalism of Quantum Optics; their approach is presented in their textbook. After the initial contributions, many authors applied Glauber's results to the rapidly evolving experimental situation in optical physics, thus creating the field today called "Quantum Optics". The present status of Quantum Optics developed into a multifarious and challenging field of research. The experiments brought measurements down to the level of single photons in the field and a few atoms, also allowing devices of ultimate stability. Thus the special quantum features of the theory are of the utmost importance.

The second part of the Nobel Prize in awarded to J.L. Hall and T.W. Hänsch in equal share for their experimental work on high precision spectroscopy.

The quest for more precise information of fundamental constants often has resulted in new discoveries that have led to revolutions in Physics. This is particularly true in atomic spectroscopy, where increasing spectral resolution led to the observation of atomic fine structure (due to the electronic spin), hyperfine structure (due to the nuclear spin), and volume isotopic shifts (due to the different charge distributions of the nuclei of isotopic species of an element). External magnetic and electric fields give rise to Zeeman and Stark energy level structures. More subtle, quantum electrodynamic effects give rise to the Lamb shift. A number of Nobel Prizes in physics have been awarded for the study of atomic structures and their interpretations. By pushing to ever higher precision and resolution, we are likely to detect new phenomena. Ultimately, a precision approaching 1 part in 10^{18} might be achievable. At very high precision, questions about the constancy of optical transition frequencies over time can be asked, an aspect related to the constancy of the fundamental constants themselves. Possible asymmetries between matter and antimatter may also be revealed. The possibility to determine optical transition frequencies very accurately is also closely related to obtaining better atomic clocks. This in turn will allow better GPS systems, better space navigation and improved control of

astronomical telescope arrays. The Nobel Prize to J.L. Hall and T.W. Hänsch this year is based on these developments.

The problem of determining the exact length of a metre illustrates one of the challenges offered by laser spectroscopy. By use of measurements of spectra, an atom-based definition was introduced: a metre was defined as a certain number of wavelengths of a certain spectral line in the inert gas krypton. Some years later also an atom-based definition of a second was introduced: the time for a certain number of oscillations of the resonance frequency of a particular transition in cesium, which could be read off the cesium-based atomic clocks. These definitions made it possible to determine the speed of light as the product of wavelength and frequency. John Hall was a leading figure in the efforts to measure the speed of light, using lasers with extremely high frequency stability. However, its accuracy was limited by the definition of the metre that was chosen. In 1983, therefore, the speed of light was defined as exactly 299,792,458 m/s, in agreement with the best measurements, but now with zero error! In consequence, a metre was the distance traveled by light in 1/299,792,458 s.

The main technical features that limit the achievable resolution in spectroscopy manifests in many forms. The frequencies of visible light lie in between 10^{14} to 10^{15} Hz. In this region of electromagnetic spectrum, under normal conditions, the observed frequency resolution is limited to 1 GHz owing to the so-called Doppler broadening. Even if we limit *"extrinsic"* (also termed as imhomogenous) Doppler broadening, still it is difficult to improve resolutions better than 1 MHz due to *"'intrinsic"* limitation in the form of natural linewidth. The resolution achievable at microwave or radio regions is many orders larger than that in the visible region. It could be viewed as if light leaves its corpuscular nature more or less completely at larger wavelengths, and this way it manifests its dual nature at the extreme ends of the spectrum.

Hänsch and his collaborators developed a technique, known as 'optical frequency combs' to improve resolutions as high as $1{:}10^{18}$. The new measurement methods are based on fundamental relations between cavity modes in a continuously operating laser and their interference, which leads to a repetitive train of short pulses. However, a prerequisite is that the cavity modes, spaced by $\Delta\nu = c/2L$, (c is the velocity of light, L the length of the resonator) have a constant internal phase relation, since otherwise the interference becomes random. The more modes are locked together, the shorter the pulses become. This reflects the properties of the Fourier transform; a 5 fs pulse requires the locking of about 10^6 modes, covering a large fraction of the visible region. Thus, only laser media with a broad gain profile (dyes, titanium doped sapphire, etc.) can be used for femtosecond pulse generation. At mode-locking, a small "ball" of light bouncing between the mirrors is created by interference inside the cavity, and part of the light is coupled out as an external beam with the pulse separation equaling the cavity round trip time $T = 2L/c$. For a 1 metre long resonator the pulse separation is about 7 ns. The early development was related to a description of an improved frequency resolution through repeated interaction with an electromagnetic field, as is the case for the Ramsey fringe technique. M.M. Salour in a paper together with C. Cohen-Tannoudji demonstrated the effect for double pulse excitation. Hänsch simultaneously demonstrated the case of multiple pulse interaction and a corresponding increased resolution. Hänsch soon extended the concept to an infinite pulse train from a mode-locked laser in studies of the 3s-4d transition in sodium. He realized that it was more fruitful to consider the phenomena observed as the atomic interaction with the continuous sharp laser modes in the frequency domain rather than using the multiple Ramsey fringe language. Hänsch's paper with Eckstein and Ferguson was thus the starting point in the development of frequency comb techniques. In published confer-

