# Chapter-5

## Effect of Self-Generated Magnetic Fields on Electron Heat Flux in Laser Produced Plasmas

### 5.1 Introduction

There are three energy transport mechanisms, such as, classical electron thermal conduction, hot (suprathermal) electron transport and radiation transport. The presence of both hot and cold electrons can lead to plasma instabilities which produce a turbulent state in the plasma corona, tending to inhibit the thermal conduction process. A well-ordered large-scale d.c. magnetic field slows electron transport along magnetic field, when the electron Larmor radius is less than the collisional mean free path.Under this condition, the step size for random walk of electrons across the field becomes Larmor radious instead of collisional mean free path. So, an well-ordered megagauss magnetic fields play an important role on transport inhibitation. But, the magnetic fields inhibit transport of hot electrons in one hand, and on the contrary it is harder to inhibit colder electrons on the other hand. As a result, the megagauss (MG) range magnetic fields produced by the laser plasma interaction processes are capable of inhibiting significantly the lateral (toroidal) and the axial (poloidal) transports for both thermal and suprathermal electrons. Hence, the study of thermal conduction of electron heat flux is important to understand the implotion phenomena in laser fusion plasmas, because of the fact that the ablative processes are modified in a great extent in presence of such fields [Max etal., (1978)]. Mead etal., (1984) have reported that weak indication of lateral transport are found in laser produced and axial transport appears strongly inhibited due to laser generated MG magnetic fields. But, it is fact that the transport into high-density material in presence of such fields is more difficult to understand its inhibition properties related to the implotion physics of laser irradiated targets [Max (1982), Duderstadt and Mose (1982), Kruer (1988)]. However, the constraints on energy transfer in an inhomogeneous and magnetized plasma were derived easily from plasma stability within the context of quasi-particle discription. Bychenkov etal., (1995) have developed a nonlocal linear theory of electron transport in plasmas with arbitary electron collisionality. Closure relation for fluid equations are also derived from a solution to the electron Fokker-Planck equation, where electron collisions are considered in the limit of large ion charge. Moreover, electron transport coefficients, the electrical conductivity and a new transport coefficients related to ion flow have been derived [Bychenkov etal., (1995)]

In this Chapter, we have calculated here analytically the amount of heat flux emmited for one-component, one-temperature , nonrelativistic magnetized plasmas. It is observed that for $CO_2$ laser of 10.6 μm wavelength with 5nsec pulse and irradiance of $10^{15}$ W/cm$^{-2}$ with 4.5 KeV electron plasma, the lateral heat flux of electron thermal conduction increases exponentially , but the axial heat flux of electron conduction has no significant role. Hence, our study is confined to estimated the effect of magnetic fields on lateral heat flux only, and consequently we develop the plasma transport due to self-generated magnetic fields in laser irradiate targets.

## 5.2. <u>Formulation of the problem</u>

(A) <u>Basic assumptions</u> The classical transport is defined as that due to electron and ion Coulomb collisions excluding the effects of various micro-instabilities and small scale magnetic fields. Its coefficients are genearlly calculated for a sufficiently collisional plasma. It is fact that the ion motion is very small with respect to the electron motion. So, the electrons are moving in a static ion background and the plasma then be considered as a one-component plasma. The distribution function becomes a Maxwellian in a time of the order of the collision time. Hence, all the plasma quantities must not change significantly during collision time. In an underdense plasma collision time is large. So, between two collisions, we can use collisionless plasma equations. We use basic equations of Chapter-2 and the self-generated magnetic field in that process modify the transport coefficients in both axial and lateral directions.

