Thomson scattering from dense non-equilibrium plasmas.

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X-ray Thomson scattering (XRTS) experiments in the soft and hard X-ray regime yield information on fundamental parameters of high-density systems [1]. Pump-probe experiments with variable time delay provide insight into the excitation and relaxation dynamics in dense plasmas on short time scales. Often, a theoretical description of states is applicable in which the electrons and ions are thermalized to different temperatures. At even shorter time scales, states arise in which the electron distribution function (EDF) cannot be described by local equilibrium functions and a more detailed kinetic description is necessary.

Besides non-equilibrium effects on the EDF, there is an influence of spatial inhomogeneities on the scattering signal. The simplest approximation is to sum the contributions of the different volume elements assuming local equilibrium conditions [2]. Belyi [3] showed that the inclusion of gradients might have a great influence on the field and density fluctuations in a non-equilibrium plasma. Kozlowski et al. [4] discussed implications for Thomson scattering spectra for inhomogeneous plasmas in the warm dense matter regime based on a gradient expansion within real-time Green's functions theory. They used, however, some simplified approximations, see also [5].

Giving a derivation with some more rigor, we discuss density and field fluctuations in non-equilibrium systems as well as the relation to the fluctuation-dissipation theorem in equilibrium [6]. Especially in the collective scattering regime, Thomson scattering spectra are modifed substantially by spatial inhomogeneities. Within a first-order gradient expansion, the dispersion relation for plasmons is determined. Further the ratio of the heights of the plasmon peaks is changed, preventing, e.g., a simple estimation of the plasma temperature from a detailed balance relation.

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