CHAPTER IX

SUMMARY AND CONCLUSIONS

What has been thrown:

In the community of physicists, plasma physicists are especially known for their knack of circumventing the hurdles by throwing away terms under the garb of "suitable approximations". As such there is nothing wrong in throwing away things (as long as you do not hurt others with it) but sometimes it may so happen that in this process of throwing one may throw away the baby with the bath. As a safeguard against such a folly it is required from a plasma physicist that he should clearly identify what he has thrown and show that at least he has not thrown away the baby with the bath.
The calculations presented in this thesis are no different from others in this respect. Lot of terms have been thrown away. Hence in this Chapter we will make an attempt to identify what have we thrown, how much has been lost in this throwing and how can it be picked up again if the need arises again.

Clearly in the calculations presented in this work we did not wish to reproduce exactly the observations of $\beta - 2$, 2XIIB, Base-Ball II, Constance II. Our aim has been rather modest. Our aim was to identify certain physical processes which we think are responsible for the observations of 2XIIB, Constance II, Base-Ball II and $\beta - 2$ and further to evaluate their relative importance in some simplified situations. To this end approximations have been made which will certainly have to be dispensed with far more quantitative accuracy. In this respect these calculations are to be regarded as only an initial step towards a more complete calculations. It is on this aspect that the merit of these calculations require judgement.

As can be clearly seen that the general direction of the work presented in this thesis is in studying various normal modes of mirror plasmas, their non-linear couplings, their suppression or enhancement in the presence of electron beams or lower hybrid waves, their nonlinear saturation and their suppression by feedback circuits. In the second chapter we have studied the nonlinear instability of a low frequency flute mode first predicted by Varma (1) for mirror plasmas. In our calculations we have studied the nonlinear instability of this mode in the presence of ion-cyclotron oscillation which were seen alongwith
Varma mode in Base-Ball II (2). The interesting feature of this coupling between the Varma mode and ion-cyclotron mode is that the kinetic wave equations yield a solution which periodically bursts in time. The time scale of these bursts turns out to be $400 \frac{1}{\Omega_i}$ ($\Omega_i$ is the ion-cyclotron frequency) which is quite similar to the bursts of large amplitude flute mode seen in Base-Ball II. This is in contrast to the results obtained by Simon and Weng (3) who studied the nonlinear instability of Varma mode in the presence of the other flute modes and got an explosive solution for the Varma mode which they correlated to the instability observed in 'Alice' and 'Phoenix'. In Base Ball II such a coupling is not possible as all the flute modes are linearly stable. However, this work suffers from incompleteness on following accounts, firstly we have not made any effort to identify the other small amplitude stable flute mode (0.5 V) observed in Base-Ball II. We suspect that this could be one of the other flute modes. Probably because of its low energy content the coupling of this mode to the ion-cyclotron mode is weak and hence it remains stable. Of course such a statement can be made only after a calculation has been made to show that the matrix element of the coupling of this mode with ion-cyclotron mode is small as compared to the matrix element of coupling between the Varma mode and the ion-cyclotron mode. Secondly, in Section 3 of Chapter III the linear theory of the Varma mode is worked out for a perfect flute mode i.e. $|k| = 0$ while in the nonlinear instability calculation we have considered the Varma-mode with finite $|k|$. Qualitatively a finite $|k|$ would give rise to linear damping by particles which has been included in the calculations. But as far as nonlinear instability
is concerned, it will not be off as it depends on \( \kappa_{11} = \kappa_{11}^1 - \kappa_{11}^n \)
which remains finite as long as one of \( \kappa_{11}^n \) remain finite.

Nevertheless to have a better calculation, the linear theory of the Varma mode with finite \( \kappa_{11}^n \) should be examined. These considerations will be taken up in future.

In Chapters III, IV and V, we have examined the effect of electron beam (EB) induced Langmuir waves on DCLC or HFCLC instabilities. It should be pointed out at the outset that in all our calculations regarding DCLC or HFCLC instabilities we have made use of the electrostatic approximation and have neglected the effect of temperature gradients. Baldwin (4) and Catto et al (5) have pointed out their importance in experimental situations. They have a stabilizing effect. However, we have dropped them from our calculations as we wanted to consider the worst possible situations. For better quantitative accuracy, they certainly will have to be considered.

In Chapter III we have identified a physical process which we think plays an important role in suppression or enhancement of DCLC turbulence in electron beam injected mirrors i.e. the process of resonance damping by electron beam induced Langmuir plasmons. Of late this technique has achieved special attention as it provides an efficient method of suppressing DCLC turbulence in the end plugs of tandem mirrors (5). The usual warm plasma stabilization method may not be quite useful here because it cools the electrons which leads to a reduction of the multipolar potential of the plugs and thus worsens the confinement in the central cell (7). The electron beam method does not suffer from this
defect, we have shown that by resonant damping it controls the DCLC turbulence and due to collapse of Langmuir turbulence it heats up the electrons which lead to an increase in the ambipolar potential and thus a better confinement for the central cell ions. The only defect of this method is that for certain range of beam powers it enhances the turbulence. In Chapter III, we have outlined an approach by which this range can be identified and avoided. In the same chapter we have given a set of closed equations to study the time evolution of the ion distribution function and to calculate some important parameters like final electron and ion temperatures, ion life times, final fluctuation level.

