Syllabus of lecture "Principles of plasma physics" (12ZFP, summer term, 3+1)

1. Introduction, basic terms

plasma definition, quasi-neutrality, collective behavior, difference between plasmas and gases, Debye shielding, Debye length, plasma frequency, plasma parameter, collision frequency, Coulomb logarithm, ideal and non-ideal plasma, coupling parameter, degenerate plasma, examples of plasmas in nature and laboratory

2. Particle motion in external fields

cyclotron frequency, Larmor radius, drift in crossed electric and magnetic fields, gradient drift, curvature drift, polarization drift, adiabatic invariants, 1st adiabatic invariant, magnetic mirror, ponderomotive force

3. Particle in self-consistent fields – transition to kinetic and fluid description

microscopic distribution functions, Klimontovich equation, Klimontovich equation for plasma, ensemble and averaging over ensemble, fluctuations, transition to Vlasov equation, Krook collision term, plasma as electric medium, temporal and spatial dispersion, low-frequency plasma permittivity, plasma as mixture of fluids, transition from Vlasov equation to fluid description, pressure tensor, drift motions of a fluid, diamagnetic drift, plasma approximation

4. Electron plasma waves

linearization of fluid equations, wave classification, dispersion relation, electron plasma oscillations, impact of collisions, impact of non-zero temperature and propagation of plasma waves, derivation from Vlasov equation, Landau integration curve, physics of Landau damping, plasma permittivity, plasma wave energy, non-linear Landau damping, BGK modes, two-beam instability, principle of Particle-In-Cell simulation method, demonstration of wave behavior using PIC code

5. Other linear waves in plasma

ion-sound waves, electromagnetic waves in plasmas without B_0, plasma permittivity, cutoff frequency, critical density, collisional absorption of elmg. waves, propagation in inhomogeneous plasmas, WKB approximation, non-linearities during elmg. wave propagation, filamentation and self-focusing, elmg. waves in magnetized plasmas (O, X, R, L waves), CMA diagram, ion electromagnetic waves (Alfven and magnetosonic waves), parametric instabilities, stimulated scattering, physics of corona and laser interaction with plasmas

6. MHD description, hydromagnetic equilibrium and instabilities

transition to one-fluid description, ideal MHD, hydromagnetic equilibrium, parameter β, non-ideal MHD, plasma diffusion into magnetic field, Rayleigh-Taylor instability, Kruskal-Schwarzschild instability (RT in magnetic field)

7. Diffusion and transition layers

diffusion in weakly ionized plasmas, ambipolar diffusion, diffusion perpendicularly to B, Bohm diffusion, plasma-wall transition layers, Bohm criterion, Child-Langmuir law, collisionless shock

8. Introduction into atomic physics of plasma

classification of multiply charged ions, energy level schematics, autoionization states, energy level splitting, resonance transitions, collisional processes, impact excitation and de-excitation, impact ionization and three-body recombination, dielectronic recombination, radiative processes, free-free, free-bound and bound-bound transitions, Einstein coefficients, line broadening, radiative transport, optical thickness, ionization equilibrium (Saha equation), thermodynamic equilibrium and LTE, coronal equilibrium, principle of detailed balance

9. Introduction to controlled fusion

fusion reactions, necessity of heating, ideal ignition temperature, Law2son criterion, magnetic and inertial confinement, magnetic toruses, plasma heating, pinches, inertial confinement fusion – direct and indirect drive, drivers - lasers or particle beams

10. Elastic collisions and their impact

Liouville equation, equations' hierarchy for distribution functions (BBGKY hierarchy), Vlasov equation, correlation functions, equation for binary correlation function, Bogoliubov's hypothesis – weakening of initial correlations, assumptions leading to Fokker-Planck (-Landau), Boltzmann and Lenard-Balescu collision terms, applications of Landau collision integral (relaxation of electron momentum, electron-ion energy relaxation, high-frequency plasma conductivity)

Reading to the lecture

compulsory

/C/ F.F. Chen: *Introduction to Plasma Physics and Controlled Fusion, 3rd edition*, Springer, Berlin 2016

/N/ D.R. Nicholson: *Introduction to Plasma Theory*, J. Wiley&ons, New York 1983

recommended

/S/ V.P. Silin: *Vvedenie v kineticheskuyu teoriyu gazov, Nauka, Mosva 1971 (in Russian)*

/E/ S. Eliezer: *The Interactions of High-Power Lasers with Plasma*, IOP Publishing, Bristol and Philadelphia 2002

/I1/ S. Ichimaru, *Statistical Plasma Physics, Volume I: Basic Principles*, Addison-Wesley Publishing Co., Redwood City, Ca. 1992

/K/ Ju.L. Klimontovič: Statistical Physics, CRC Press, Boca Raton 1986

/Ku/ W.L. Kruer: The Physics of Laser Plasma Interactions, Westview Press 2003 (also CRC Press 2018), e-Book CRC Press 2019

/M/ A.B. Michailovskij: *Theory of Plasma Instabilities, Volume 1*, Consultants Bureau 1974

/H/ H. Hora: *Physics of Laser Driven Plasmas*, J. Wiley&Sons, New York 1981

/G/ P. Gibbon: *Short Pulse Laser Interactions with Matter: An Introduction*, Imperial College Press, London 2005

/D/ R.P. Drake: *High Energy Density Physics*, Springer, Berlin 2006

/Sa/ D. Salzman: *Atomic Physics in Hot Plasmas*, Oxford University Press, Oxford 1998

/MB/ P. Mulser, D. Bauer: *High Power Laser-Matter Interaction*, Springer, Berlin 2010

/BL/ C.K. Birdsall, A.B. Langdon: *Plasma Physics via Computer Simulations*, Adam Hilger, Bristol 1991

/T/ G.J. Tallents, *An Introduction to the Atomic and Radiation Physics of Plasmas*, Cambridge University Press, Cambridge 2018