ence presentations, Hänsch developed these concepts as early as 1976 and 1977.

Hänsch and his co-workers has further extended this techniques to VUV and X-ray regions. Ultimately, atomic clocks in the X-ray region may emerge. Attosecond pulses can be formed if the equidistantly spaced high harmonics are phase-locked together, in a way analogous with the case of a mode-locked laser in the visible region. In the generation process of single attosecond pulse, as well as for the study of many ultra-high intensity interaction phenomena, it is advantageous if the optical phase is stabilized.

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Velocity Map Imaging in Dissociative Electron Attachment

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Introduction

Recent developments in charged particle imaging have provided unprecedented details of the dynamics of the processes in photoionization, photodissociation, intense field ionization, electron and ion impact ionization and neutral-neutral collisions. By combining the use of appropriate magnetic and electric fields with a two dimensional (2-D) position sensitive detector (PSD), a host of new imaging techniques have been developed, depending on the collision process and the physics under consideration. Initially developed for ion-atom collision experiments, Recoil Ion Momentum Spectroscopy (RIMS) (Ullrich et al., 1991) and its variation using a cold target (COLTRIMS) (Dörner et al., 1997) have provided detailed dynamics of atomic and molecular ionization under the influence of swift ion projectiles (Schulz et al., 2003), photoionization (Weber et al., 2004) and intense field ionization (Rottke et al., 2002). In these as well as in similar multi-particle coincidence experiments (Amitay and Zajfman, 1997; Helm et al., 1993), all the three momentum components of one or more particles are measured simultaneously to obtain the kinematic details of the collisions and to derive the corresponding physics. Velocity Map Imaging (VMI) is another charged particle imaging technique which had its origin in laser photodissociation experiments (Chandler and Houston, 1987; Eppink and Parker, 1997). Since then, this technique has been used extensively in many of its variations in reactive collisions, photodissociation, photodetachment and photoionization experiments (Whitaker, 2003) and improvements and modifications of this technique are continuing to appear (Gebhardt et al., 2001; Townsend et al., 2003; Dinu et al., 2002; and Beguenard et al., 2004). All these techniques have been used in experiments where the charged particles, which are imaged, are created by either a high energy projectile or a short pulse laser. This allows the use of appropriate electric/magnetic fields for the necessary imaging configuration, without worrying about their effect on the ionizing agent or the collision process. In contrast to this, the area of low energy electron collisions has missed out on the advantages of these developments in charged particle imaging techniques. The major obstacle in this respect has been in providing an appropriate electric field configuration which does not affect the incoming low energy projectiles, and the necessary time resolution to measure the velocity components accurately. In this context, we have developed at TIFR a technique to carry out VMI of the ionic fragments produced in electron-molecule collisions (Nandi et al. 2005). This report is intended to give an introduction to the VMI followed by a short description of how we have implemented it for electron collision studies.

What is VMI?

In order to understand the details of any collision process, one needs to measure the initial momentum vectors of the colliding particles and the final momentum vectors of the products. The initial momenta are generally known from the way one prepares an experiment. For example, if one studies an ion-atom collision, one could decide the energy of the ion beam and its direction. The gaseous target atoms may be considered to be standstill at room temperatures. However, one does not have any control over the products as they could emerge in any direction with a wide distribution of energies. Thus, in order to understand the collision process, the products have to be detected as a function of their energies and the angle of ejection. VMI is one of the charged particle imaging techniques that fulfills the above requirement.

