Chapter -1

An Introduction to Spontaneously Generated Magnetic Fields and Transport of Laser Light in Plasmas

1.1 Introductory remarks:

Plasma is a highly nonlinear medium. Studies on the nonlinear interactions of electromagnetic waves with plasmas first started in the microwave region [Whitmer and Barrett (1961, 1962)] and later extended in the optical frequency ranges [Bloembergen (1963, 1972), Shen (1976, 1991)]. But, with the advent of high power lasers, the subject of laser plasma interaction has rapidly expanded [Hughes (1975), Kruer (1987), Mima etal., (1994)]. Second and third order nonlinear intensity dependent optical effects, such as Inverse Faraday effects(IFE), self-action effects (namely, self-focusing, self-trapping etc.), stimulated Raman and Brillouin scattering, harmonic generation and multiphoton transition have also been detected [Bloembergen and Shen (1966), Pershan etal., (1966), Steiger and Woods (1972), Chakraborty etal., (1984), Bychencov and Tikhonchuk (1993)]. Nonlinear optical processes in plasmas are closely connected with the programmes of a laser induced fusion. Therefore, their studies become important in recent years [Motz (1979), Duderstadt and Moses (1982), Hora (1991)]. Magnetic moment field generation, also called the inverse Faraday effect (IFE) magnetization [Pomeau and Quemada (1967), Steiger and Woods (1972), Talin etal., (1975), Bhattacharyya (1994), Sheng and Meyer-ter-Vehn (1996)] and other sources of magnetization in plasmas have strong influence in experiments on inertial confinement fusion [Hughes (1975), Motz (1979), Mulser (1980), Duderstadt and Moses (1982), Hora (1991),Yamanaka (1991)]. Such fields create problems in laser focussing and energy transport mechanism in laser produced plasmas [Nuckolls (1974), Max (1978, 1982), Mead etal., (1984), Kruer (1988)]. For this reason, the study of magnetic field generation in laser produced plasmas has increased much now [Wilks(1992), Gorbunov etal., (1996), Berezhiani etal.,(1997), Mason and Tabak (1998), Bhattacharyya etal., (1998), Tikhonchuk etal., (1999)]. The mode of energy transport is also an important problem of physics of both laboratory and astrophysical plasmas [Zeldovich etal., (1983), Hora (1991), Yamanaka (1991)]. Many authors [Key etal., (1983), Strauss etal., (1984), Duston etal., (1985), Mulser (1986), Rhul (1997), Uberoi (1997), Hain (1999)] have studied this problem.

1.2 Preliminary survey for magnetic field generation: Theory and experiment

The study of laser-produced plasmas has been an active area of both theoretical and experimental research because of its relevance to inertial confinement fusion (ICF) by lasers. In the experimental studies an intense pulse of laser radiation is focussed to a small diameter of a solid target. The resulting laser-produced plasma, known as the corona, is rich in physics. For the last two and a half decade, the major effort has been taken to unravel much of this physics and some of the mechanisms of laser-plasma interactions those contribute to efficient absorption of the laser energy and its subsequent transport to the interior of the target.

The coronal plasma is observed to support the existence of large and small scale magnetic fields. These "spontaneous" or "self-generated" magnetic fields are produced by laser-plasma interaction and do not require an initial field. Their production is directly related to the character of the laser pulse and also depends on the plasma properties.

So far, the spontaneous generation of magnetic field was observed by Korobkin and Serov (1966) in the laser induced breakdown of a gas. Subsequently, Askaryan etal., (1967) reported an observation of magnetic field in the plasma produced by laser irradiation of a solid target. At the same time, Pomeau and Quemada (1967) observed first the inverse Faraday effect for a circularly polarized wave in terms of electron dipole approximation, which gives rise the magnetic fields.

The magnetic fields, qualitatively, are classified in two different ways with respect to the direction of the laser field and also to the position of the target. They are known as lateral (or toroidal) and axial (or poloidal) magnetic fields. The lateral field may be defined as a field that is perpendicular to the axis of the laser field or parallel to the target plane. Whereas, the axial field is along the axis of the laser or perpendicular to the target plane. Both lateral and axial fields are quantified in large and small scales too in order of their magnitudes. Various mechanisms have been proposed for the generation of large and small toroidal (lateral) and poloidal (axial) magnetic fields in laser produced plasmas.

Sources of large scale toroidal magnetic fields are the thermo-electric processes [Semper etal., (1971)], the radiation processes [Woo and DeGroot (1978), Mora and Pellat (1981)], the rippled surface irregularities [Yabe etal., (1983)], the nonuniformities in laser intensity and hot electron ejection from the focal spot [Raven etal., (1979), Winsor and Tidman (1973)] in one hand, whereas, on the other hand, the filamentation [Yabe etal., (1982), Greek etal., (1978)], the resonance absorption [Speziale and Catto (1978), Stamper and Tidman (1973), Bezzerides etal., (1977)], dynamo effect [Witalis (1974)] and the Weibel instability [Estabrook (1978), Ramani and Laval (1978), Matte etal., (1987)] are the sources of small scale toroidal magnetic fields. In fact, the sources of large or small scale poloidal magnetic fields are not properly understood yet. But the various mechanisms are reported by scientists for the generation of axial magnetic fields in laser plasmas. Briand etal, (1985) showed that dynamo effect produces axial magnetic fields of megagauss range. Kitagawa etal., (1986) showed that rippled surface irregularities are the sources of axial magnetic field in laser plasma interaction. The ion acoustic turbulence is another source of axial magnetic field in laser produced plasma which has been reported by Draglia (1987) and Bychenkov etal., (1984). Also, Chakraborty et al. (1984, 1990), Bera etal., (192), Khan etal., (1998) and Bhattacharyya (1994) reported that nonlinear optical response of the plasma can induce axial magnetization in plasma produced by laser irradiation of a solid target. Sudan (1993) reported that another source of large (~gigagauss range) axial magnetic field is electron current driven by spatial gradients and temporal variation of ponderomotive force. Tripathi etal., (1994) reported that a short pulse laser propagating in a plasma channel or an axially inhomogeneous plasma produces a nonuniform transverse quasistatic magnetic field via, ponderomotive mechanism. The magnetic field lasts for the duration of laser pulse. Stamper (1991) reviewed various applications of such magnetic fields in laser-fusion plasmas and also pointed out that these fields can be measured very accurately by means of Faraday rotation of a probe laser beam or by using the Zeeman profile diagnostics.

