Zero-Carbon Energy Kyoto 2011
The 3rd International Symposium: Kyoto University Global COE Program
"Energy Science in the Age of Global Warming – Toward CO2 Zero-emission – "
18 – 19 August 2011, Suwon, Korea

Theoretical Study of Particle Motion under High Intensity Laser-Plasma Interaction Aiming for High Energy Density Science

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Abstract:

Being a high-quality and coherent energy source, ultra-short high power lasers have opened up attractive applications such as fast ignition-based laser fusion, which has been eagerly studied as one of the clean and abundant energy sources to replace fossil fuel. Furthermore, higher intensities of $10^{23\text{-}26}$ W/cm^2 that will be achieved in the near future enable the exploration of an entirely new scientific regime called high energy density science. In these studies, it is strongly required to understand relativistic interaction between tightly-focused high intensity lasers and plasmas. Among the physics dominating such an interaction, the *ponderomotive force* (light pressure) plays an essential role. The force has been expressed in the form proportional to the laser field gradient, using the averaging method to the equation of motion. However, as the laser field is tightly focused, not only gradient but also higher-order structures such as field curvature become important. These higher-order effects are generally difficult to be precisely investigated applying the conventional averaging method.

In order to investigate such a complicated particle motion in non-uniform laser fields, here, we apply the noncanonical Lie perturbation theory based on the phase space Lagrangian dynamics [1]. The method has been shown to be powerful in determining the relativistic particle dynamics in complex electromagnetic fields [2, 3].

As a result, we derived equations of motion describing the relativistic ponderomotive force including the effect of higher-order field structures. Moreover, we found an analytical solution corresponding to a *betatron-like oscillation*, by which the particle is confined to a finite radial region.

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Keywords: high intensity laser, ponderomotive force, noncanonical Hamiltonian mechanics, Lie transformation