However, this work suffers from a certain degree of incompleteness on the following account: firstly we have not undertaken the numerical integration of these equations to calculate parameters mentioned above but rather by qualitative arguments and estimates we have made attempts to explain the observations from these equations. One reason why such a study was not taken up was the lack of efficient computing facilities at the institute and secondly parameters like background gas flux, evolution of electron and ion temperatures, ion life time, diffusion rates in different energy channels which would have been required for integration and confirmation of these equations were not made available in the published references.

The other source of error in the calculation may be that for the stationary spectrum we have used the stationary spectrum calculated by Tsytoyich et al (8) in the absence of the magnetic field. This has been done under the approximation \( \omega_{Te} > \omega_{ce} \) where the effect of
field on particle motion is not very strong. Thus while a more exact
calculation of the stationary spectrum may very well offset the quanti-
tative behaviour, it will not alter much the qualitative features of
the process considered in the model (i.e. the resonant damping by
Langmuir plasmons).

Hence on the whole it can be said about this calculation that
to obtain a better confirmation (or refutation?) of the model we must
integrate the closed set of equations given in Chapter III and calcu-
late the final fluctuation level, electron and ion temperatures, ion
life time and compare them with the experimental values (if they can
be achieved). Such a programme will be taken up in future here.

In the Fourth and Fifth Chapters, we have studied the effect
of electron beam induced Langmuir waves on another loss cone generated
instability i.e. the HFCLC instability. We find that while in the high
frequency part of HFCLC, Langmuir waves have favourable effects i.e.
they generate sufficient anomalous resistivity to stabilize the HFCLC
mode, in the low frequency range, their effect is harmful for the confine-
ment; they tend to reduce the critical lengths. In our estimates
regarding the reduction of critical lengths we have not included the
important reflections mechanism like reflection due to corrections to
WKB approximation (9), incoherent bouncing of electrons (10), turning
points due to ion-cyclotron resonances (11), etc. M. Gerver (12) has
pointed that all these mechanisms along with high-\(\beta\) effect tend to
reduce the critical length. On this account our estimates about
critical length may not be of experimental interest. But neither they
were meant to be so. All we wanted to show from these estimates was that even in simple situation (low- \( Q \) effect, and absence of wave reflections) the electron beam is harmful enough. If the various wave-reflection mechanisms are considered the situation will become worse.

In the Sixth Chapter, we have given a simple calculation to show the importance of orbit diffusion effects in the saturation of DCLC turbulence in mirrors. Hitherto all the theories put forward for the saturation of turbulence in mirrors are based on perturbation schemes. One of the unsatisfactory features of any perturbation expansion schemes in general is that they do not furnish a prescription for the truncation of the series. Because of this it becomes difficult to decide upto what orders one must retain terms in order to explain a physical process. Thus on one hand we have Galeev (13) and Baldwin et al (14) who think that the first order effects like plateau formation etc. are enough to explain the saturation of DCLC turbulence in mirrors. On the other hand we have Rosenbluth and Aamodt et al (15) who think that one has to go to third order effects like detuning of resonance in order to explain the saturation of turbulence in mirrors. Perturbed orbit formalism does not suffer from such defect as it is not based on any perturbation scheme. This interesting result borne out by the calculations is that damping due to perturbed orbit effects is sufficient to overcome the growth due to ion distribution. These results are not very surprising especially in the light of the fact that velocity space diffusion which is responsible for the diffusion of trajectories is very strong in mirrors i.e. 100 eV/\( \mu \)s (7). In the same chapter we have also shown that in perturbed
orbit formalism the fluctuation level is proportional to fourth power of the linear growth while ion life time is inversely proportional to third power of the linear growth. So that in the presence of the warm plasma where the linear growth is reduced by a small amount, fluctuation level may decrease by a large amount and ion life time may increase significantly. This points out the importance of the effect of orbit diffusion in stabilization of DCLC turbulence in the presence of warm plasma streams. However, this calculation may suffer from incompleteness because perturbed orbit theory itself is not a complete theory. In it, the operator is normalised but vertex normalisation is not taken care of. The theory which satisfactorily takes into account operator and vertex normalisation is the "Direct Interaction Approximation". A study of ion-cyclotron turbulence under this approximation is being considered at present.

In Chapter VII, we have pointed out the efficiency of damping of DCLC turbulence by lower hybrid turbulence. A modest level of lower hybrid turbulence is going to be inevitable in future neutral beam injected mirrors. In this case this turbulence may serve a double purpose i.e. it will lead to an efficient heating of electrons and ions (16) and it will help in controlling the DCLC turbulence. As stated before for more reliable estimates the effects of magnetic perturbations and temperature gradients should be included.

In Chapter VIII, we have investigated the possibility of suppressing the DCLC turbulence by feedback circuits. In these
calculations we have made use of the assumption that electron sources are present uniformly in the plasma. This is not a very correct assumption because metal probes (which act as sources) are present at finite points only. However, as Rutherford (17) has pointed out, this assumption gives results which agree fairly well with the experimental observations. The other source of incompleteness is that we have not investigated the stability in phase angles other than $90^\circ$. This has to be done numerically and may be taken up in future.
REFERENCES