So far, the first and oldest experimental observation of magnetic field generation in laser produced plasma was made by Korobkin and Serov (1966) by using probe method where probe was placed near the target. Stamper etal., (1971) used a variety of targets in different background pressures to measure magnetic fields of the order of kilogauss of a laser produced plasma. Also, using Faraday rotation measurement, the toroidal megagauss magnetic field arising from $\nabla T \times \nabla n$ mechanism was measured by Stamper and Ripin (1975). By using the light of a probing beam and specularly reflected laser light, megagauss range magnetic fields were derived. Such megagauss fields were also observed by Stamper etal., (1978) near the focus of a high power laser pulse by using Faraday rotation technique. An axial magnetic field in megagauss range was detected by Briand etal., (1985), from measurement of the angle of Faraday rotation, in a laser produced plasma, by analyzing the polarization of the backscattered radiation. The rotation was estimated from the relation $\Delta\alpha \sim BL$, where α is in degrees, B is in megagauss, and L is the characteristic gradient scale length in microns. The experiment shows that the backscattered light undergoes a Faraday rotation of 3°, which corresponds to the presence of 0.6 megagauss axial magnetic field. Nowadays, numerical experiments are studied for the generation of magnetic fields [Boyd etal., (1982), Wilks etal., (1992), Ruhl (1997)].

In fact, from the available literature it appears that the generation of either toroidal or poloidal magnetic fields have been reported separately with supporting mechanisms. But, both the fields are generated simultaneously and spontaneously in laser produced plasmas. One of the motivations of our thesis is to develop a mathematical model for the simultaneous generation of toroidal and poloidal magnetic fields by the interaction of an intense laser light with plasmas.

1.3 Self -action effects in plasmas

The field intensity dependent self-action effects, due to interaction of powerful electromagnetic waves with plasmas, have become important in recent years, owing to their involvement in laboratory and space plasma [Ginzburg (1970), Davidson (1972), Hughes (1975), Parker (1979), Zeldovich (1983), Yamanaka (1991)]. Very powerful laser fields and other such sources help to promote the study of nonlinear responses of medium to wave fields [Kruer (1988), Chakraborty (1997)]. The refractive index has an intensity dependent nonlinear shift [Winkles and Eldridge (1972), Goldstein and Salu (1973), Arons and Max (1974), Forslund etal., (1975), Bhattacharyya and Chakraborty (1979), Chakraborty etal., (1984, 1988)]. The wave phase (self-phase modulation) and amplitude (self-focusing, self trapping etc.) have intensity dependent changes [Kaw and Dawson (1970), Svelto (1974), Max (1973, 1976)] and an intensity induced rotation of the polarization ellipse (self-precession for an elliptically polarized wave) is found to occur [Arons and Max (1974), Max etal., (1974), Shen (1976), Decoster (1978), Chakraborty etal., (1984, 1988)]. The wave induced bending of direction of motion of the plasma constituents then led to the inverse Faraday effect (IFE) and hence the magnetic moment field, which was reported first probably by Pomeau and Quemada (1967). Subsequently, IFE was observed in plasmas by many authors [Steiger and Woods (1972, Abdullaev and Frolov (1981), Bera etal., (1992), Das etal., (1993)]. Other nonlinear optical effects are harmonic generation and parametric processes [Bobin etal., (1973), Nishikawa and Liu (1976), Chakraborty (1977, 1997), Grebogi etal., (1983), Rose etal., (1987)]. The Stimulated Raman Scattering (SRS) and Stimulated Brillouin Scattering (SBS) are also significant self action effects those occur in laser produced plasmas and in other materials that allow dispersion and absorption of waves [Liu etal., (1974), Moffat (1978), Rose etal., (1987), Kruer (1988), Hora (1991)]. Which one of the simultaneously occurring self-action effects will be dominant that depends on the experimental conditions, including the power of the laser beam [Kaw and Dawson (1970), Max (1976)]. Below a threshold power limit, the self-focusing and self-trapping mechanisms are insignificant [Max (1973), Svelto (1974), Shen (1991), Hora (1991), Chakraborty (1997)] and the intrinsic nonlinear instabilities, due to SRS and SBS, when driven by a strong laser beam, can be minimized [Shen (1976), Max (1976), Kruer (1988)]. The threshold power, for initiating self-focussing, is larger for picosecond pulses than for shorter pulses. For isotropic and homogeneous media, the magnetic moment field is dominant in the coronal region of the plasma. But, for inhomogeneous plasmas, the field generation, due to ponderomotive force, is a dominant processes [Srivastava etal., (1992), Sudan (1993), Triphati and Liu (1994)]. The IFE is effective both in cold and hot plasmas. Whereas, the field generation due to ponderomotive force is effective only in hot plasmas having temperature gradient.

1.4 Sources of magnetic field generation

Mechanisms of generation of magnetic field, due to dynamical processes in plasmas have been identified. Some of these depend on a seed field [Parker (1979), Zeldovich etal., (1983)] and some do not depend on the seed field [Moffat (1978), Stamper (1991)]. Hence, there are two sources for magnetic field generation namely, primary source and secondary sources. Primary sources do not require any seed field for their evolution viz., thermoelectric magnetic field [Stamper (1971)], magnetic moment field [Chakraborty etal., (1990), Bhattacharyya and Sarkar (1990), Bera etal., (1992)] etc. Secondary sources require the seed field for their evolution viz., dynamo effect [Zeldovich etal., (1983)]. We cannot categorically say which of the mechanisms of magnetic field generation would be dominant in a problem, and whether all the listed mechanisms are independent of each other. It is natural to expect that whether a field generation mechanism will be dominant or not would depend on the parameters specifying the plasma, and the applied fields. Moreover, depending upon the local and global scale length, one can say whether the source is local or global. By local scale length we want to mean the variation of any parameter over a very small region compared with the whole volume of the plasma. On the other hand, global scale length signifies variation of the concerned parameter over the whole volume of the plasma.

The primary fields of the thermo-electric effect [Stamper etal., (1971)], the radiation effect [Mora and Pellat (1981), Woo and DeGroot (1978)], the effect of rippled surface irregularities [Yabe etal., (1983)], the filamentation effect [Yabe etal., (1982), Greek etal., (1978)], the resonance absorption effect [Bezzerides etal., (1977)], the effect of hot electron ejection from the focal spot [Raven etal., (1979)] and the ponderomotive force effect [Triphati and Liu (1994), Sudan (1993)] are considered important in laser produced plasma. The primary moment field is also important for the laser and space plasmas [Steiger and Woods (1972), Abdullaev and Frolov (1981)]. The dynamo effect [Briand etal., (1985)], the ion-acoustic turbulence [Dragila (1987), Bychenkov etal., (1993)], the diffusion effects are powerful secondary mechanisms of generation of magnetization in plasmas. The presence of strong seed field, nonlinear optical response in plasmas may be important [Bhattacharyya and Sarkar (1990)]. Ohmic dissipation causes diffusion of magnetic energy that is always present in a plasma system. Most of these generation mechanisms are the sources of the order of megagauss range magnetic field and have been verified experimentally [Briand etal., (1985), Stamper (1971), Stamper and Ripin (1975), Yabe etal., (1983)]. The structure of such magnetic fields has also been discussed [Boyd etal., (1982), Yoshida (1993)].