As the name suggests, the VMI technique basically images the three dimensional (3-D) velocity information of the charge cloud on 2-D PSD. Every event in such experiment produces the ion with some momentum. Considering many such events occurring, these ions build up spherical distribution in the velocity space called Newton (velocity) sphere. This Newton sphere carries the information about the velocity distribution and in turn provides the momentum information of the ions. The projection of such Newton sphere on the 2-D PSD is obtained by forcing all the ejected particles to move in a specific direction using a combination of electric field as shown in Fig.1. This image retains the information of the kinetic energy of the fragments along with the angle of ejection of the ions and thus provide complete picture of the reaction.

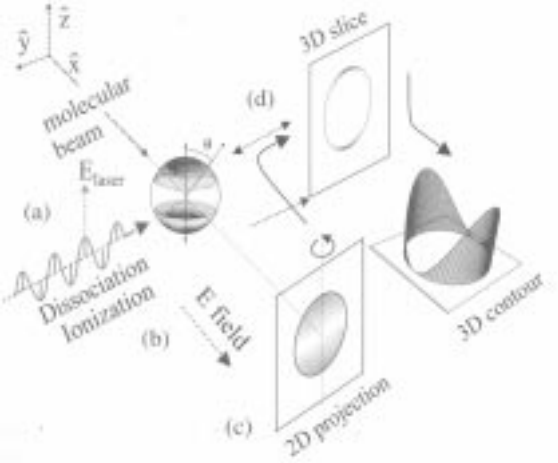

Figure 1: Schematic diagram of the VMI technique in a typical photodissociation / ionization experiment. (a) Photodissociation / ionization of molecules using linearly polarized light making up the Newton sphere. (b) Electric field for the ion imaging. (c) Projection of ion spheres onto 2-D detector. (d) Mathematical transformation of the 2-D image back to 3-D data of step (a). *(from Whitaker 2003).*

For example, consider a plane polarized laser beam propagating in the Y-direction is interacting with a molecular beam directed in the X – direction (Fig.1). The electric field of the laser beam is marked as E_{Laser} and is in the Z-direction. This axis defines the direction of the photodissociation or photoionization process. The Newton sphere of particles ejected from this process will have certain angular distribution with respect to this direction as shown in the figure. The particles are extracted using an electric field towards the PSD (In the case of neutral dissociation, another laser is used to ionize a selected fragment, so that it could be imaged). At the detector, the 3-D Newton sphere is projected on to 2-D plane.

But in the practical situation, the ions are generated in a region consisting of some finite volume instead of a point. The important aspect of the VMI technique is related to mapping each of the velocity vectors of the fragments onto a specific point on the 2-D detector for such an extended source of ions using certain combination of electric fields as shown in Fig. 2. The first two electrodes define the interaction region. The ions formed in this region are extracted towards the detector. The electrostatic lens formed between the second and third electrodes focuses their trajectories at the focal plane. The focusing is such that irrespective of the point of origin, the ions of a given velocity get focused at a given point in the focal plane. A 2-D PSD kept in this plane thus provides the velocity map image. In the case of an experiment giving rise to more than one type of species, the velocity map for each one of them is achieved by making the detector operate only for a certain time window corresponding to the arrival of that particular species. This is done by pulsing the detector bias voltage. Usually the 2-D PSD is made up of a set of two or three micro channel plates (MCP) stacked one behind the other to have high enough gain to detect single ion event at the front plate. The position information of the ions striking the detector is recorded either optically or electronically. In optical method a fiber optic window with a phosphor layer is often used along with a CCD camera to detect the signal. The output of the MCPs, which is nothing but a bunch of secondary electrons, is accelerated further and made to hit the phosphor window. This produces the light flashes on the phosphor layer and they are recorded using the CCD camera. In electronic method of position recording, the output pulse of electrons from the MCPs is allowed to fall on specially patterned anodes. The electric signals from this anode configuration are recorded using the appropriate electronics and stored in the data acquisition system in the form of the (y, z) coordinates of the position hit and the time of arrival of the ion. Using this information, the

entire 3-D Newton sphere for a given ion species can be generated using appropriate mathematical transformations.

