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CONTENTS

P1.11: Adam OBRUSNIK, P. Dvořák, M. Mrkvičková, V. Procházka, J. Voráč - *Numerical simulations of a dielectric barrier discharge in a mixture of argon, hydrogen and oxygen*

P1.12: Adriana ANNUSOVA, P. Coche, P. Viegas, L. L. Alves and V. Guerra - *Discussion on using the approach of a Maxwellian electron energy distribution function from low to moderated pressures in a global kinetic model for pure O_2 discharges*

P1.13: Natalia BABAEVA, Dmitry V. Tereshonok and George V. Naidis - *Initiation of breakdown in bubbles immersed in liquids: pre-existed charges and proximity of bubbles*

P1.14: Mokhtar LABIDOD, N. Ikhlef, O. Leroy - *Microstrip Line Antenna of micro Plasma Application Modelling and Simulating*

P1.15: Marija RADMILOVIC-RADJENOVIC, A. Bojarov, Z. Lj. Petrović - *Ion energy of argon ions incident on the electrodes of an EAE CCRF discharge with energy dependent secondary electron emission model*

P1.16: Marija RADMILOVIC-RADJENOVIC, M. Savić, Z. Lj. Petrović - *Monte Carlo simulation of radio-frequency breakdown in argon in electron dominated regime*

P1.17: Jean BRETAGNE, C. Vitelaru, P. Fromy, T. Minea - *Collisional Radiative Model of a HIPIMS discharge and comparison with time dependent Optical Emission Spectroscopic diagnostic*

P1.18: Krasimir IVANOV, T. Bogdanov, E. Benova - *Theoretical study of plasma sustained around dielectric cylinder by travelling electromagnetic wave*

P1.19: Leanne PITCHFORD - *Status report on the LXCat project: an open-access, community-wide project on data needed for modeling low-temperature plasmas*

P1.20: Djamila BENNACEUR-DOUMAZ, Djemai Bara - *Modeling of laser produced plasma expansion into vacuum with kappa distributed electrons*

P1.21: Plamena MARINOVA, M. Atanasova, E. Benova - *Heavy particles and rate coefficients in HF and MW discharges in Argon at atmospheric pressure*

P1.22: Masheyeva RANNA, K.N. Dzhumagulova, Z. Donkó, T.S. Ramazanov, M. Bonitz, T. Ott - *Cage correlation functions of three-dimensional Yukawa systems in external magnetic field*

P1.23: P. G. C. ALMEIDA - *Computing DC discharges in a wide range of currents with COMSOL MultiPhysics: time-dependent solvers vs. stationary solvers*

P2.09: Susumu SUZUKI, H. Itoh - *Measurement of effective lifetime of metastable excited atom Ne(3P2)*

P2.10: Haruo ITOH, I. M. Rusinov, S. Suzuki, K. Teranishi and N. Shimomura - *Loss rate of ozone at inner surface of photoabsorption cells*

P2.11: Abel KALOSI, P. Dohnal, R. Plašil, J. Glosík - *Time resolved absorption spectroscopy of helium dimers*

P2.12: Dmitry ZHILYAEV, B.M.Smirnov, V.P.Afanas'ev - *Stepwise ionization of gas discharge plasma of inert gases*

P2.13: Hiroyuki IWABUCHI, S. Matsuoka A. Kumada, K. Hidaka - *Influence of pressure on V-t characteristics across micrometer-scale surface gap*

P2.14: Petr KULHANEK -*Runaway electrons behaviour*

P2.15: Thuy Dung TRAN, R. Plasil, S. Rouck, D. Mulin, S. Rednyk and J. Glosik - *Reactions of NH+ with H at low temperatures*

P2.16: Nevena PUAC, V. Stojanović, Z. Raspopović, Ž. Nikitović, Z. Petrović - *Cross section set and transport properties for Ar+ in CF4*

P2.17: Haruaki AKASHI, T. Yoshinaga, K. Sasaki - *Ignition time improvement in pre-mixture gas of methane, oxygen and argon using plasma*

