Professor Man Mohan’s Research Group

1. Our Group Contribution in Collisional and Radiative Processes in Plasma

Dr. Avnindra Kumar Singh (Group Leader at DDU College, Associate Professor in Physics), Dr. Alok Kumar Singh Jha (Assistant Professor in Physics), Dr. Nupur Verma (Associate Professor in Physics), Dr. Sanjay Tyagi (Associate Professor in Physics), Mayank Dimri (Doctoral Student) and Dishu Dawra (Doctoral Student)

Dr. Narendra Kumar (Group Leader at Shyam Lal College, Assistant Professor in Physics), Dr. Jagjit Singh (Assistant Professor in Physics), Sunny Aggarwal (Assistant Professor in Physics) and Ravinder Kumar (Doctoral Student)

Prof. Rinku Sharma (Group Leader at Delhi Technological University (DTU), Delhi), Arun Goyal (Assistant Professor in Physics), Indu Khatri (Physics Lecturer)

In recent years, the high quality observational data recorded by space missions such as International Ultraviolet Explorer (EUVE), the Advanced Satellite for Cosmology and Astrophysics (ASCA), the Hopkins Ultraviolet Telescope (HUT), the Hubble Space Telescope (HST), and Solar and Heliospheric Observatory (SOHO), has highlighted the need for highly accurate atomic data. There is no doubt that this situation will be further emphasized by the launch of future space missions such as FUSE. The accuracy of atomic data is crucial for the interpretation of the spectra from these missions in terms of the physical conditions in the astrophysical sources. The need for accurate atomic and molecular data is immense, with applications in such diverse fields such as astronomy, fusion research, and lasers. The type of data depends upon the region or the object being studied. As very few of the ions of interest can be studied experimentally in the laboratory, the user must depend primarily on theoretical data. Nowadays, measurement and calculation of photoionization cross section and collision strength has become a subject of great interest. Photoionization cross sections are necessary for the computation of photoionization and recombination rates for ionization balance in astrophysical plasmas. Accurate electron-impact inner-shell ionization cross section data are necessary for precisely measuring the impurity density in fusion plasma.

In this direction, our group is involved in the calculations of accurate collision strengths, radiative and autoionization decay rates, photoionization cross-sections, oscillator strengths and wavelengths for allowed and forbidden transitions which are needed for the interpretation of observational data & for modeling of astrophysical objects. In our calculations, important physical effects mainly configuration interaction, autoionizing resonances, exchange, coupling and relativistic effects are incorporated by using Configuration Interaction Technique for the atomic structure and accurate R-matrix method for the collisions. For atomic structure calculations, we use grasp2k, GRASP, FAC and CI3 techniques whereas for collision problems we use very sophisticated R-Matrix (both relativistic and non-relativistic) state-of-art technique. We have reported energies and radiative data for E1, E2, M1 and M2 multipole transitions for lowest 110 fine structure levels of Cs XXV ion. We have identified 46 EUV and 33 SXR spectral lines from ground state. We have predicted many new spectral lines, which are yet to be observed, and which will form the basis for the future experimental work. We have also calculated line intensity ratio (R) and electron density and studied their behavior graphically with high plasma temperatures. Moreover, for providing support to experimentalists and extend the data base, we reported the atomic data for Ne-like ions (Z=72-75) by calculating energies and lifetimes for 209 fine structure levels of Hi LXIII, Ta LXIV, W LXV and Re LXVI, along with 109 fine structure levels available in the literature for W LXV. Tungsten being a plasma facing material in fusion reactors, EUV and SXR transitions of high Z ions are of Astrophysical interest. Therefore, we have reported the atomic data for W XLIV such as energies for the lowest 100 fine structure levels. Additionally, the radiative data for all E1 and M1 transitions from ground state among the lowest 100 levels were tabulated. We have identified 5 EUV and 38 SXR spectral lines in dipole transitions. We have calculated the line intensity ratio by considering the maximum plasma temperature of 1010 K, which increases with increasing temperature. For T ≥ 109K, the increase in R < 0.001%. This information may be useful for producing optically thin plasma in LTE at higher temperatures for W XLIV.

02. Our Group Contribution in Atoms & Molecules in Strong Radiation Fields & Chemical Physics

Dr. Rachna Kundliya (Assistant Professor in Physics), Dr. Sidharth Lahon (Assistant Professor in Physics), Dr. Manoj Malik (Assistant Professor in Physics) and Dr. Kriti Batra (Assistant Professor, IP University)