When collision process under scrutiny has a symmetry axis, all the relevant information about the process is contained in the central slice of the Newton sphere that contains the symmetry axis. The information about this central slice of

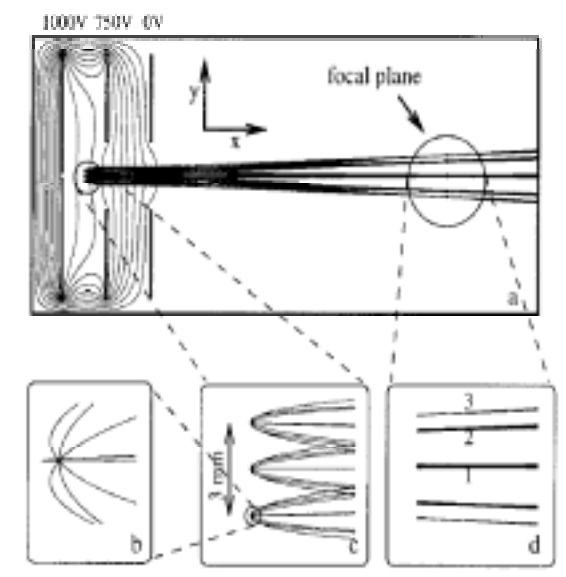

Figure 2: Ion trajectory simulation of VMI set up (a) using 'Simion' trajectory program. Three different starting positions 1mm apart (c) simulate the interaction volume. Trajectories of all the ions begin to bend in the field direction (b) are focused in the velocity mapping focal plane where the detector is placed. *(from Whitaker 2003)*

the Newton sphere is achieved using some special mathematical transformations of the recorded data. Usually the inversion method is used to retrieve the information of the initial velocity distribution. The techniques like Abel inversion, onion pealing algorithm are used for such reconstruction of the 3-D Newton sphere. In the absence of a symmetry axis, forward convolution method is used. In this method the experiment is simulated in a computer model that produces 2-D data that are then compared with the experimental data. By optimizing the parameters in the computer model the best reconstruction of the experimental data is obtained.

One of the disadvantages of using mathematical transformations is that the reconstruction of the 3-D data is prone to some artificial noise in the form of distortion of the image or the presence of some false distribution towards the axis of symmetry. This problem is overcome in another method used for the ion imaging called Velocity Slice Imaging (VSI) where no mathematical transformation methods are used to retrieve the momentum distribution of the ion. The basic principle behind VSI is very simple. The 3-D ion cloud of a given ion species that is generated in the interaction region is made to fall on the PSD such that the VMI condition is satisfied. However the ions are made to arrive at the detector at different time corresponding to their angle of emergence with respect to the axis of the flight tube / detector. This is achieved either by delayed extraction of the ions from the interaction region in the case of pulsed extraction (Fig. 3) or by modifying the field conditions in the case of DC extraction field. Now one can obtain any slice of the Newton sphere that is parallel to the detector plane by either pulsing the detector bias voltage for a small interval around the time of arrival of the ions from the slice of interest or by using the time of arrival information that is stored with the position information of the ions detected (x, y, t).

The main advantage of the VMI over the conventional turn table technique is the simplicity and efficiency of data collection. The conventional method of making the measurements of differential cross sections using energy analyzers and turn tables for energy and angular distributions is

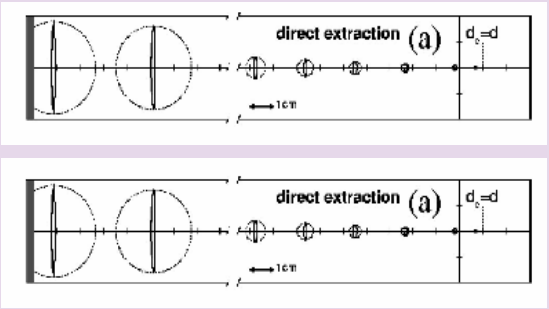

Figure 3: Spatial evolution of ion cloud with direct and delayed extraction. *(from Whitaker 2003)*

very tedious and it has to be carried out in sequence. The charged particle imaging techniques aimed at making these measurements in one go by detecting the particles with simultaneous measurements of their angle of ejection and their energies, that is, all their three momentum components. Most importantly, these imaging techniques provide the information of the relative differential cross section of the process for the entire 2π angle which is not possible in the conventional technique due to mechanical constraints.

