Theory challenges from X-ray FEL's

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Free-electron Lasers (FEL's) have started operating since a few years. The salient features of these x-ray sources are the very short pulses, down to a few *fs* duration; the extremely high peak power, approaching and probably soon surpassing the ~ 100 *GW* range; the peak brilliance, exceeding that at the best synchrotron sources by many orders of magnitude. Experiments using these revolutionary sources have started to open up new frontiers for x-ray physics.

Both experimental observations and theoretical considerations show that interaction between FEL pulses and atomic, molecular and condensed matter takes place under conditions that are quite different from the usual. The intensity of the radiation field is in a regime where important non-linearities are expected and indeed observed. Phenomena familiar from laser physics at much longer wavelengths (multi-photon absorption processes, self-induced transparency, sum-frequency generation and possibly parametric down-conversion and stimulated Raman scattering) are entering the x-ray domain. The theoretical basic tools for the interpretation of these experiments are being developed, and the important new information on the electronic properties of matter that could be gained shall be described.

At the same time, the very short duration of the pulses opens up the possibility to explore the dynamics of electronic and structural properties on an unprecedented time scale, well below the *ps* region. The challenges, but also the potential scientific pay-off, for theoretical investigations of time-dependent properties are briefly described.