"He (Infinite Brahman) is whole and this (Karya Brahman) is whole, taking the whole (Karya Brahman) from the whole (Infinite Brahman), the whole remains"

Mathematically speaking, this sloka implies that infinity minus infinity remains infinity.
Chapter 5

Summary

5.1 Brief summary of thesis work

The present thesis work is centered around a few basic research problems on equilibrium and dynamic characterization of the plasma sheath in Child limit of the applied wall voltage. The sheath equivalent electrical circuit model of the Child sheath is focussed as the prominent feature to complement the hydrodynamical model of the Child sheath description. In fact, the Poisson’s equation describes the behavior of localized nonlinear space charge electric field that is created either by boundary-plasma interaction processes or by the nonlinear saturation processes of the plasma instabilities.

It is quite difficult to analytically solve the Poisson’s equation, which is inherently highly nonlinear in character. Only numerical methods provide the appropriate tool for exact solution of the Poisson’s equation. However, the Child sheath equation is an approximate solution of the Poisson’s equation in high voltage limit ($\phi >> T_e/e$) of the applied wall potential. Similarly, the ion matrix sheath solution is also an approximate solution of the Poisson’s equation under constant ion density equal to bulk plasma density.

In the present thesis, the sheath equivalent electrical circuit equation is used for self-consistent characterization of equilibrium and dynamic properties of the Child sheath. An interesting physical idea of current equivalence principle is coined to justify the closure property of the Child sheath equation. Theoretical and numerical calculations are performed for realistic plasma parameters of practical importance. The calculations of equilibrium Child sheath width and current are in good agreement with conventional model calculations. The scaling behavior of the Child sheath width and current with respect to
applied wall voltage confirms the scaling derived by conventional model approach.

The temporal relaxation behavior of the observed ion implantation current profile in transient sheath experiments is well described by the governing equations of the sheath equivalent electrical LCR circuit with a self-consistent source term of the sheath potential. The model equations derived to govern the static and dynamic Child sheaths are based upon the dual behavior of the Child sheath as discussed in chapters 2 and 3. This is to point out that the dual behavior of the Child sheath is, for the first time, reported to highlight the source and sink (load) character of the sheath as a whole. Here the duality of the sheath means that the sheath acts simultaneously as a source and sink (load) both, where the sheath potential offers as the source emf and the equivalent electric circuit network as the load (sink) to self-consistently decide the sheath width and the current flowing through it.

Finally, wave turbulence model is proposed as a new basic paradigm towards solving the problem of sheath edge singularity. Under this proposal it is assumed that the sheath edge behaves as a diffuse boundary with finite spatial width supposed to scale as $\lambda_{De} < l_{turb} << L_{preshe}$. Here the notations $l_{turb}$ and $L_{preshe}$ represent the scale length of the turbulent zone also termed as the transonic zone and the scale length of the presheath scale respectively. Under this model it is proposed that a finite level of localized shorter scale acoustic wave turbulence (in unmagnetized plasma) should exist to cause ion flow transition from sub-sonic to super-sonic speed.

Of course, the work on wave turbulence model included in the present thesis is very preliminary in nature and simply deals with the problem of the linear amplitude variation of acoustic fluctuation as it reaches the sheath edge of conventional model origin. More detailed investigations of linear and nonlinear eigen mode analysis under matrix formulation will be needed to make any final comment. This is in fact, quite involved problem and hence needs further extensive research. Moreover, as pointed out in chapter 4 the transonic zone provides a quasi-neutral plasma system with drifting ions at near sonic speed.

In such condition the acoustic fluctuations become susceptible to finite but weak electron inertial delay effect that causes linear resonant growth of the acoustic fluctuations. In such condition the usual ion acoustic soliton is shown to suffer structural transformation leading thereby formation of oscillatory shock-like structures depending on the level of ion flow deviation from sonic speed. This is to further comment that the usual soliton solution with amplification or suppression of the amplitude is obtained only for infinitely long wavelength source driving. For shorter wavelength source driving oscillatory shock-like
solutions are more likely to exist. These calculations may have some bearing to understand wave turbulent activities at the sheath edge.

5.2 Overall conclusion of the thesis

The main conclusion of the thesis can be put in following words. The sheath equivalent electrical circuit behavior of the Child sheath offers an important aspect of sheath physics to develop a self-consistent set of governing equations to deal with the equilibrium and dynamic properties of the Child sheath. The wave turbulence model is forwarded as a new basic paradigm to resolve the problem of sheath edge singularity under three-scale analysis of the plasma-sheath transition. The transonic zone (or to say as the turbulent zone) being susceptible to finite but weak electron inertial delay effect may cause structural transformation of the usual acoustic solitons passing through it.

In brief, it can be stated that the sheath edge singularity may be resolved by appropriate consideration of an additional intermediate scale with finite level of the wave turbulence supposed to arise as a consequence of residual effect of the sheath formation mechanism. However, it is quite difficult to say more than this at this stage of preliminary formulation and analysis of the problem. Furthermore, it is conjectured that any localized non-neutral space charge layer should be treated as an equivalent electrical circuit analog of circuit elements in series or some combination of series and parallel networking.

5.3 Future scope

The problems of basic sheath physics are quite interdisciplinary in nature. An understanding of the non-equilibrium phenomena in plasma sheath is a fundamental problem. The problem overlaps many other problems in science and engineering, which include boundary layers that occur in laser physics, laser-matter interaction physics, fusion devices, aeronautics, space science, astrophysics, solar surface physics, chemically reactive systems, radiation physics, etc. The charging of the colloidal particles in colloidal/dusty plasmas and in colloidal solutions requires the basic understanding of sheath formation physics. Furthermore, theory of metallic probes and surface engineering by plasma based technology also requires the basic knowledge of sheath physics and associated phenomena.

It is thus obvious to note that the future scope of sheath physics has wide ranging
5.3 Future scope

applications in problems to be addressed in specific cases under consideration. The problems as highlighted above may require deep insight of cross-disciplinary approach of knowledge.