VMI for Dissociative Electron Attachment (DEA) process

The dynamics of dissociative ionization and dissociative attachment in electron-molecule collisions have been studied using kinetic energy spectrometry for several molecules. However, the angular distribution measurements have been rather limited. Anisotropy in angular distribution of fragment negative ions is characteristic of the dissociative attachment process (Dunn, 1962). The angular distribution measurements allow one to determine the quantum state of negative ion resonance and the partial waves of the electrons that are captured (O'Malley and Taylor, 1968) giving detailed picture of the DEA process. The measurements reported till now on angular distributions have been carried out using the conventional turn-table arrangement and subsequently limited to finite angular range. Our motivation for the development of the VMI technique for electron-molecule collisions has been to measure the angular distribution in the entire 2π angle as well as to improve the sensitivity (and thus the data acquisition time) for experiments involving low cross sections or small target densities as in the case of electron collisions on excited molecules (Krishnakumar et al., 1997; Rangwala et al., 2001). The VMI also provides the information on the kinetic energy of the fragment ions. The simultaneous detection of the presence of more than one dissociation limit within a given resonance is achievable using this technique.

The major limitation on any low energy electron molecule collision experiment is the effect of the electric fields that are used for the ion extraction on the electron beam. This is overcome by using the pulsed electron beam and the synchronized pulsed ion extraction field. The extraction field is delayed with respect to the electron beam so that the interaction takes place in the field free environment. This small but finite delay in the extraction makes the VSI a natural choice for the study of the angular distribution of the negative ion ejection in the DEA process.

The experiment uses a magnetically collimated and pulsed electron gun, an effusive molecular beam target generated using a capillary array, and the VMI arrangement. Typically 50 Gauss of magnetic field is used for the electron beam collimation and energy resolution of the electron beam is 0.5 eV. The experiments are carried out at 10^{-6} Torr background pressure under gas load.

The ion optics for VMI along with the rest of the experimental arrangement is shown in Fig. 4. It consists of three electrodes and a relatively short flight tube. The ion extraction is provided by the electric field between the 'pusher' and the 'puller'. The lens electrode between the puller and the flight tube provides the appropriate velocity focusing at the detector. In this arrangement, the ions are produced in a field free region. They are extracted out after a finite time interval. The extracted ions are velocity mapped onto a 2-D PSD employing microchannel plates along with the Wedge and Strip anode. The time delayed extraction in the experiment allows the Newton sphere to expand both in the direction of flight as well as perpendicular to it. We employed electron pulses of width 200 ns and extracted the ions after a delay of additional 200 ns using a negative pulse of 22 V applied to the pusher plate. The rest of the electrodes were biased appropriately for velocity mapping condition.

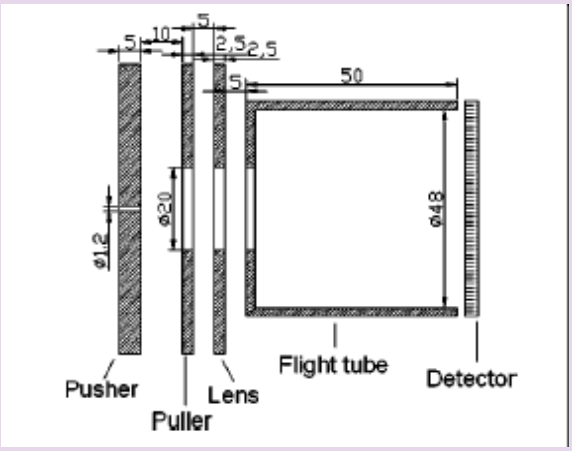

Figure 4: Scaled schematic of ion optics used for velocity map imaging.

The ions were detected using three microchannel plates of 50 mm diametein Z-stack assembly. The position information was obtained using a Wedge and Strip anode. The wedge-and-strip anode is mounted behind the MCP at a distance of 3 mm. One side of the anode, which is facing the MCP assembly, is coated with semiconductor germanium layer (as shown in the panel (a) of the Fig. 5). The other

side of the anode contains three different structures, where the position information is obtained by charge division. These anode structures are 'wedge' with increasing width from bottom to top, rectangular arrays called 'strips' with increasing width from left to right. The space between these two structures is called 'meander'. The basic structure of the wedge-and-strip anode with a typical periodicity of 1.5 mm is shown in the panel (c) of the Fig. 5. The pulse height of the signals obtained from strip and wedge electrodes are proportional to the X and Y co-ordinate of the centroid of the charge cloud, as long as the charge cloud covers an area larger than the period of the anode structure.

