CSO202: Atoms Molecules and Photons

Lecture-1

Debabrata Goswami

CSO202 : Atoms, Molecules and Photons – 2024-2025-Sem-I
First Course Handout

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Lectures: Mon, Wed, and Thu 9-10 AM; **Venue**: L2

Tutorials: Fri 9-10 AM; **Venue**: L2

Course Description: This course is dedicated to inspire students of undergraduates through the discourses of several landmark experiments and theoretical models. The course sets the stage to apprehend chemical structure, reaction and dynamics of matter – through the lenses of light-matter interaction. In this semester, we shall focus on the aspects of studying tiniest and fastest details of molecules and their perpetual motions in chemical reactions.

Some Path-breaking research in the field of chemical reaction dynamics

Before the turn of this century

Nobel Prizes, Chemical Dynamics

1901: Jacobus Henricus van't Hoff, for his pioneering work on chemical dynamics and osmotic pressure in solutions.

1903: Svante August Arrhenius, in recognition of the extraordinary services he has rendered to the advancement of chemistry by his electrolytic theory of dissociation.

1909: Wilhelm Ostwald, in recognition of his work on catalysis and for his investigations into the fundamental principles governing chemical equilibria and rates of reaction.

1943: George de Hevesy, for his work on the use of isotopes as tracers in the study of chemical processes.

1956: Sir Cyril Norman Hinschelwood and Nikolay Semenov for their researches into the mechanism of chemical reactions.

1967: Manfred Eigen, Ronald Norrish, and George Porter for their studies of extremely fast chemical reactions, effected by disturbing the equilibrium by means of very short pulses of energy.

1981: Kenichi Fukui and Roald Hoffmann for their theories, developed independently, concerning the course of chemical reactions.

1983: Henry Taube, for his work on the mechanisms of electron transfer reactions, especially in metal complexes.

1986: Dudley Herschbach, Yuan Lee, and John Polanyi for their contributions concerning the dynamics of elementary chemical processes.

1992: Rudolph Marcus, for his contributions to the theory of electron transfer reactions in chemical systems.

1995: Paul Crutzen, Mario Molina, and F. Sherwood Rowland for their work in atmospheric chemistry, particularly concerning the formation and decomposition of ozone.

1998: Walter Kohn and John Pople. Kohn: for his development of the density–functional theory; Pople: for his development of computational methods in quantum chemistry.

1999: Ahmed Zewail, for his studies of the transition states of chemical reactions using femtosecond spectroscopy; for showing that it is possible with rapid laser technique to see how atoms in a molecule move during a chemical reaction.

Module-1

Current century

2007: Gerhard Ertl *"for his studies of chemical processes on solid surfaces"*

2013: Martin Karplus, Michael Levitt and Arieh Warshel "for the development of multi-scale models for complex chemical systems".

2014: Stefan W. Hell, Eric Betzig, and William E. Moerner *"for the development of super-resolved fluorescence microscopy"*.

Module-2

Nobel Prize in Physics 2018

Debabrata Goswami

On Tuesday, 02 October 2018, Arthur Ashkin of the United States, who pioneered a way of using light to manipulate physical objects, shared the first half of the 2018 Nobel Prize in Physics. The second half was divided equally between Gérard Mourou of France and Donna Strickland of Canada for their method of generating high-intensity, ultra-short optical pulses. With this announcement, Donna Strickland, who was awarded the Nobel for her work as a PhD student with Gérard Mourou, became the third woman to have ever won the Physics Nobel Prize, and the 96-year-old Arthur Ashkin who was awarded for his work on optical tweezers and their application to biological systems, became the oldest Nobel Prize winner. According to Nobel.org, the practical applications leading to the Prize in 2018 are tools made of light that have revolutionised laser physics – a discipline which in turn is represented by generations of advancements and not just a single example of brilliant work.

Debabrata Goswami is a Senior Professor at Indian Institute of Technology Kanpur and holds the endowed Prof. S Sampath Chair Professor of Chemistry. His research work spans across frontiers of interdisciplinary research with femtosecond lasers that have been recognised globally, the latest being the 2018 Galileo Galilei Award of the International Commission of Optics. As a part of his doctoral thesis at Princeton, Prof. Goswami had developed the first acousto-optic modulated ultrafast pulse shaper, wherein the 2018 Physics Nobel Prize winner, Prof. Strickland, also participated as a postdoctoral fellow at that time in the same laboratory.