We are studying numbers of striking non-linear phenomenon in atoms and molecules, which occur when they are exposed to intense short femto-second laser pulses. Some of these are Above threshold ionization ( ATI) i.e. the absorption of more photons then necessary for ionization and High harmonic generation (HHG), which has become potential method to produce coherent radiation with wavelength reaching into soft X-ray region. In super-intense field we found that the real atom can be stabilized against ionization due to drastic change of atomic structure using two laser pulses differing in phase. For studying such processes, we have developed number of non-perturbative methods like Floquet and Quasi Energy approaches. For real laser pulses with non-periodic Hamiltonian we have developed numerical computational methods, such as Split Operator Technique (SOT), Fast-Fourier Technique (FFT) and Runge-Kutta (RK) method etc. for solving dynamical coupled equations. We have also developed an efficient pseudo-spectral L2 technique for calculating accurate multi-photon ionization cross-sections of atoms, which give results in agreement with experimental results. Our group is also involved in the calculation of simultaneous electron-photon excitation (SEPE) processes aiming for explaining the projected experiment using electron and high frequency synchrotron photon beams such as ELECTRA at Trieste and ALS at Berkeley. The theoretical approach followed is non-perturbative and is based on the Floquet theory and quasi energy technique. Floquet theory is employed to solve the equation of motion for laser driven intrainband
transitions between the states of the conduction band of quantum dot with spin effect. Floquet theory relates the solution of Schrodinger equation involving a periodic Hamiltonian to the solution of another equation with a time independent Hamiltonian represented by an infinite matrix (called the Floquet matrix). Spin flipping with rashba spin orbit coupling in presence of laser fields for the quantum dot is also studied.

2. Our Group Contribution in Bose Einstein Condensate, Cold Atoms & Quantum Optics

Dr. Tarun Kumar (Assistant Professor in Physics), Dr. Priyanka Verma (Assistant Professor in Physics), Dr. Sonam Mahajan (Assistant Professor in Physics) and Dr. Neha Aggarwal (Assistant Professor in Physics)

Our group at University of Delhi is looking at various theoretical aspects of the physics of dilute trapped Bose Einstein Condensates, which includes exotic quantum phases of light coupled to an atom in a cavity through multiphoton transitions, Novel quantum optical effects in periodically modulated BEC interacting with light field, nonlinear excitations in BEC, interaction of two component BEC in 1D, 2D and 3D, localization properties of BEC and Dynamics of BEC in time dependent optical lattices. The research on BEC's in optical lattice is a part of a more extensive investigation of the properties of BEC’s, in which we are involved. Because the wave mechanical properties of the atoms are amplified to levels at which they can be observed and manipulated directly, BEC atomic assemblies are particularly interesting and useful for the study of macroscopic quantum effects, which is one of the main aim of our research. We have studied a hybrid optomechanical quantum device formed by a Bose Einstein Condensate (BEC) confined in a high quality factor optical cavity with an oscillatory end mirror for the detection of weak forces. We show using the stochastic cooling technique that the atomic two-body interaction can be utilized to cool the mirror and achieve position squeezing essential for making sensitive measurements of weak forces. We further show that the atomic two-body interaction can also increase the signal to noise ratio (SNR) and decrease the noise of the off-resonant stationary spectral measurements. We investigated the possibility of approaching the quantum ground-state of a hybrid optomechanical quantum device formed by a Bose-Einstein condensate (BEC) confined inside a high-finesse optical cavity with an oscillatory end mirror. Cooling is achieved using two experimentally realizable schemes: back-action cooling and cold damping quantum feedback cooling. In both the schemes, we found that increasing the two body atom-atom interaction brings the mechanical oscillator to its quantum ground state. It has been observed that back-action cooling is more effective in the good cavity limit while the cold damping cooling scheme is more relevant in the bad cavity limit. It is also shown that in the cold damping scheme, the device is more efficient in the presence of BEC than in the absence of BEC. We have also developed a new tool for controlling the superfluid properties of a condensate loaded in an optical lattice inside a cavity. The optomechanical system we have studied is given in the Fig. below. We have observed that motion of a cavity mirror gives a powerful insight into the way superfluid fraction of the condensate can be enhanced or diminished. We have studied the optomechanical effects (effects of moving one of the cavity mirror) on the Bloch energy, effective mass, Bogoliubov excitation spectrum, superfluid fraction and the Mott-superfluid phase diagram of a Bose-Einstein condensate confined in an optical cavity.

04. Our Group Contribution in Nano-Technology & Photonics

Professor Rinku Sharma (Group Leader at Delhi Technological University (DTU), Delhi), Dr. Monica Gambhir (Assistant Professor in Physics), Dr. Sidharth Lahon (Assistant Professor in Physics), Dr. Manoj Malik. (Assistant Professor in Physics) and Miss Suman (Doctoral Student)

Photonics refers to the science and technology relating to the transportation of information by light, and underpins the information revolution in which light is used to transmit, store and sort information. Nanoscience is directed at discovering and understanding the way matter behaves at the nanoscale, and underpins the technology of creating materials, devices and systems through the control of matter at the atomic level. The nanostructure exhibit strongly size dependent chemical & physical properties which represent limiting behaviors for different types of matter (atomic to bulk) The variations with size are enormous, and represents a new opportunity to optimize material properties by varying their size & shape rather than by changing their chemical composition. Thus the primary advantage of any nanostructure material lies in the extensive tunability of its properties. For example, the fundamental characteristics of a material, such as it melting temperature, color, saturation magnetization and coercivity, charging energy, chemical reactivity, etc., are all functions of size and shape. For instance, the color of semiconductor quantum dots can be varied continuously from the near infrared to the ultraviolet. Such colors changes correlate to electron and hole energy levels, which in turn affect the catalytic and chemical behavior of the particles. Thus, nanoscale building blocks lend major new experimentally controllable variables for fabricating desired materials. Atom manipulations, and matter diffraction from light waves are important new tools emerging from atomic and optical physics, which may lead to new ways of fabricating nanostructures.