1.5 Mechanisms of magnetic field generation in laser plasma interaction

When a very high power laser light hits directly the solid target, some of its material will ablate from it instantaneously. As a result, there will be an expanding plasma cloud in front of the target. The expanding plasma due to the interaction of target and laser pulse was discussed in many text book viz., Hughes (1975), Motz (1979), Kruer (1988) etc. It is fact that the laser will propagate upto a certain distance, beyond which it will not be able to penetrate [Ginzburg (1970), Duderstadt and Moses (1982), Chen (1984)]. This is evident even in a simplest form of dispersion relation.

$$k^2 c^2 = \omega^2 - \omega_p^2 \qquad (1.5.1)$$

where ω and ω_p are laser and plasma frequencies respectively, k is the propagation vector, c is the velocity of light in a vacuum, $\omega_p = \sqrt{\frac{4\pi n e^2}{m}}$, where m is the mass of an electronic charge e, n is the expanding plasma density. Since ω_p increases as the plasma density increases, i.e., as the solid density is approached maximum upto a particular point $\omega^2 = \omega^2_p$ which follows that the propagation vector **k** vanishes, i.e., $\mathbf{k} = 0$; the wave does not propagate beyond this cut off region, which is know as the critical density surface, the density at that point is well known as critical density and is denoted by n_c.

When a laser light interacts with a solid target, it produces plasma expanding away from the target (viz., fig 1.1) having density gradient ∇n along the axial direction. The temperature is maximum where the laser light hits the target and develop temperature gradient ∇T along lateral directions. In such expanding plasma, magnetic fields of the order of megagauss have been observed in many cases. The important field generation mechanisms will now be discussed briefly.

(A): <u>($\nabla T \times \nabla n$)</u> <u>mechanism or thermo-electric effect</u>

When a laser beam is made to propagate into a solid target it produces the expanding plasma having density gradient ∇n along the axial direction, i.e., the direction parallel to the axis of the laser beam. The temperature is maximum where the laser beam hits the target and the temperature decreases along lateral directions, i.e., the direction perpendicular to the axis of the laser beam, causing the development of ∇T along the transverse direction. In such an expanding plasma, lateral magnetic fields of the order of megagauss range may be generated spontaneously, A brief discussion for magnetic field generation by $\nabla T \times \nabla n$ mechanism (i.e., by thermo-electric effect) [Stamper etal., (1971), Stamper and Ripin (1978)] is stated below.

Neglecting the electron inertia, the momentum balance equation becomes

$$en\mathbf{E} = -\nabla p \qquad (1.5.2)$$

where e, n, **E** and p represent charge, density, electric field and plasma pressure respectively.

The electric field of (1.5.2) arising from charge separation is due to a very high radiation pressure.

Using the equation of state $p = nk_B T$, the relation (1.5.2) becomes

$$\mathbf{E} = -(\frac{1}{en})\nabla(nk_B T)$$

where k_B is the Boltzmann constant.

Then the Maxwell equation $\nabla\times\mathbf{E} = -\frac{1}{c}(\frac{\partial \mathbf{B}}{\partial t})$ can be rewritten as

$$\frac{\partial \mathbf{B}}{\partial t} = -c[\nabla\times(-\frac{1}{en}\nabla\{nk_B T\})] = \frac{ck_B}{e}\nabla(\frac{1}{n})\times\nabla(nT) = \frac{ck_B}{en}\nabla T\times\nabla n \qquad (1.5.3)$$

It is evident that the magnetic field is produced due to the existence of the density and temperature gradients perpendicular to each other in laser produced plasma.

(B) Dynamo mechanism

Dynamo effect generates magnetic fields. In underdense and moving plasmas, a turbulent dynamo effect is possibly a source of magnetic field [Briand etal., (1985)]. The small scale fluctuating magnetic field, generated due to any primary effect (like $\nabla T\times\nabla n$ mechanism), may lead to large scale magnetic field [Moffat (1978), Kruer (1988)]. In electrodynamics, the dynamo action converts mechanical energy into electrical energy. For magnetic field generation, the dynamo action should be such that it converts mechanical energy into magnetic energy [Dragila (1987), Bychenkov etal., (1993)].

(C) Magnetic moment field

When the electromagnetic field passes through plasma it perturbs the charge particle trajectory. The disturbance is not symmetric in all directions. Due to this asymmetric disturbance there will be some gain in angular momentum which gives rise to a magnetic moment field of ordered circular motion of charges, in the presence of strong, circularly polarized electromagnetic waves, which was initially called the Inverse Faraday effect (IFE) [Pomeau and Quemada (1967), Steiger and Woods (1972)], because it is essentially the inverse of the Faraday rotation effect. Suggested names for the moment field [Jackson

(1972), Chakraborty (1997), Alexander etal., (1984)] are :(i) magnetic moment field, (ii) **r** cross **j** field or displacement cross current ($\mathbf{r}\times\mathbf{j}$) field, (iii) magnetic moment scattering field, (iv) inverse Faraday effect field. This moment field, however, evolves, more generally, for different types of wave induced bending of direction of motion of the plasma constituents. It vanishes when the wave induced material displacement is parallel to the wave induced current. Only the equations for motion of elements of all the plasma constituents, induced by a strong applied field, are required. The magnetic moment density is proportional to the vector product of the wave induced displacement and velocity. The zero harmonic part only of this density is important like the zero harmonic part of the d.c. power of an a.c. field.

(D) Field from ponderomotive force

Ponderomotive force, due to a spatially inhomogeneous laser beam, is an important mechanism for generation of an axial magnetic field. Gradov and Stenflo (1983) showed that a laser beam with a Gaussian profile can generate large toroidal magnetic fields even when the density and temperature are constant. It has been reported that the magnetic field in the range of megagauss could be generated by the ponderomotive action of a plasma [Srivastava etal., (1992), Sudan (1993), Triphati and Liu (1994)].

(E) Effect of anisotropic electron pressure

The effect of anisotropic electron pressure plays an important role for creating large scale magnetic fields in laser produced plasmas even when the electron density and the temperature gradients are parallel [Duderstadt and Moses (1982)]. A brief discussion for magnetic field generation by the anisotropic electron pressure in laser produced plasmas is stated below. Neglecting electron inertia, we consider the momentum balance relation as

$$\mathbf{E} = -\frac{1}{en}\nabla p \qquad (1.5.4)$$

The growth of magnetic field is then be written from Maxwell's equation as.

$$\frac{\partial \mathbf{B}}{\partial t} = -\frac{c}{e}[\nabla\times(\frac{1}{n}\nabla p)] \qquad (1.5.5)$$

Thus, even if ∇n is parallel to ∇T, a toroidal nature of **B** field can be produced when pressure tensor is not diagonal.