It is easy to take lasers for granted; more so in 2018, as they are a near-ubiquitous symbol of technological acumen. Light may be a wave, but producing coherent (in-phase), monochromatic (of a single wavelength), and high intensity (high power) light is still non-trivial. These are just some of the factors that make lasers and their study so unique. Lasers are used at a lab scale for machining, spectroscopy, and various detection tools. They are also amongst the most sensitive instrumental probes possible for large scientific equipment to measure disturbances. For example, Laser Interferometer Gravitational-Wave Observatory (LIGO) measures tiny changes in spatial distances when a gravitational wave passes.

However, lasers are also used for atmospheric remote sensing, optical communications, for measuring the distance to the Moon, quantum optics, and for creating artificial 'guide stars' in astron-

Keywords
Nobel, lasers, optical tweezer, pulses, chirped pulse amplification.

Figure 1. Physics Nobel Laureates for the year 2018: Arthur Ashkin (left most), Gérard Mourou (middle) and Donna Strickland (right most). (Photo courtesy and copyright of Nobelprize.org.)

Curt W. Hillegas, Jerry X. Tull, Debabrata Goswami, Donna Strickland, and Warren S. Warren, Femtosecond Laser Pulse Shaping by Use of Microsecond Radio-frequency Pulses, *Opt. Lett.*, 19, pp.737–739, 1994.

Nobel Prize in physics–2018, D Goswami - Resonance 23, 1333-1341 (2018)

The Nobel Prize in Physics 1963

Photo from the Nobel Foundation archive.

Eugene Paul Wigner

Prize share: 1/2

Photo from the Nobel Foundation archive.

Maria Goeppert Mayer

Prize share: 1/4

Photo from the Nobel Foundation archive.

J. Hans D. Jensen

Prize share: 1/4

The Nobel Prize in Physics 1963 was divided, one half awarded to Eugene Paul Wigner "for his contributions to the theory of the atomic nucleus and the elementary particles, particularly through the discovery and application of fundamental symmetry principles", the other half jointly to Maria Goeppert Mayer and J. Hans D. Jensen "for their discoveries concerning nuclear shell structure"

Donna Strickland
Facts

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Donna Strickland
The Nobel Prize in Physics 2018

Born: 27 May 1959, Guelph, Canada

Affiliation at the time of the award: University of Waterloo, Waterloo, Canada

Prize motivation: "for their method of generating high-intensity, ultra-short optical pulses"

Prize share: 1/4

A gap of 55 years for a woman Physicist to get the Nobel Prize!

Strickland is only the third woman winner of the physics award, along with Marie Curie, who won in 1903, and Maria Goeppert-Mayer, who was awarded the prize in 1963.

Life

Donna Strickland was born in Guelph, Ontario, Canada. She became interested in laser and electrooptics early and studied at McMaster University in Hamilton, Ontario. She pursued her doctoral studies in the U.S. at the University of Rochester, where she did her Nobel Prize awarded work. She obtained her PhD in 1989. She subsequently has worked at Princeton University and since 1997 at the University of Waterloo in Canada.

Course plan

Module 1

Module 2

CSO 202

Module 3

Module 4

9 Lectures per Module (tentative)

Debabrata Goswami

Module 1: Chemical Reaction Dynamics with Molecular Beams & Ultrafast Chemical Reaction Dynamics with Ultrashort-Pulsed Lasers