For each ion detected, its position and time

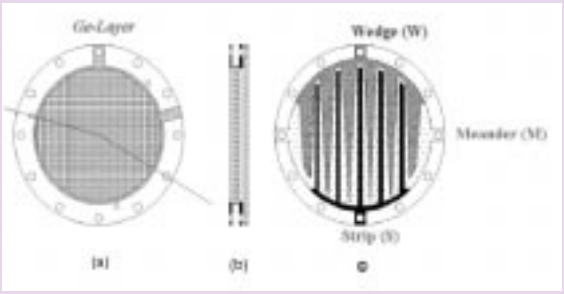

Figure 5: Structural representation of the Wedge-and-Strip anode. (a) the anode coated with Ge-Layer and facing the MCP, (b) the side view of the detector and (c) the main structural form of the Wedge-and-Strip anode.

of arrival were recorded separately using the list mode data acquisition using the LAMPS program (Chatterjee) running on Linux operating system. The offline data analysis is also carried out using this program.

Measurements on O_2

To begin with, the angular distribution of O^- from O_2 by DEA was measured. The DEA from O_2 is known to occur as a broad peak centered at 6.5 eV. The dissociation limit for the observed resonance is known to correspond to both the O^- and O fragments in their ground states. The angular distribution of O^- from this process has been measured earlier using the turn table technique in the range of 20 to 160 degrees.

The ion yield curve for O^- from O_2 obtained by us is shown in Fig. 6. The arrows indicate the energies at which the VMI measurements were made. A typical time of flight spectrum of the O^- ions is shown in Fig. 7.

The time of flight distribution shows two peaks about a central minimum. The asymmetry in the heights of the peaks is believed to be due to differing field conditions that the ions ejected towards the flight tube and away from the flight tube experienced. This difference does not hamper our measurements, since we are interested only in the central part of the time of flight spectrum. This central section corresponds to ions ejected in the plane perpendicular to the time of flight axis and contains all the velocity information that we seek to obtain. The VMI

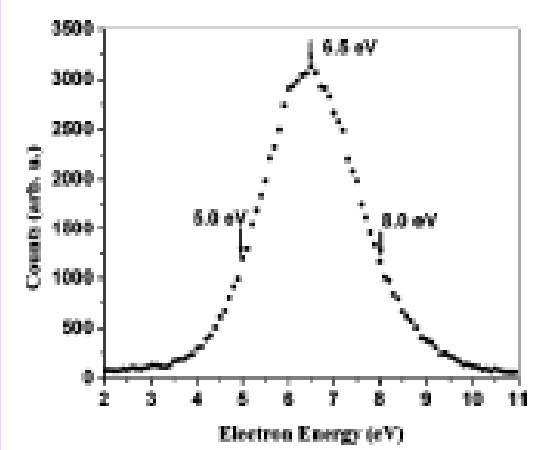

Figure 6: Ion yield curve for the formation of O^- from O_2 by DEA. The arrows represent the electron energies where the velocity map images are taken.

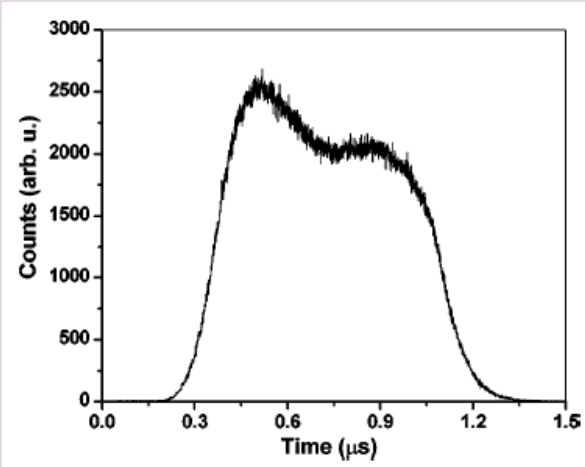

Figure 7: Typical time of flight spectrum of O^- from DEA to O_2.

data obtained from the central part of the time of flight spectra at three different electron energies are shown in Fig. 8. The direction of the electron beam is vertically down in all the cases. The figure also shows the distributions of intensity as a function of the position on the detector at these energies.