1.6 <u>Theory of Magnetic Moment field (Phenomenological)</u> [Jackson (1970), Alexander etal., (1984)]

The magnetic moment per unit volume $\boldsymbol{\mu}$ is defined as the product of the volume current I and the surface area vector $\Sigma\hat{\mathbf{n}}$ of the current loop

$$\boldsymbol{\mu} = \frac{1}{2c} I \Sigma \hat{\mathbf{n}} \qquad (1.6.1)$$

where $\hat{\mathbf{n}}$ is the outward unit normal to surface Σ and follows the right-hand screw rule. Evaluation of this magnetic moment does not depend on the analytical formalism, involving the conception of charged particles of classical electrodynamics and their motion. A particle of charge e, rotating in a magnetic field, is equivalent to a current.

$$I = \frac{e\Omega}{2\pi} \qquad (1.6.2)$$

where Ω is the gyration frequency. The orbit represents a loop of area Σ ($= \pi r^2$, where r is the radius of the loop). Then from equation (1.6.1) the magnetic moment per unit volume may be written as

$$\boldsymbol{\mu} = \frac{e r^2 \Omega}{2c} \hat{\mathbf{n}} \qquad (1.6.3)$$

The general formula for a magnetic moment per unit volume at a point may be obtained by summing over all the species of charges in the unit volume there.

1.7 <u>Basic theory of magnetic moment generation related to inverse Faraday effect</u>

The inverse Faraday effect (IFE) and its relation with Faraday rotation effect was probably pointed out by Pershan (1963) in a crystalline medium due to propagation of circularly polarized waves. Vanderziel etal., (1965) observed the same effect experimentally in diamagnetic glass and also in several organic and inorganic compounds. The quantum mechanical origin of IFE in Crystals was also studied [Pershan etal., (1966)]. So far, in plasma the IFE was first reported by Pomeau and Quemada (1967) for a circularly polarized wave in terms of nonrelativistic electron dipole approximation. Steiger and Woods (1972) calculated the IFE in plasma and applied the results to the laser plasma interaction. Talin etal., (1975) explained the IFE as a consequence of the wave induced plasma polarization, and evaluated the effects of thermal motion on it. The relativistic motion of charges and also inhomogeneity of plasmas has some impact on IFE [Abdullaev and Frolov (1981)]. Perhaps, the effect of ion motion in the IFE was first demonstrated by Chain (1981). For strong electromagnetic radiation, the same effect in wave induced plasma motion including the interaction of standing wave with cold plasma was evaluated by many authors [Chakraborty etal.,(1984, 1990), Stamper (1991), Bera etal., (1992), Das etal., (1993), Bychenkov etal., (1993), Bhattacharyya (1994), Sheng and Meyer-ter-Vehn (1996, 1997), Berezhiani etal., (1997), Haines (1997), Mason and Tabak (1998), Bhattacharyya and Sanyal (1999)].

Considering the plasma as a system of N charged particles having mass m_i, charge q_i and position vector r_i with respect to a given origin (the subscript i represents the i-th species of particle and I varies from 1 to N) the angular momentum and the magnetic moment expressions are

$$\mathbf{L} = \sum \mathbf{L}_i = \sum m_i (\mathbf{r}_i \times \dot{\mathbf{r}}_i) \tag{1.7.1}$$

$$\boldsymbol{\mu} = \sum \frac{1}{2c} q_i (\mathbf{r}_i \times \dot{\mathbf{r}}_i) = \sum \frac{q_i}{2cm_i} \mathbf{L} \tag{1.7.2}$$

where the dot represents derivative with respect to time t. If $\mathbf{j}_i$ is the surface density of current of the i-th particle, then we have

$$\boldsymbol{\mu} = \sum \frac{1}{2c} (\mathbf{r}_i \times \mathbf{j}_i) \tag{1.7.3}$$

The field induced displacement **r** and charge current **j** are expressible as sum of the all the wave harmonics, including the zero harmonic and other mixed harmonics as well. Then, in addition to a double harmonic, a zero harmonic obtains from the vector product $\mathbf{r}\times\mathbf{j}$ in wave plasma interactions. This zero harmonic moment is important when it has a sizeable magnitude, and particularly when it grows exponentially in time.

We have studied the magnetic field generation due to IFE which is to be studied by using classical theory. The breakdown of classical theory is possible for strong magnetic fields. From classical point of view, the electron spirals about a magnetic field line. When the field strength is increased, the size of the orbit becomes smaller. If the field is so high that the orbit radius becomes of the order of magnitude of the de-Broglie wave length of electrons, the classical theory has to be replaced by quantum theory. In this thesis, we have not considered the case of so strong magnetic field.

When the applied field is circularly polarized, the collective effects of the magnetic moments lead to the IFE field, which is the inverse of the Faraday rotation effects (rotation of plane of polarization of plane polarized light by magnetic field). A plane polarized light is a combination of two circularly polarized lights, one right circularly polarized (RCP) and other left circularly polarized (LCP). The magnetic field gives rise to asymmetry in the propagation of these two circularly polarized components, when they reunite after passing through the magnetic field, to become plane polarized again, the plane of polarization is rotated.

When a wave field passes through plasma it disturbs the charge particle trajectory. This disturbance is not symmetric in all directions. For the asymmetry, there will be some gain in angular momentum, which gives rise to a magnetic moment. Collective effect of the magnetic field arising from the inverse Faraday effect is important, because the nonoscillating part of this field is periodic and hence is necessary to study the magnetic moment density further. This rotational effect due to magnetic field causes asymmetry to the propagation. On the other hand, in IFE, the asymmetry in the perturbation of charge particle trajectories, due to electromagnetic and other wave fields, gives rise to the induced magnetic field. This moment field can be studied both from phenomenological and analytical point of view. The magnetic moment of a single particle of charge q is defined as

$$\boldsymbol{\mu} = \frac{1}{2c}(\mathbf{r}\times\mathbf{j}) \qquad (1.7.4)$$

Where **r** is its displacement from a fixed origin and **j** (= q $\dot{\mathbf{r}}$) is its current. This moment is directly proportional to the angular momentum **L** (= **r** x **p**, if **p** is the linear momentum). Specifically,

$$\mu = \frac{e}{2mc}\mathbf{L} \qquad (1.7.5)$$

For a plasma having several species of charge under the simultaneous influence of several force fields, the equation (1.7.1) is generalized as

$$\mu = \frac{4\pi}{2c}\sum((\mathbf{r}_\beta^\alpha)\times(\mathbf{j}_\beta^\alpha)) \qquad (1.7.6)$$

α denotes the αth force field, β denotes the βth species of charge, $\mathbf{r}_\beta^\alpha$ is the displacement induced by the αth force field on the βth species of charge; $\mathbf{j}_\beta^\alpha$ is the surface density of current induced by the αth force field on the βth species of charge. This field is identical to the field specified by Biot Savart's law which states that a current through a closed loop produces an axial magnetic field.