Module 2: Super-resolution Microscopy

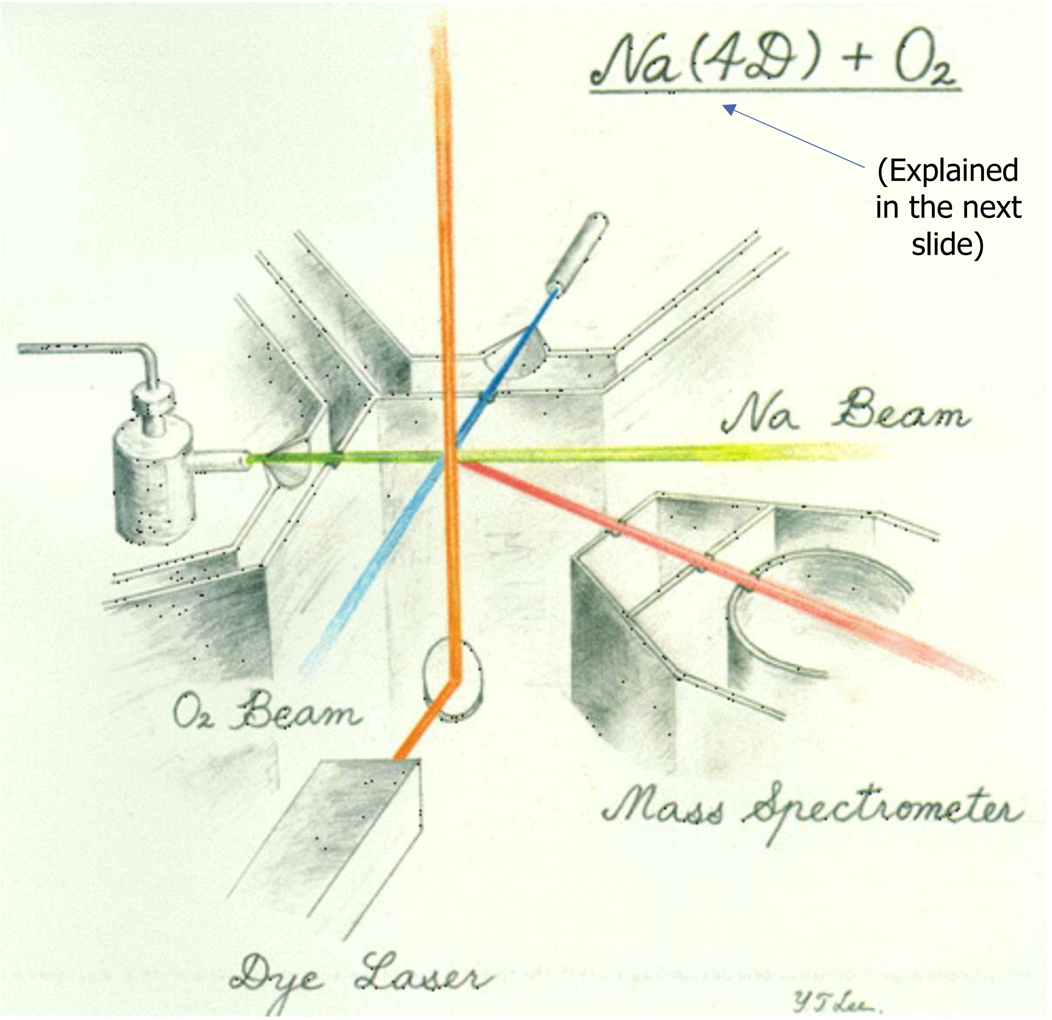
Module 3: Molecular level understanding of chemical processes

Module 4: Nobel-winning electronic structure models

D L V K Prasad

Module 1 (Part A):

Chemical Reaction Dynamics with Molecular Beams



(Explained in the next slide)

Instructor:
Debabrata Goswami

Excerpt from Nobel Lecture of Y.T. Lee

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Molecular beam studies of photochemical processes

In the investigation of reaction dynamics, lasers have become increasingly important. Not only are they used extensively for the preparation of reagents and quantum state-specific detection of products, but they have also become indispensable for the investigation of the dynamics and mechanisms of photochemical processes.

One of the more exciting applications of lasers in crossed molecular beam experiments is the control of the alignment and orientation of electronically excited orbitals before a reactive encounter. For example, in the reaction of Na with O_2, if linearly polarized dye lasers are used to sequentially excite Na atoms from the 3S to 3P to 4D states, the electronically excited 4D orbital can be aligned along the polarization direction of the electric field vector of the lasers. Consequently, the effect of the alignment of the excited orbital on chemical reactivity can be studied in detail by simply rotating the polarization of the lasers with respect to the relative velocity vector.

For many atom-molecule reactions that proceed directly without forming long-lived complexes, for example, K + CH_3 I, F + H_2 and D_2, and Na(4D) + O_2, the dependence of chemical reactivity on the molecular orientation can be obtained from measurements of product angular distributions.

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