Seminar

==

Institute for Plasma Research

==

Title: Laser-cluster interaction in strong external magnetic field

Speaker: Ms. Kalyani Swain
Institute for Plasma Research, Gandhinagar

Date: 12^{th} August, 2024 (Monday)
Time: 10:00 AM
Venue: Seminar Hall, IPR
Join the seminar online: https://meet.google.com/rwv-thdx-bgk

Abstract

The interaction of electromagnetic radiation with matter is a fundamental and promising area of research due to its immense applications in inertial confinement fusion, material sciences, medical fields and generation of new light sources. For example, such interaction may generate energetic particles (e.g., electrons, ions, neutrals) and photons in the wide frequency range (e.g., x-rays). Based on this promising idea, for the last few decades, research on table-top size laser-plasma particle-accelerators have drawn significant attention with the aim to replace the traditional multi-kilometer high-energy particle-accelerators. These advancements have been possible through the use of high-power lasers, modifications to targets, and the inclusion of strong magnetic fields. In this thesis, we primarily focus on the interaction of an intense laser with the nano-meter size cluster target in an ambient magnetic field. We look for the possibility of enhancing the absorbed energy by laser-driven cluster-electrons, their beam-like emission and analyze the fundamental physical process.

Though laser-driven cluster targets were studied earlier in many works, the problem of coupling of *more* laser energy to the cluster electrons has not been paid much attention. Through an extensive literature survey, we find that the maximum energy absorption by the cluster electron (E_A) in the collision-less regime of laser cluster interaction (laser intensity I_0>10^{16}W/cm^2 and laser wavelength λ>600 nm) is limited near 2-3 times of its ponderomotive energy (Up). Hence, the question arises: can E_A be enhanced further? This problem is addressed in the present thesis. We first consider the interaction of linearly polarized 5-cycle broadband laser pulses (intensities $I_0 = 7.13 \times 10^{16} - 1.83 \times 10^{17}$ W/cm^2 and wavelength of 800 nm) with a deuterium cluster of radius 2.2 nm in presence of an externally applied magnetic field (B_0) in a crossed orientation to the laser electric field. Using a rigid sphere model (RSM) and a 3D particle-in-cell (PIC) simulation we show a significant enhancement of E_A up to 15-30 times, meaning E_A~30-70 U_p [1]. The required B_0 ranges from 0 to 2ω (here, ω is the laser frequency) and varies ~13-20 kilo Tesla. The energy enhancement is shown to happen in two stages, anharmonic resonance (AHR: 1st stage) and electron cyclotron resonance (ECR) or relativistic ECR (RECR: 2nd stage) by satisfying the required frequency matching as well as phase matching conditions for a prolonged duration of the laser pulse. Again, by analyzing the energy and angular distributions in the position as well as momentum space, it is shown that these energetic electrons form a nearly mono-energetic weakly relativistic conical-spiral beam with a narrow angular spread 5°-6° that traverses a few hundreds of cluster radius R_0 with momentum p/c>1.7 in the presence of an ambient magnetic field near ECR/RECR [2] which may not be

possible only with the laser field. With the increasing cluster size from 2.2nm to 4.4nm, though energy absorption per cluster electron remains the same, the total energy absorption increases with more energy carriers (electrons). Hence, our results also show an energetically intense relativistic electron beam (REB). Additionally, E_A is shown to be further enhanced by 4-5 times with the multi-charge state argon and xenon clusters compared to the single charge state deuterium cluster of similar sizes [2]. We also show that laser polarization plays an important role. A circularly polarized (CP) laser enhances E_A significantly by more than $10U_p$ compared to the case of linearly polarized (LP) laser in an ambient magnetic field [3]; and the angular spread of the electron beam is further improved to ~1°-2°. This enhancement of E_A is possible, since the field components of a CP laser do not vanish simultaneously and the phase-matching as well as frequency-matching conditions are shown to be greatly improved. In all the cases, PIC results are supported by RSM.

Apart from the applications discussed above, this work may also find its importance in understanding the dynamics of a charged particle in strong magnetic fields, such as in laser-solid interactions and astrophysical plasmas (e.g., neutron stars and pulsars) where magnetic fields exists in the range of ~10-10000 kilo Tesla.

References:

[1] **K. Swain** , S. S. Mahalik, and M. Kundu, Scientific Reports **12**, 11256 (2022).
[2] **K. Swain**, S. S. Mahalik, and M. Kundu, Physical Review A **108**, 053104 (2023).
[3] **K. Swain** and M. Kundu, Physics of Plasmas, 2024 (Manuscript under review).