The most important effect of thermal motion lies in transport phenomena: transport of heat, matter and momentum. Heat transport is called thermal conduction. In steady state situation, absorbed intensity is carried away by heat conduction, which in a plasma is dominated by electrons. Ablation process is regulated by it [Max etal., (1982)]. The transport coefficients of a fully ionized plasma have been computed by many authors. A method for obtaining the transport equations from the kinetic equations is given in details in the monograph by Chapman and Cowling [1960]. Magnetic fields in MG range are generated internally in the laser plasma and tend to inhibit thermal conduction in the direction perpendicular to strong magnetic field [Winsor etal., (1973)]. Here we have demonstrated the effect of lateral thermal conduction due to increase of the lateral magnetic field. The effect on axial thermal conduction due to the same will not be analysed here.

(B) <u>Basic equations</u>: Plasma and laser in this case are taken in a physical state, same as in Chapter-2. Self-generation of MG range magnetic fields in laser produced plasmas is studied separately, where vector product of displacement and velocity gives MG range magnetic fields without the application of any external field [Stamper etal., (1971), Chakraborty etal., (1988), Briand etal., (1985)]. Using this velocity in transport equations we get electron flux. Transport equations for a simple plasma comprise the equations of continuity, motion and heat balance [Braginskii (1965 )].

The electron heat flux (q) made up of two analogue parts, namely, electron heat flux ($q_u$ ) and electron thermal flux ($q_T$) and can be written as

$$q = q_u + q_T, \tag{5.2.1}$$

where, $q_u$ is due to the existence of a relative velocity along with collisional effect, and $q_T$ is due to the presence of electron thermal gradient.

But we have taken plasma of uniform temperature. So, $q_T$ be treated zero value. The effect of temperature gradient (i.e. $q_T \neq 0$) will be considered in future. Assuming, $Z = 1$, and for high magnetic field ($\Omega\nu >> 1$, where $\Omega$ is the electron gyrofrequency and $\nu$ is the electron collision frequency) the electron heat flux can be written as,

$$q_u = 0.71nTeu_{\parallel} + (3/2)(nT)/(\Omega\nu)[\mathbf{h}\times\mathbf{u}_{\perp}] \tag{5.2.2}$$

where **h** (=**B**/B) is the unit vector in direction of the magnetic field (**B**). $\parallel$ and $\perp$ refer to the direction of **B**-field. **u**, n, T are the plasma velocity, density and temperature respectively. e is the electronic charge.

Rewriting the equation (5.2.2) in component wise, we have

$$q_{u_y} = 0.7 \; \hbar T u_y + \frac{3}{2}\frac{nT}{\Omega\nu}\left(\frac{B_y}{|B|}u_z - \frac{B_z}{|B|}u_y\right) \tag{5.2.3}$$

$$q_{u_z} = 0.7 \; \hbar T u_z + \frac{3}{2}\frac{nT}{\Omega\nu}\left(\frac{B_x}{|B|}u_y - \frac{B_y}{|B|}u_x\right) \tag{5.2.4}$$

where the subscripts x, y and z represent the components of the variables along the three co-ortinate axes.

In fact, by changing the laser intensity and plasma density, we can observe the change in lateral heat flow and magnetic field. Then we can say that internally generated magnetic field affect heat flux. Lateral heat flux increases with increasing density when intensity remains constant. While keeping plasma density constant, the intensity is varied, lateral heat flux increases continuously with increasing intensity. Numerical results along with graphical representation of lateral electron heat flux with laser intensity have been discussed in the next section.

## 5.3 <u>Results and discussions</u>

To understand plasma transport, in particular, electrn heat flux of theremal conduction in laser irradiated targated, we explain the numerical results for a target with radius of 80μm interacted with a carbon-di-oxide laser of 10.6 μm wavelength, 5nsec pulse length and of laser intensity $10^{15}$ W/cm$^2$ . It is evedient from our earlier studies in Chapter-2 that the change in plasma density gives the change in self-generated magnetic fields and consequently, the lateral heat flux will be changed significantly. Moreover, it is observed that for changing intensity of incident laser beam, the lateral the magnetic fields will be changeand and subsequently the lateral heat flux will be changed importantly.