Since electrons and ions move in opposite directions, the magnetic moment field due to electrons is in a direction opposite to that due to ions. So, one field is parallel to a laser beam and other is antiparallel.

Charges are displaced from their original trajectories by waves. The bending of the particle trajectories by fields from the direction at time t to that at time t + δt, there will be an infinitesimal contribution to **r** x **j**, where the wave induced displacement of a charge particle from its original trajectory is **r**, and the corresponding surface density of current is **j**. So, in a unit volume, at the point **r**, the sum of contributions to **r** x **j** from all the charges yields the magnetic moment of the IFE magnetization. For high frequency laser fields ionic motion may be ignored [Chakraborty etal (1992), Bhattacharyya and Sanyal (1999)]. But for low frequency, both electron and ion motion are important [Chakraborty etal., (1990), Bera etal., (1992)]. The analytical definition for μ is useful in calculating the nonoscillating part of the magnetic moment per unit volume, due to the wave induced motion of the plasma constituents, in case of plasma interaction, and wave-wave interaction in plasma.

1.8 Importance of magnetic field studies in laser plasmas

The major motivation for studying these self-generated magnetic fields stems from the fact that they could in turn affect the laser-plasma interactions and hence the physics of inertial confinement fusion (ICF) in a variety of ways. Many experiments [Stamper etal., (1971), Raven etal., (1979), Briand etal., (1985)] and several numerical simulations [Nuckolls (1973), Boyd etal., (1982), Wilks etal., (1992)] of laser-produced plasmas consider a single beam of laser focussed onto a planar target. For a reasonably uniform illumination, the tangential gradients are minimized and the complications due to magnetic fields are expected to be reduced. However, early target designs requiring high laser irradiance were found to be rather sensitive to nonuniformities in the laser irradiation in the underdense region ($n < 10^{12} cm^{-3}$) where laser energy is absorbed. At higher laser intensities ($\geq 10^{15}$ W/cm^2), the direct effects of laser radiation become significant and the production of magnetic fields depends on the laser polarization, as in the case of resonance absorption and on the local direction of the field momentum (Poynting flux). Besides uniform laser intensity over the pellet surface, a radial direction for energy flux is required to estimate the quantity of the magnetic field. Small initial perturbation in the density or temperature may lead to the growth of magnetic fields by means of field generating instabilities [Max (1982), Duderstadt and Moses (1982)].

The performance of an ICF target can be affected by the magnetic fields in a number of ways. Fields generated in the underdense region because of nonuniform laser irradiation may inhibit the thermal transport and consequently reduce the implosion symmetry and ablation pressure. Also the large magnetic fields generated in the ablation region due to the composition discontinuities and shocks [Tidman (1975)] contribute to a decrease of ablation pressure and a consequent degradation of the pellet performances [Brueckner and Jorna (1974), Duderstadt and Moses (1982)].

The magnetic fields may have some beneficial effects also viz., resonance absorption can be enhanced in the magnetized plasma [Thompson etal., (1975), Bezzerides etal., (1977), Woo etal., (1978), Kolodner and Yabldnovitch (1979)]. The magnetic fields produced in the underdense region may be convected toward the ablation region and amplified [Nishiguchi etal., (1984)]. These fields could inhibit hot electrons preheat of the fuel. The fields if large enough could even suppress the growth of Rayleigh-Taylor instability. Finally, the magnetic fields, amplified in the fuel by plasma compression, may lead to increase in the fusion yield [Jhon and Mead (1986)].

Incidentally, the inertial confinement fusion effort has evolved to the point that many laboratories all over the world are now conducting vigorous research programs using a variety of driver and target design [Motz (1979), Mulser (1980), Stamper (1991), Yamanaka (1991), Key (1991), Hora (1991), Ruhl (1997)]. Most of the early implosion experiments used exploding pusher targets based on simple glass microballoons filled with D-T gas at high pressure. These targets have the advantage that they can yield relatively large number of neutrons with moderate scale drivers [Mima etal., (1994)]. Earlier, Chase etal., (1973) have pointed out that these fields increase the sensitivity of neutron production and electron temperature, if the anomalous correction $C_A = 1 + \frac{kI}{I_T}$ is included, where C_A is the instability correction, k is an adjustable parameter, I is the local intensity of the laser light I_T is the threshold intensity above which the instability occurs. Although thermonuclear ignition could be obtained with a sufficiently large exploding pusher target, the energy required to drive such a target is beyond the capabilities of any projected driver.

Moreover, the high fuel compressions and the high implosion velocities can be achieved through high laser intensities in fusion experiments and have a significant role in laser fusion applications. A significant fraction of the incident light energy is converted into high energy of electrons. These fast energetic electrons degrade target performance by preheating the fuel core and make more complicated to understand the pellet implosion process [Max (1982), Kruer (1988), Mima etal., (1994)].

