Chaos of charged particle orbit in a compact levitated dipole experiment

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The behavior of charged particles in a strongly inhomogeneous dipole magnetic field is important for the understanding of transport and self-organization processes of plasmas in both nature and laboratories [1]. It is well known that the orbit of charged particle in the dipole field consists of gyration, bounce, and toroidal precession motions. This results in the conservation of three adiabatic invariants as actions for these periodic motions, which ensure the excellent confinement properties of particles on the magnetic surfaces. Experimentally, dipole field configurations are utilized for the formation of high-beta plasmas suitable for advanced fusion [1] and for a particle trap especially aiming for the formation of electron-positron plasmas [2]. On the formation process of self-organized states of plasmas in the dipole field, cross-field radial transport driven by the so-called low-frequency fluctuations play essential roles through the selective breakdown of the third adiabatic invariant [1]. For high-energy particles, on the other hand, coupling between the gyro and bounce motions can cause the non-integrable and chaotic trajectories [3]. In a previous study, it was shown that considerable ratio of positrons emitted from a Na-22 source (endpoint kinetic energy is 543keV) has chaotic long orbit in the dipole field of the RT-1 experiment [4], which can be applied to an efficient injection scheme of positrons across closed dipole field lines.

For the formation of electron-positron plasmas, it is needed to operate a compact levitated dipole trap for the realization of the high-density plasma state of rare antiparticles. For this purpose, we are on a way to develop a small volume levitated dipole experiment using a high-temperature superconducting coil winding that is directly cooled (i.e., without using the circulation of coolant helium gas) by a cryocooler [5]. In the present study, we focus on the behavior of relatively low-energy electrons and positrons trapped in the planned compact levitated dipole experiment. It is shown that gyro and bounce motions couple for lower energy charged particles in the compact levitated dipole trap when compared with the case in RT-1. This is because of the relatively low magnetic field of the new trap configuration with a magnetic null line located close to the confinement region. For considerable ratio of particles, both magnetic moment and longitudinal (second) invariant are therefore not conserved in this trap system. We report the properties of the chaotic behavior of electrons and positrons in the planned new dipole trap, together with its development status and expected enhanced trapping proerties realized by the coil levitation.

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