P2.18: Ilarion MIHAILA, V. Pohoata, R. Jijie, A.V. Nastuta, I.A. Rusu, I. Topala - *Influence of discharge geometry on extraction of positive ion populations from atmospheric pressure plasmas*

P2.19: M.A. MAHMOUD, Y.E.E.Gamal *- Kinetics of Ion Formation in Rubidium Vapour Excited by Nanosecond Resonant Laser Pulses*

P2.20: Nicolina POP, N. Pop, J. Zs Mezei, S.Niyonzima, F. Colboc, S. Ilie, M. D. Epée Epée, D. A. Little, B. Peres, V. Morel, O. Motapon, K. Chakrabarti, A. Bultel,K. Hassouni, J. Tennyson, I. F. Schneider - *Electron-impact excitation and recombination of molecular cations in cold ionized gases: application to H2+, BeH+, CH+, CO+, N2+, BF+ and AlO+*

P2.21: Karlygash DZHUMAGULOVA, E.O. Shalenov, T.S. Ramazanov - *Phase shifts and cross sections of electron-atom scattering in the dense semiclassical plasma*

Cage correlation functions of three-dimensional Yukawa systems in external magnetic field

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We investigate the effect of an external magnetic field on the cage correlation functions of the particles in a three-dimensional strongly coupled Yukawa system, via numerical simulations. The results show that with increasing strength of the magnetic field the caging time increases, i.e. the particles remain caged for a longer time. The investigation of the cage correlation functions is carried out in a wide range of the system parameters (coupling strength Γ, screening parameter κ, and reduced magnetic field strength β).

1. Introduction

The interest in the physics of complex plasmas has been continuously increasing during last few years. Motivated by their applications and by the need of understanding their fundamental physical effects, the properties of dusty plasmas are actively investigated on the basis of theoretical and experimental methods.

In many settings complex plasmas are affected by external electric and magnetic fields. The influence of magnetic fields on strongly coupled dusty plasmas became an important topic in the last few years [1,2]. The results of theoretical and simulation studies have shown the formation of magnetoplasmons and their higher harmonics in strongly coupled Coulomb and Yukawa systems [1]. The effect of magnetic field on the velocity autocorrelation and the caging of particles in two dimensional Yukawa liquids have been studied in Ref. [3].

2. Simulation method

We investigate the cage correlation functions of three–dimensional Yukawa systems in external magnetic fields by the molecular dynamic simulation method. The particles in such systems interact via screened Coulomb (Debye-Hückel, or Yukawa) potential:

$$\phi(r) = \frac{Q}{4\pi\varepsilon_0}\frac{\exp(-r/\lambda_D)}{r}, \qquad (1)$$

where Q is the charge of the particles and λ_D is the screening (Debye) length. The ratio of the nearest - neighbour potential energy to the thermal energy is expressed by the coupling parameter

$$\Gamma = \frac{Q^2}{4\pi\varepsilon_0 a k_B T}, \qquad (2)$$

where T is the temperature, $\kappa = a/\lambda_D$ is the screening parameter, $a = (3/4\pi n)^{1/3}$ is the Wigner-Seitz radius, and n is the number density of the particles.

The strength of the magnetic field is expressed in terms of

$$\beta = \frac{\omega_c}{\omega_p}, \qquad (3)$$

where $\omega_c = QB/m$ is the cyclotron frequency and $\omega_p = \sqrt{nQ^2/\varepsilon m}$ is the plasma frequency.

The changes of the surroundings of the particles at $t = 0$ and $t > 0$ are measured by the list correlation function:

$$C_l(t) = \frac{\langle l_i(t)\cdot l_i(0)\rangle}{\langle l_i(0)^2\rangle}, \qquad (4)$$

where l_i is the "neighbor list" of particle i, which consists of 0-s and 1-s, the latter represent the particles situated within the first correlation shell around particle i. $\langle\cdot\rangle$ denotes averaging over particles and initial times. The number of particles that have left the original cage of particle i at time t can be determined as

$$n_i^{out}(t) = \left|l_i(0)^2\right| - l_i(0)\cdot l_i(t), \qquad (5)$$

where the first term gives the number of particles around particle i at $t = 0$, while the second term gives the number of "original" particles that remained in the surrounding after time t elapsed. The cage correlation function $C^c_{cage}(t)$ can be calculated by