As we are here dealing with internally generated magnetic fields and their effects on lateral transport, the lateral heat flux will depend upon laser and plasma parameters, which is natural. This is reflected in numerical results. We have taken the variation of heat flux with plasma density and laser intensity. Absolute value of heat flux in lateral direction increases with density. Absolute value of lateral heat flux increase with laser intensity while magnetic field in lateral direction also increases with laser intensity. So, it is clear that internally generated magnetic field specially in this way enhances heat flow. Enhanced lateral heat flow due to magnetic fields is consistent with the work of Max etal., (1978). From the numerical results we can conclude that with increasing self-generated magnetic fields in laser produced-plasma, transport in toroidal direction increases. The variation of lateral trsnsport with plasma density and laser intensity is shown in figs.5.1(a) and 5.1(b) respectively. From fig. 5.1(a) we can conclude that lateral transport increases almost linearly with plasma density when laser intensity remains constant. Similarly, from fig. 5.1(b) we can conclude that the lateral transport increases with increasing laser intensity exponentially when plasma density remains constant. The variation of axial heat transport with the internally generated axial magnetic field can be studied in future.

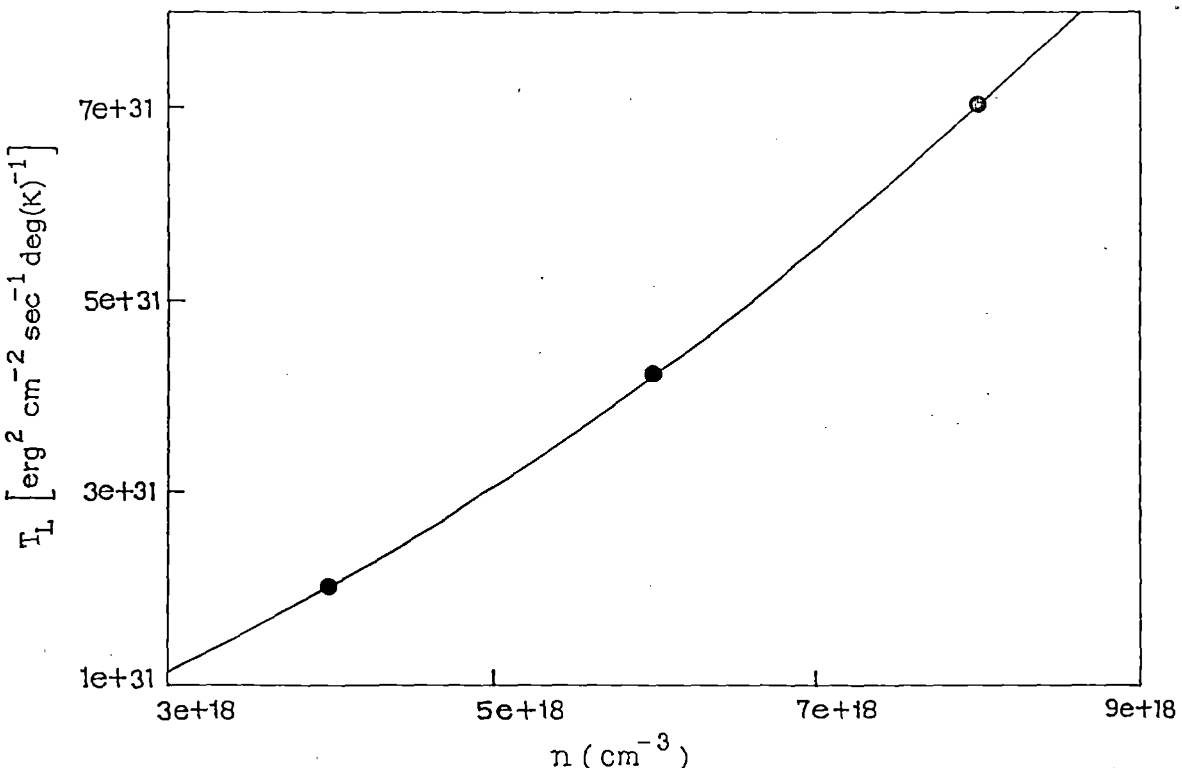


Fig.5.1: (a) The variation of lateral transport $T_L$ in $erg^2 cm^{-2} sec^{-1} deg(K)^{-1}$ with plasma density in $cm^{-3}$: at $\lambda = 10.6\,\mu m$, $I = 10^{15}\ W/cm^2$, $T_e = 4500$ ev , $\tau = 5$ nsec.

