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Rewriting the Rules Governing High Intensity Interactions of Light with Matter

Alex B. Borisov[1], John C. McCorkindale[1], Sankar Poopalasingam[1], James W. Longworth[1], Peter Simon[2], Sándor Szatmári[3], and Charles K. Rhodes[1]

[1]Laboratory for X-Ray Microimaging and Bioinformatics, Department of Physics, University of Illinois at Chicago, Chicago, IL 60607-7059, USA

[2]Laser-Laboratorium Göttingen e.V.
Hans-Adolf-Krebs-Weg 1, D-37077 Göttingen, Germany

[3]Department of Experimental Physics, University of Szeged
Dóm tér 9, H-6720 Szeged, Hungary

ABSTRACT

The trajectory of discovery associated with the study of high-intensity nonlinear radiative interactions with matter and corresponding nonlinear modes of electromagnetic propagation through material that have been conducted over the last 50 years can be presented as a landscape in the Intensity/Quantum Energy [I-$\hbar\omega$] plane. Based on an extensive series of experimental and theoretical findings, a universal zone of anomalous enhanced electromagnetic coupling, designated as the Fundamental Nonlinear Domain, can be defined. Since the lower boundaries of this region for all atomic matter correspond to $\hbar\omega \sim 10^3$ eV and $I \approx 10^{16}$ W/cm^2, it heralds a future dominated by x-ray and γ-ray studies of all phases of matter including nuclear states. The augmented strength of the interaction with materials can be generally expressed as an increase in the basic electromagnetic coupling constant in which the fine structure constant $\alpha \rightarrow Z^2\alpha$, where Z denotes the number of electrons participating in an ordered response to the driving field. Since radiative conditions strongly favoring the development of this enhanced electromagnetic coupling are readily produced in self-trapped plasma channels, the processes associated with the generation of nonlinear interactions with materials stand in natural alliance with the nonlinear mechanisms that induce confined propagation. An experimental example involving the Xe ($4d^{10}5s^25p^6$) supershell for which $Z \cong 18$ that falls in the specified anomalous nonlinear domain is described. This yields an effective coupling constant of $Z^2\alpha \cong 2.4 > 1$, a magnitude comparable to the strong interaction and a value rendering as useless conventional perturbative analyses founded on an expansion in powers of α. This enhancement can be quantitatively understood as a direct consequence of the dominant role played by coherently driven multiply-excited states in the dynamics of the coupling. It is also conclusively demonstrated by an abundance of data that the utterly peerless champion of the experimental campaign leading to the definition of the Fundamental Nonlinear Domain was Excimer Laser Technology. The basis of this unique role was the ability to satisfy simultaneously a triplet (ω, I, P) of conditions stating the minimal values of the frequency ω, intensity I, and the power P necessary to enable the key physical processes to be experimentally observed and controllably combined. The historical confluence of these developments creates a solid foundation for the prediction of future advances in the fundamental understanding of ultra-high power density states of matter. The atomic findings graciously generalize to the composition of a nuclear stanza expressing the accessibility of the nuclear domain. With this basis serving as the launch platform, a cadenza of three Grand Challenge Problems representing both new materials and new interactions is presented for future solution; they are (1) the performance of an experimental probe of the properties of the vacuum state associated with the Dark Energy at an intensity approaching the Schwinger/Heisenberg Limit, (2) the attainment of amplification in the γ-ray region (~ 1 MeV) and the discovery of a nuclear excimer, and (3) the determination of a path to the projected super-heavy Nuclear Island of Stability.