Lateral energy transport in laser-produced plasmas was studied by irradiating planer polystyrene foils with 0.53 μm wavelength, spatially nonuniform laser beams by Vick etal., (1995). In this experiment, the spatially resolved x-ray emission patterns and spectra were recorded to infer the temperatures, ionization states and time integrated hydrodynamic histories of plasma originating from tracer layers embedded in the targets. The conditions of the experiment was also simulated using a two-dimensional single-fluid hydrodynamic code. These experimental results agree with code-predictions which suggest that a moderate amount of ablation occurs in the nonirradiated region of the target. The constraints on energy transfer in inhomogeneous magnetized plasmas and on plasma stability within the context of quasi particle description has been derived. Bychenkov etal. (1995) studied a nonlocal linear theory of electron transport in plasmas with arbitrary electron collisionality. Closure relations for fluid equations are derived from a solution to the electron Fokker-Planck equation where electron collisions are considered in the limit of large ion-charge. They found out the nonlocal expression for electron transport coefficients; the electric conductivity and new transport coefficients related to the ion flow. Pomraning (1995) reported the development of a flux-limiting algorithm for radiative transfer in a Markovian mixture consisting of two immiscible materials. The flux-limited diffusion description developed here is applicable to general three-dimensional geometry. It is contrast to the earlier effort where algebraic difficulties prohibited explicit results except in a one-dimensional setting. Odagawa etal., (1993) experimentally investigated the separate confinement hetero-structure (SCH) layer thickness and the SCH band-gap wavelength dependence of the effective carrier recombination coefficient of strained InGaAs multiple quantum wall lasers. The dependence is explained by the carrier transport between the SCH layers and the walls. Craxton etal., (1977) showed that spontaneously generated magnetic fields can substantially reduce thermal conductivity in pellet atmospheres and give rise to localized hot spots, which may lead to the ablation of anomalously fast ions. It is reported [Max etal., (1978), Max (1982)] that electron crossfield transport is affected by laser generated megagauss magnetic fields. Mead etal., [1964] reported that weak indications of lateral transport are found in laser produced plasma and axial transport appears strongly inhibited. It is shown [Spitzer and Harm (1953)] that electron heat flux relates linearly to the electron temperature gradient. Experimental results in the context of laser-plasma interaction show that this leads to an overestimation of the actual heat flow. It has been shown [Brueckner and Jorna (1976)] that the absorbed laser energy appears as thermal energy of the absorbing layer, as kinetic energy of expanding plasma and as thermal and kinetic energy of the overdense plasma into which energy is transferred primarily by electron conduction. The penetration of energy into the overdense plasma is accompanied by a hydrodynamic refraction wave following the thermal conduction wave. Consequently, the energy deposited by the laser is markedly depleted by the loss of energy to outward motion and expansion of plasma heated by the conduction wave and removed by the hydrodynamic refraction wave. The interaction of driver, target design and reactor design is so complex that it is impossible to say whether or not an economical ICF reactor can be designed, even if driver-target physics problems are solved. Despite this uncertainty, there is still a strong support for continued research and development of the ICF concept for energy applications. Axial and lateral magnetic fields generated spontaneously in laser-plasma interaction have great impact on driver energy deposition in the target, energy transport in dense plasmas and finally implosion, compression and thermonuclear burn in the process of ICF [Hughes (1975), Motz (1979), Mulser (1980), Yamanaka (1991), Duderstadt and Moses (1982)].

We have proposed the mechanism of simultaneous generation of poloidal and toroidal magnetic fields first for electron and then for electron-ion nondissipative plasmas. This mechanism originates from the transformation of kinetic energies of ordered motion of charged particles, in the presence of the wave, into the energy of the induced magnetic fields both in poloidal and in toroidal directions. Such toroidal and poloidal fields are d.c. over the fast laser time scale (i.e., $\frac{2\pi}{\omega}$). But for measuring such fields in a laboratory the field should be d.c. for longer time scales viz. laser pulse length (5ns, say) or hydrodynamics time scale ($\frac{L}{v_{thi}}$, where L is the characteristic length and v_{thi} is ion acoustic velocity). Even for such longer time scale our result in this chapter-2 do not show any qualitative change with the results of Chapter-3, because of the fact that the effects of ion motion and moderate laser intensity have been taken into account for the field generation studies. However, it may be pointed out that the assumptions for one-temperature two-component nondissipative plasmas would be important for an entirely underdense plasma but then the relevance to ICF is problematic. However, these assumptions may have some relevance with future ICF target studies where a very long density scale length is important [Mead etal., (1984)].

Most of the magnetic fields generated in the laser produced plasmas are toroidal in nature. However, axial or poloidal magnetic fields may also be generated by certain mechanisms. The poloidal fields are of much importance in unconventional laser fusion approaches that rely on thermal insulation by magnetic fields [Daido etal., (1986), Hasegawa etal., (1986, 1988)]. The poloidal magnetic field could be beneficial in creating a spheromak like magnetic field, which could lead to better thermal insulation in ICF schemes [Daido etal., (1986), Hasegawa etal., (1986, 1988)]. Moreover, the combination of toroidal and poloidal fields set up by the laser may lead to the formation of a magnetic cage [Eliezer etal., (1992)] and that could be used for plasma confinement in a manner similar to tokamaks, toroidal pinches etc. [Bhattacharyya and Sanyal (1999)]. Such a configuration may serve well for magnetic confinement fusion (MCF) scheme.

With the advent of ultra-short pulse lasers, the wake-field generation in an underdense plasma is of current interest because of the fact that such fields play an important role in plasma accelerators [Dubinov etal., (1994), Gorbunov etal., (1996), Esarey etal., (1994, 1997)]. The occurrence of such strong magnetic fields can affect the plasma behavior through hydro magnetic effects or from alterations of plasma transport coefficients in laser fusion scheme.

1.9 Contents of the present thesis

From the literature available, it appears that different mechanisms for the generation of axial (poloidal) and lateral (toroidal) magnetic fields have been studied separately. However, no such mechanism has so far been reported which can describe a simultaneous generation of poloidal (axial) and toroidal (lateral) fields in laser produced plasmas. Perhaps this is the first thesis which shows the existence of their simultaneous generation and describes their occurrence in a systematic manner for different physical model in subsequent two chapters i.e., Chapter-2 and Chapter-3.

In Chapter-2, we present a model for the simultaneous generation of axial and lateral magnetic fields in laser produced plasmas. These fields are generated by the interaction of an intense laser beam with a one-component plasma consisting of electrons only. The plasma is assumed to be hot and collisionless. The thermal velocity is assumed to be small compared with the phase velocity of the incident radiation field. Debye length is taken to be small compared with the density scale length of the plasma. The intensity of the radiation fields should not exceed the threshold limit of power so that the phenomenon of self-focussing, self-trapping, self-phase modulation do not appear. The instabilities due to stimulated Raman scattering (SRS) and stimulated Brillouin scattering (SBS) are ignored. The width of the conversion layer is assumed to be much less than the laser wavelength and so inhomogeneity due to Landau damping can be neglected.

The interaction of a laser beam with a plasma is described by the macroscopic behavior of an electron plasma, within the fluid model. For this purpose, the equations of continuity and momentum, along with the Maxwell equations are considered. Only a Kerr-type nonlinearity [Newell and Moloney (1992), Aliev etal., (1992)] is to be studied here and so, a simple perturbation technique [Bellman (1964), Ames (1965)] has been used here. Assuming the form of the electric field of first order, first order magnetic field, electron velocity and density, are found out. Then using the expressions for the first order electric and magnetic fields and other variables, the expressions of second order variables are found out. Then by using the expressions of the first and the second order variables the expressions for the secular free third order [Chiao and Godine (1969)] variables are found out. From these variables, average angular momentum over a time period $2\pi/\omega$ is obtained. The average component of the angular momentum along the direction of laser is shown to give rise to the axial (poloidal) magnetic field. The resultant of components of angular momentum in the two directions perpendicular to the laser beam produces the lateral (toroidal) magnetic field, which is in the plane perpendicular to the laser beam.