Our group is focusing on the recent developments in nanoscience using new theoretical computational tools. For example, the interaction of shaped pulses sequences could contribute to the “assembly” of nanostructured materials, or to the manipulation of electronic coherence in quantum dot molecules and solids. The interaction of intense optical fields with nanostructures is of interest. Multiphoton ionization, and the measurement of nonlinear susceptibilities as a function of the size are currently important fields. In strong field, collisions of atoms or molecules with the nanostructures will allow electron transfer from quantum dot to the colliding atom or tunnel directly to vacuum states. Such enhanced electron emission processes will find applications in, for example, electron induced catalysis, air pollution abatement, etc. Using UV or even low energy x-rays from synchrotron light sources, 3-dimensional nanostructures or layers can be produced.
05. **Our Group Contribution in Molecular Dynamics & Inter Molecular Energy Transfer Processes**

**Dr. Kriti Batra** (Assistant Professor, IP University) and **Dr. Nisha Singhal** (USA)

Knowledge of the chemical, energetic and spectral properties of polyatomic molecules is important for studies of chemical reactivity, isotope separation, combustion processes, chemical lasers and other technologies as well as being a splendid stimulus to the ever-expanding predictive abilities of chemical theorists.

In the field of Molecular dynamics, we are investigating the nature of multiphoton excitation of several triatomic molecules in its ground electronic state coupled to different vibrational modes under strong laser field using non-perturbative techniques. The quantum theory of chemical reactions and theory of intermolecular energy transfer is the basis of chemical dynamics and molecular modeling. Our group is using different approaches to study energy transfer in various processes like rotational-rotational (R-R), rotational-vibrational (R-V), vibrational-vibrational (V-V) for explaining the flow of energy in Chemical dynamics i.e. where does it go, how long does it take to get there which has direct practical applications.

**Some Important Research Publications of the Group**

[53] Spin-orbit interaction effect on nonlinear optical rectification of quantum wire in the presence of electric and magnetic fields Manoj Kumar, Siddhartha Lahon, Pradip Kumar Jha, Man Mohan. Physica B: Condensed Matter, 438, 29 (2014), ISSN: 0921-4526, IF: 1


National and International Collaboration of our Group (Past & Present)

1. **Atomic Structure, Collision Physics with Plasma & Astrophysical Applications**
   
   Prof. P G Burke  
   Department of Applied Mathematics & Theoretical Physics  
   Queen's University of Belfast  
   Northern Ireland

   Prof. A. Hibbert  
   Department of Applied Mathematics & Theoretical Physics  
   Queen's University of Belfast  
   Northern Ireland

   Prof. Francis Keenan  
   Department of Applied Physics  
   Queen's University of Belfast  
   Northern Ireland

   Prof. Maryvonne Dourneuf  
   Observatoire De Paris  
   France

   Prof. J G Doyle  
   Research Astronomer  
   College Hill, Armagh  
   Norther Ireland

   Prof. Yoshiro Azuma  
   Sophia University  
   Faculty of Science and Technology  
   Tokyo, Japan

   Prof. Anil Pradhan  
   Department of Physics  
   Ohio-State, University, U.S.A

   Prof. Sultana Nahar  
   Department of Physics  
   Ohio-State, University, U.S.A

   Prof. Shivanad Chaurisya  
   BARC, Bhabha Atomic Research Centre  
   Laser-Plasma & Attosecond Section  
   Mumbai, India

2. **In the Field of Chemical Physics**

   Prof. Robert E Wyatt  
   Department of Chemistry  
   University of Texas  
   Texas, U.S.A

3. **Interactions of Strong Laser Field with Matter**

   Prof. A.D Bandrauk  
   Universite de Sherbrooke  
   CANADA

   Prof. T. Tung Nguyen-Dang  
   University Of Laval, Quebec  
   CANADA
4. In the fields of Quantum Optics, Bose Einstein Condensation & Cold Atoms

Prof. Nickolas P. Bigelow
Institute of Optics
Rochester
University, U.S.A

Prof. Peter Littlewood
FRS, Fellow of Royal Society
Cavendish Laboratory, U.K.

Prof. H. Walther
Max Planck Institute
Garching
Univ. of Munich, Germany

5. In Nanotechnology

Prof. A.K. Shukla
Department of Physics
Indian Institute of Technology, Delhi

Prof. Y Azuma
Sophia Univ. Japan

Prof. K. Hakuta
Chofu, Tokyo, Japan

As Senior Associate of ICTP Trieste, we have also Research Collaboration with Scientists in ICTP, Trieste, ITALY.