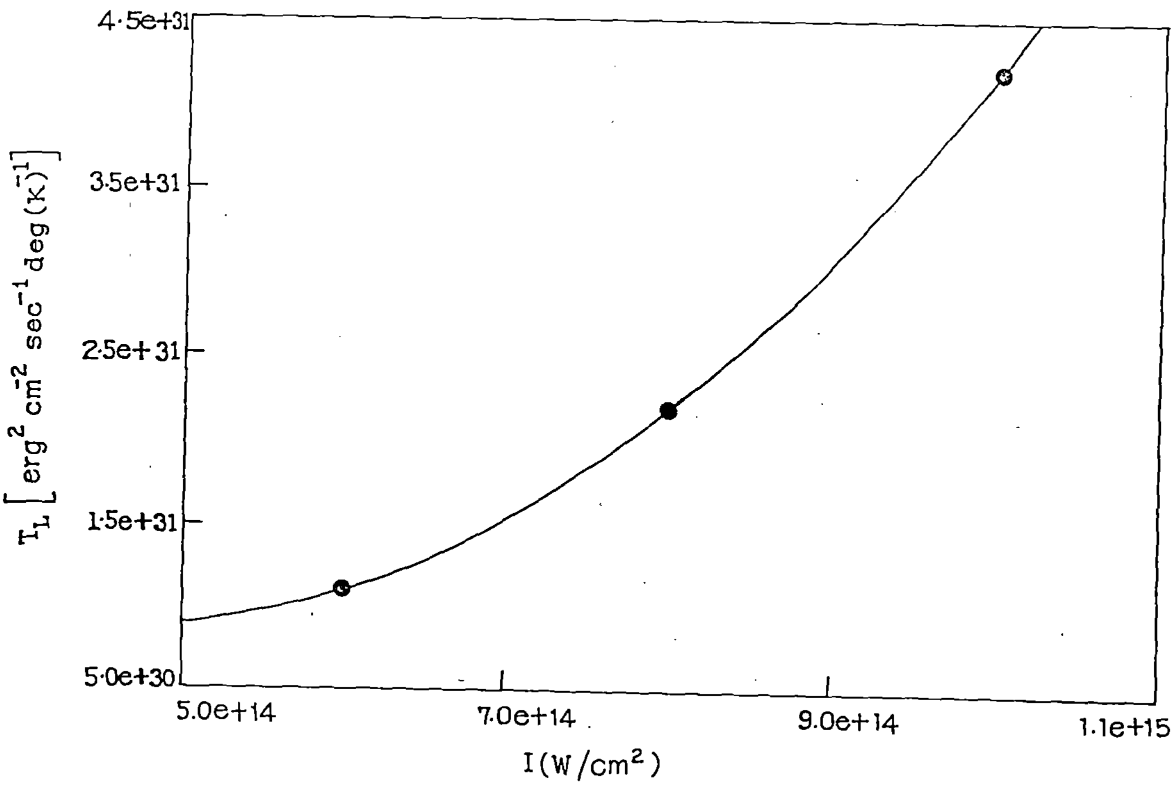


Fig. 5.1(b): The variation of lateral transport $T_L$ in $erg^2\, cm^{-2}\, sec^{-1}\, deg(k)^{-1}$ with laser intensity I in $W/cm^2$: at $\lambda = 10.6\,\mu m$, $I = 10^{15}\ W/cm^2$; $T_e = 4500$, $\tau = 5\,nsec$, $n = 0.6 \times 10^{19}$ cr