Numerical results show that the axial and lateral magnetic fields increase very slowly towards the critical density. It has also been observed that the maximum value of the lateral field is well below the critical density surface, whereas the axial magnetic field has the maximum value at the critical density surface. Physically our mechanism implies that the kinetic energy of the ordered motion of electrons is transformed into the energy of the induced magnetic field in the presence of an electromagnetic wave. The field generation mechanism in our case is therefore a direct process because average nonlinear angular momentum of electrons has been calculated to obtain the magnetic fields. In contrast we obtain a mechanism like Inverse Faraday Effect (IFE) [Steigerand Woods(1972),Talin etal., (1975)] which is an indirect process of field generation. At high frequencies, the IFE is relevant over time scales shorter than twice the oscillation period of the driving wave. Beyond this time scale, the wave becomes unstable [Stenflo (1977)] and the IFE is not effective for producing magnetic field. However our mechanism of field generation is effective even beyond the time scale where IFE is not effective.

Our mechanism is also different from dynamo effect [zeldovich etal., (1983), Draglia (1987)]. In dynamo effect, the magnetic fields are produced in a cyclic manner, i.e., axial fields are produced for some time with the help of the lateral fields and vice versa, or in other words, it requires seed field for producing magnetic fields. But in our mechanism, both axial and lateral magnetic fields are produced simultaneously. This does not require any seed field.

Also as the temperature gradient is ignored in our formulation, and so, it is different from magnetic field generation due to thermoelectric effect [Stamper etal., (1971)]. Resonant absorption gives rise to a magnetic field in a plasma which was shown by Bezzerides etal., (1977) and many other authors. We exclude this effect as our interest is in calculating magnetic fields in underdense plasma region.

The mode conversion (i.e., electromagnetic mode to electrostatic mode) is possible even in the underdense region for thermal plasma [Kull (1981, 1983)]. We consider in this thesis a very small amount of energy of laser light converted into electrostatic field energy. It may be pointed out by Kull (1981) that a full conversion of laser light is possible in an underdense plasma region through relativistic thermal effects. Such energy conversion is directly related to the width of the conversion layer. We must emphasize here that the mode conversion process established by Kull (1981, 1983) is crucial for our mechanism of simultaneous generation of poloidal and toroidal magnetic fields. Electrons move in the self-generated magnetic field and are trapped in a layer of thickness of the order of electron Larmor radius. Thus lateral field enhances lateral energy transport, but degrades axial energy propagation, which was shown by Max (1982). Then obviously axial field enhances axial energy transport from a critical surface to an ablation surface. Our results show that the lateral magnetic field dominates over the axial magnetic field in laser plasma interactions. Both the fields may have a considerable impact on uniform compression of ICF targets, which needs extensive studies for better understanding of ICF processes.

In Chapter-3, we extend the formulation presented in chapter 2 by considering the ion contribution along with the electron contribution for the spontaneous generation of magnetic fields both in axial and lateral directions simultaneously. We assume here a hot, nondissipative, two-component homogeneous plasma. Our results show that toroidal (lateral) magnetic fields dominate over the poloidal (axial) magnetic field in the interaction of Nd-glass laser with this two-component plasma. The poloidal magnetic field induced by the electron current is just in opposite direction of the poloidal magnetic field induced by the ion current and they nearly cancel each other. Hence, the resultant poloidal magnetic field is very low in magnitude. The induced toroidal magnetic field due to electron current is opposite to that due to ion current. But toroidal field for electrons are much stronger in magnitude than that for ions. These toroidal magnetic fields play an important role in energy transport. They enhance lateral energy transport, but inhibit axial energy transport, which degrades implosion [Mead etal., (1984), Shkarofsky (1980), Max etal., (1978)]. On the other hand poloidal magnetic field enhances axial energy transport and hence are useful for implosion of ICF targets.

In one-temperature and two-component plasma, the thermal velocities for electrons and ions are given due importance. For making the problem simpler, the electron temperature is taken to be equal to the ion temperature. Moreover, the temperature is taken to be uniform. Gradient of pressure exists in the field equations [Kull (1983)] . Collisional frequency is assumed to be much less than the laser frequency (i.e., plasma is nondissipative). The width of the resonance layer is small compared with the laser wavelength and so, the phenomena occurring at the resonance layer may be neglected. Thermal velocity is small compared with the phase velocity of the radiation field and Debye length is small compared with the density scale length of the plasma. Plasma is assumed to be homogeneous. Very long density scale length and uniform temperature suggest that the laser beam energy be absorbed almost completely in an underdense region of plasma. The intensities of the incident waves lie below the threshold value for the generation of inhomogeneities which give rise to self-action effects. The intrinsic nonlinear instabilities due to SRS and SBS are being neglected. All these basic assumptions were also used in Chapter-2.

To describe the interaction of laser with plasma, we consider the macroscopic behavior of two-component plasma, based on fluid-theory. Equations of continuity and momentum are considered for electrons and ions along with Maxwell's equation. Equation of state for electrons and ions is also assumed. The perturbation technique of Chapter-2 is also employed in Chapter-3 to find the linear and nonlinear solutions of different orders. Once again in Chapter-3 a similar form of linear electric field is taken to evaluate first and second order variables. It is found that first and second order solutions contain first and second harmonics respectively. This means that the second order wave field does not generate a magnetic field. Then third order variables are found out using which the electronic and the ionic nonlinear magnetic moments are calculated. This nonlinear magnetic moment gives the nonlinear angular momentum and hence, we have in turn induced nonlinear magnetization. The component of magnetization in the direction of a laser beam gives rise the poloidal magnetic field whereas the resultant of two other different components perpendicular to the laser beam generates the lateral magnetic field for a two-component laser produced plasmas.

The kinetic energy of ordered motion of charged particles (i.e., electrons and ions) in the presence of an electromagnetic wave is transformed into the energy of the induced magnetic field both in axial and lateral directions. Such fields are unidirectional over the fast laser time scale. But for longer time scale viz. laser pulse length magnetic field value does not vary much. Varying different parameters of laser and plasma in our study, we have noticed the variation of poloidal and toroidal magnetic fields. Poloidal field reaches a maximum value near the critical density, but toroidal field is maximum at a point far below the critical density and decreases in magnitude while advancing towards critical density. The poloidal magnetic field shows no change with varying laser pulse length, but the toroidal magnetic field decreases with an increase in laser pulse length. With the increase in laser intensity, poloidal and toroidal fields both increase in the same manner. Poloidal magnetic field increases with an increase in laser wavelength and toroidal magnetic field increases very slowly with increasing a laser wavelength.