Phase shifts and cross sections of electron-atom scattering in the dense semiclassical plasma

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Collisional characteristics of the electron-atom scattering in the dense semiclassical plasma were calculated within the dynamic model of interaction. This model takes into account the quantum mechanical diffraction effect and dynamic screening which depends on the velocity of the colliding particles. On the basis of the Calogero equation the phase functions and the phase shifts were calculated. Phase shifts and cross sections obtained on the basis of the dynamic potential are larger than those obtained on the basis of the static model and converge with them at small values of the kinetic energy of colliding particles.

1. Dynamic interaction potential of electron and atom in the dense semiclassical plasma

Development of the interaction models of the semiclassical plasma particles and research on their basis of the collisional, transport properties represent a great fundamental and practical interest (see, for example, Refs. [1-6]). It is important for development of the technologies of the many practical applications connected with non-ideal plasma, for example, thermonuclear fusion with the laser compression and others.

In works [2,3] for electron – atom interaction the effective potential considering both effects of screening and diffraction was presented:

$$\Phi_{ea}(r) = -\frac{e^2\alpha}{2r^4(1-4\bar{\lambda}_{ea}{}^2/r_D{}^2)}\left(e^{-Br}(1+Br)-e^{-Ar}(1+Ar)\right)^2 \tag{1}$$

where

$$A^2 = \frac{1}{2\bar{\lambda}_{ea}{}^2}\left(1+\sqrt{1-4\bar{\lambda}_{ea}^2/r_D^2}\right),$$

$$B^2 = \frac{1}{2\bar{\lambda}_{ea}{}^2}\left(1-\sqrt{1-4\bar{\lambda}_{ea}^2/r_D^2}\right).$$

$\bar{\lambda}_{ea} = \hbar\big/\sqrt{2\pi\mu_{ea}k_BT} \approx \bar{\lambda}_e$ is the de Broglie thermal wavelength; $\mu_{ea} = m_e m_a/(m_e+m_a)$ is the reduced mass of electron and atom.

Potential (1) is screened and also has finite values at the distances close to zero. It is necessary to note that traditionally the screening of the electric field in plasma is represented by the static Debye – Huckel screening. This approach is valid, if the velocities of the colliding particles are near to the thermal velocity. Screening, depending on the velocity of the colliding particles, was called as the dynamic screening and now is often used in research of the non-ideal plasma properties. In works [4-6] the way of accounting of the dynamic screening was described. It is reduced to the replacement of the static Debye length by some effective one that is connected with the dynamic screening:

$$r_0 = r_D\left(1+\frac{v^2}{v_{Th}^2}\right)^{1/2} \tag{2}$$

Here v is the relative velocity of the colliding particles, v_{Th} is the thermal velocity. Then the pseudo-potential (1) for electron-atom interaction, which takes into account the dynamic screening, in a dimensionless form is:

$$\Phi_{ea}^{dyn}(r) = -\frac{e^2\alpha}{2r^4(1-4\bar{\lambda}_{ea}{}^2/r_o{}^2)}\left(e^{-Br}(1+Br)-e^{-Ar}(1+Ar)\right)^2 \tag{3}$$

$$A^2 = \frac{1}{2\bar{\lambda}_{ea}{}^2}\left(1+\sqrt{1-4\bar{\lambda}_{ea}^2/r_o^2}\right),$$

$$B^2 = \frac{1}{2\bar{\lambda}_{ea}{}^2}\left(1-\sqrt{1-4\bar{\lambda}_{ea}^2/r_o^2}\right).$$

$$\delta = v/v_{Th}$$

In this work the following dimensionless parameters were used: $\Gamma = Z_\alpha Z_\beta e^2/(a\,k_BT)$ is the coupling parameter (the average distance between particles is $a = (3/4\pi n)^{1/3}$; $n = n_e + n_i$ is the numerical density of the electrons and ions; T is the plasma temperature; k_B is the Boltzmann constant); $r_s = a/a_B$ is the density parameter ($a_B = \hbar^2/m_e e^2$ is the Bohr radius).