

Contents

| | | |
|----------|-----------------------------------------------------------------------------------|----|
| 1 | Introduction | 1 |
| 2 | Previous Work, Status and Overview | 5 |
| 2.1 | Energy Loss in an Unmagnetized One–Component–Plasma (OCP) . | 5 |
| 2.2 | Challenges Imposed by the Magnetic Field | 11 |
| 2.3 | Classical-Trajectory-Monte-Carlo (CTMC) Simulations | 14 |
| 2.4 | Dielectric Treatment (DT), Vlasov–Poisson Equation, Linear Response (LR) | 16 |
| 2.5 | Particle-In-Cell (PIC) Simulations | 22 |
| 3 | Binary Collision Model | 25 |
| 3.1 | Introductory Remarks | 25 |
| 3.2 | Equations of Motion | 26 |
| 3.3 | Energy Loss and Velocity Transfer | 28 |
| 3.4 | General Interactions, no Magnetic Field | 29 |
| 3.5 | Binary Collisions (BC) in a Magnetic Field | 33 |
| 3.6 | Parallel Ion Motion | 39 |
| 3.7 | Chaotic Scattering and Validity of the Perturbation Treatment | 42 |
| 3.8 | Binary Collision Model for Arbitrary Ion Motion in a Strong Field . | 51 |
| 3.9 | Binary Collisions in a Weak Field | 57 |
| 3.10 | Impact Parameter Integration and Velocity Averaging | 61 |
| 3.11 | Velocity Diffusion (Straggling) of Charged Particles in a Magnetic Field | 68 |
| 4 | Dielectric Theory | 73 |
| 4.1 | Stopping Power (SP) in Plasmas Without Magnetic field | 73 |
| 4.2 | Stopping in Plasmas With Weak Magnetic field | 76 |
| 4.2.1 | Small Projectile Velocities | 77 |
| 4.2.2 | High Projectile Velocities | 78 |
| 4.3 | Stopping in Plasmas With Strong Magnetic Field | 79 |
| 4.3.1 | Small Projectile Velocities | 81 |
| 4.3.2 | High Projectile Velocities | 81 |
| 4.4 | Stopping in the Low-Velocity Limit at Arbitrary Field Strengths ... | 83 |
| 4.5 | High-Velocity SP in a Magnetized Plasma | 85 |
| 4.5.1 | Heavy Ions With Rectilinear Trajectories | 87 |

| | | |
|----------|----------------------------------------------------------------------------------------|------------|
| 4.5.2 | Weakly Coupled Plasma with Strong Magnetic Fields | 91 |
| 4.5.3 | Light Ions, The Effect of the Cyclotron Rotation | 93 |
| 4.6 | Reduced LR (RLR) Treatment | 96 |
| 4.6.1 | RLR, LR and BC Treatments Without Magnetic Field | 98 |
| 4.6.2 | RLR, LR and BC Treatments With Strong Magnetic Fields | 100 |
| 4.7 | Conformity Between Reduced LR and BC approaches | 106 |
| 5 | Quantum Theory of SP in Magnetized Plasmas | 109 |
| 5.1 | Dielectric Theory | 109 |
| 5.2 | Equation of State for Quantum Magnetized Plasmas | 115 |
| 5.2.1 | Critical Temperature | 115 |
| 5.2.2 | Fully Degenerate Electron Plasma | 116 |
| 5.2.3 | Semiclassical and Classical Limits | 118 |
| 5.3 | Dielectric Function, Fully Degenerate Plasma | 118 |
| 5.3.1 | Fully Degenerate Plasma in a Strong Magnetic Field | 120 |
| 5.3.2 | Acoustic Plasma Resonance | 121 |
| 5.4 | Dielectric Function, Semiclassical Limit | 121 |
| 5.5 | Stopping Power in a Magnetized Quantum Plasma | 124 |
| 5.5.1 | Low-Velocity Stopping Power in a Semiclassical Regime | 124 |
| 5.5.2 | Stopping power in an Infinitely Strong Magnetic Field, Low-Velocity Limit | 126 |
| 5.5.3 | Stopping power in a Strong Magnetic Field in the Nearly Degenerate Regime | 129 |
| 5.6 | Binary Collision Treatment, Conformity Between BC and RLR | 130 |
| 5.7 | Correspondence Between Quantum and Classical BC Treatments | 134 |
| 5.7.1 | Cartesian Basis | 134 |
| 5.7.2 | Cylindrical Basis | 137 |
| 5.8 | Averaged Classical Second-Order Energy Transfer | 140 |
| 6 | Applications and Illustrating Examples | 143 |
| 6.1 | Electron Cooling in Storage Rings | 143 |
| 6.1.1 | Energy Loss and Drag Force | 144 |
| 6.1.2 | Cooling Forces | 145 |
| 6.1.3 | Emittance and momentum spread | 148 |
| 6.2 | Electron Cooling in Penning Traps | 150 |
| 6.2.1 | Modeling of the Cooling Process in a Trap | 151 |
| 6.2.2 | Cooling of Protons and Highly Charged Ions | 153 |
| 6.2.3 | Cooling of Antiprotons and Protons by Electrons and Positrons | 159 |
| 7 | Summary and Conclusion | 165 |
| A | Dielectric Function of the Magnetized Electron-Ion Plasma | 169 |
| B | Anomalous Term | 171 |

C Dielectric Function of the Magnetized Quantum Plasma 173

D Some Properties of the Function $F_{nv}(\zeta)$ 175

References 177

List of Symbols and Abbreviations 183