When toroidal fields were experimentally observed, it was known that they enhance lateral energy transport. Electrons and ions get trapped in different layers of different radii which are in order of electron and ion Larmor radii respectively. Ion's Larmor radius is greater than the electron's Larmor radius. Poloidal fields can trap both electrons and ions along the axis of the laser beam. So the rate of energy deposition due to poloidal magnetic field in conduction regions should be increased which enhances energy transport from a critical surface to an ablation surface. As already mentioned it is speculated that the poloidal field combined with the toroidal field provide better insolation and hence a better magnetic confinement in realizing magnetic confinement fusion (MCF) process. In conclusion of these, there must have many scopes in future for taking into account other contributions in the spontaneous generation of poloidal and toroidal magnetic fields for MCF and ICF studies.

In Chapter-4, we consider another interesting problem arising spontaneously with as an effect of interaction of an intense laser beam with a plasma. This has been named by us as the spontaneous nonlinear Faraday rotation (SNFR). The highly nonlinear optical behavior of plasma medium was known early in the development of nonlinear optics. Various nonlinear optical effects in plasmas, such as harmonic generation, parametric amplification and stimulated Raman scattering were predicted. It is noticed that nonlinear birefringence occurs in the interaction of a laser beam of large intensity with plasma. We modify here the Faraday rotation effect in a laser produced plasma in a way which is completely different from the earlier work. Faraday rotation (FR) is a magneto-optical effect of birefringence. The theory of Faraday rotation has been developed for a plane polarized wave of very weak field intensity and is used in infinitely small amplitude wave approximation for the linear solution of the field equations in different media including plasma [Decoster (1978), Steiger and woods (1972)]. The magnitude of Faraday rotation is modified considerably for strong laser radiation. This modification is due to appearance of nonlinearly induced effect of intense laser fields in plasma. This effect dominates when electron motion is in the relativistic limit.

Faraday rotation may induce magnetization in plasma which is known as inverse Faraday effect (IFE). It is produced by circularly polarized wave. For left circular polarization, the charged particles gyrate parallel to the direction of propagation and for right circular polarization, the charged particles gyrate antiparallel to the direction of propagation of wave. A theory is developed which will be helpful in the study of the evolution of SNFR angles by induced birefringence and the effect of IFE, which is the evolution of induced magnetic field in the plasma.

We have studied the magnitude of SNFR (spontaneous nonlinear Faraday rotation) in a plasma due to induced birefringence of electromagnetic waves. For this, the waves are assumed to be sinusoidal. The plasma is assumed to be cold and homogeneous consisting of two components-electrons and ions. The incident laser is so intense that the motion of electrons and ions becomes relativistic. First harmonic density fluctuation is not considered. But the second order density fluctuation exists and its effect on SBS and SRS are visible in third order. So, these instabilities are neglected. The self-action effects arising from ponderomotive force and thermal instabilities are neglected as pressure variation and thermal velocities are ignored.

Our formulation is based on the equations of fluid motion and Maxwell's equations. We start with a linearized wave form for electric field. For a magnetized plasma, the wave is treated as a superposition of left and right circularly polarized waves. The first order dispersion relations for two circularly polarized waves are amplitude independent. Nonlinear dispersion relations are found out from third order secular free field solutions. From these relations it appears that mutual exchange of energy occurs between two circularly polarized waves in the presence of magnetic field, and between two plane polarized waves of different amplitudes and phase difference $\pi/2$ leading to an elliptically polarized wave in the absence of magnetic field.

If the refractive indices are nonlinear, FR angle will be the sum of linear and nonlinear FR angles. The magnetic field should be the combination of the ambient magnetic field, if any, and the induced magnetic field which is spontaneous and a consequence of IFE.

We have performed a systematic study starting from linear dispersion relation to nonlinear dispersion relation. It has been shown that even in the absence of an initial magnetic field, Faraday rotation exists in a high frequency nonlinear plasma. Nonlinearly induced birefringence corresponds to a nonlinear Faraday rotation angle, which enables one to estimate the order of induced magnetization (IFE) for the propagation of polarized waves in an unmagnetized plasma. An initially applied magnetic field may enhance such magnetization. This work has already been reported by us [Bhattacharyya etal., (1998)].

In Chapter-5, we discuss the thermal conduction in laser produced plasmas and also show how transport phenomenon is affected due to the production of magnetic fields in laser produced plasma, particularly the effect of magnetic field on lateral heat flux. The corona consists of hot plasma which has been evaporated from the initially solid target during laser heating. It is in the corona that the laser light is absorbed by the target and the resulting thermal energy is conducted towards cold high density regions, where ablation occurs. Physical conditions prevailing in laser-produced plasmas are useful because the temperature, density and velocity profiles of the background plasma play a crucial role in determining which mechanisms of absorption and heat transport will prevail in a given experimental situation.

In a steady state situation, the absorbed intensity must be carried away by heat conduction, which in a plasma is dominated by electrons. In laser-heated initially solid targets, the inward flow of thermal energy towards cold, high-density region produces a compensating outward flow of plasma kinetic energy toward lower-density regions. Because the coronal electron temperature (T_e) is typically a few KeV or larger, thermal conduction in the underdense plasma tends to maintain a nearly uniform electron temperature distribution in space. Thus typical electron temperature scale lengths $L_T \equiv T_e/|\nabla T_e|$ are very long for $n_e < n_c$ where n_e and n_c are the electron plasma density and critical density respectively. The ion temperature in the corona is generally much lower than the electron temperature. Moreover, ions cool due to expansion but have no heat source in the corona. Ion thermal conduction is small and electron-ion coupling is usually negligible. Thus ion temperature and pressure are usually small relative to those of electrons and gradients in ion temperature have little physical impact.

By conservation of momentum the cold remainder of the target gets a bigger inward push due to the rocket-effect. Conversely, inhibited heat flux leads to slower outward expansion of blow-off. The inner parts of the target then implode less vigorously. Theoretical calculation for electron heat flux in laser-produced one-component dissipative plasmas are given here along with some numerical estimation for CO_2 laser with plasmas.

It is evident from our earlier discussions that the production of magnetic fields in laser produced plasmas is inevitable. Large scale d.c. magnetic fields have been observed in laser produced plasmas in Chapter-2 and Chapter-3. The mechanisms responsible for producing such fields are described in those chapters. In Chapter-4, the application of such fields are discussed in terms of SNFR (spontaneous nonlinear Faraday rotation). In Chapter-5, we will confine ourselves to study what kind of transport be important in presence of self-generated magnetic fields in laser produced plasmas. We have shown that such magnetic fields have some effect on lateral thermal conduction.