WAVE PHENOMENA IN COMPLEX (DUSTY) PLASMAS WITH LOW DAMPING

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A complex (dusty) plasma is a mixture of micron-sized grains with an ion-electron plasma and neutral gas. The grains charge up electrically and interact with each other producing a range of collective effects. They can be easily observed in real time with a video camera. Grain motion is only weakly damped by the neutral drag force making it possible to study different wave phenomena mediated by the interacting grains at a kinetic level such as Mach cones [1], solitons [2], shocks [3], various wave modes [4,5], and phonon propagation [6,7].

We made experiments in a monolayer complex plasma at very low gas pressure (0.7-2 Pa) to minimise the effect of frictional drag on the wave phenomena. The 8.9 μm grains were levitated in a sheath of a capacitively coupled radio-frequency discharge. They were confined horizontally by a rim on the rf electrode and vertically by the sheath electric field.

The theory and computer simulation were based on the equations of motion written for a monolayer of grains interacting via a Yukawa potential and moving in 2 or 3 dimensions. The ion-electron plasma was not explicitly included in the equations. The plasma-dependent parameters such as grain charge, Debye length, confining potentials, and damping rate were taken from the experiments.

The phonon spectra [6,7] were studied in a complex plasma. The longitudinal and transverse modes in the crystalline phase were found to be isotropic for small wavenumbers, and highly anisotropic for arbitrary wavenumbers. Increasing the lattice temperature we observed how the spectra changed. The transverse mode disappeared at approximately the melting point, while the longitudinal mode became isotropic and a new (compressional) dust thermal wavemode (DTW) appeared.

Vertical (transverse) wave packets [4] were observed in a crystalline monolayer. The phase speed was almost two orders of magnitude higher than the group speed and they had opposite directions as expected for an inverse optical dispersion relation. The packets propagated without apparent spreading due to combination of dispersion, inhomogeneity and neutral damping.

Monolayer crystals were found to sustain solitons [2]. Excited by an electrostatic pulse, disturbances propagated keeping their soliton parameter (amplitude times width square) constant while their amplitude decreased due to neutral damping. A theory of compressional and shear solitons propagating in an arbitrary direction in a hexagonal monolayer was developed.

Shock wave propagation [3] was observed in complex plasmas. Shocks caused melting or evaporation of the crystal. Jump condition was found at the shock front. The amplitude of the shock decreased due to damping and it decayed into a soliton.

Mach cones [1] (wakes) were obtained in monolayer crystals with low damping. Their shape was function of the time and space dependent properties of the lattice. A theory was developed to predict the wake shape and to reconstruct the lattice properties from the measured wake shape.

Experiments and computer simulations of complex plasmas with low damping showed that they are good macroscopic model systems [8] for studying various wave phenomena.

References

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