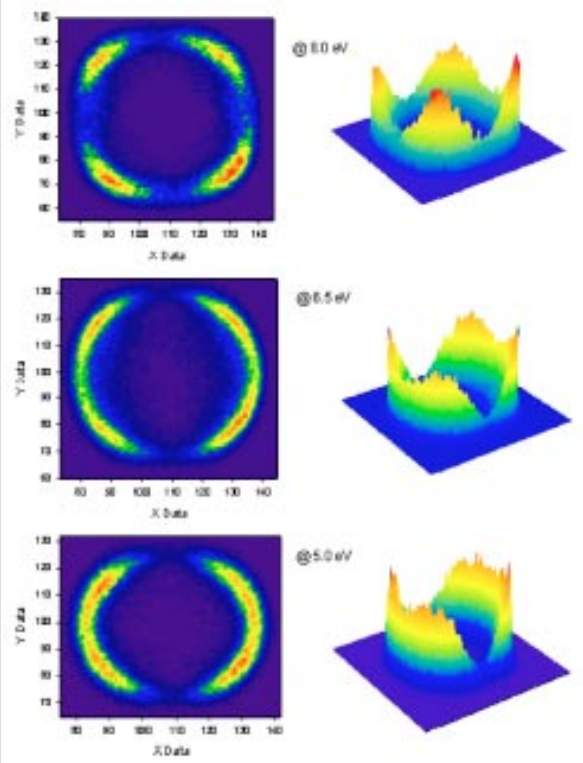

Figure 8: Time sliced velocity map image O^- from O_2 at three different electron energies. The left panel shows the 2-D pattern we obtain after time slicing. Red color shows increasing intensity and blue shows least intensity. The electron beam direction is vertically down. The right panel shows the corresponding 3-D distribution with intensity as the z-axis.

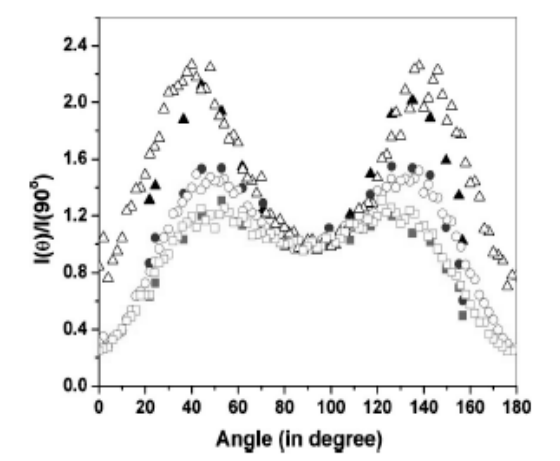

Figure 9: A comparison of the angular distribution measurements of O^- with the existing data obtained using conventional technique. The open symbols represent the angular distribution data obtained using VMI and the filled symbols represent the results from the conventional turn table method.

These velocity map images show that ions are produced with a specific energy, but with anisotropic angular distribution. In Fig. 9 we provide a comparison with the existing data. The energy and the angular resolution of the VMI image are limited by the energy resolution of the electron beam. It can also be seen that the magnetic field used for the electron beam collimation has no effect on the VMI in the form of distortion. We also found this imaging technique applicable for electron impact dipolar dissociation. As one can use this technique to image the positive as well as negative ions, it has opened up an opportunity to obtain the complete information of the dynamics of various electron impact ionization processes.

To conclude the VMI technique is an easy, fast and efficient tool to determine the angular distribution and the kinetic energies of the ions formed in various processes. The VMI developed for the imaging of the negative ions produced by electron impact has opened up a new chapter in the study of the dynamics of the various processes in the electron impact phenomena.

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The number of participants is restricted to about forty. All the selected participants will be provided to and fro train fare and local hospitality. Interested persons should send to the school director, via e-mail (preferred) or by post, (i) CV (including full postal address and e-mail), (ii) a brief write-up of the current research activities, (iii) list of publications (if any), (iv) letter of recommendation form guide or Head of Department, and (v) a short write-up indicating how the school is expected to benefit the research activities of the candidate.

Important Dates:

Last date for the receipt of applications : 7th November 2005

Intimation to selected candidates : 6th December 2005

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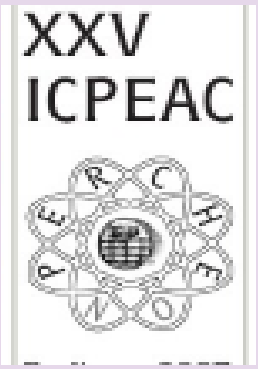

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