Chapter 1

Introduction

1.1 An Introduction to Planetary Nebulae

Planetary Nebulae (singular PN, plural PNe) represent a phase which most of the stars in our galaxy pass through. PNe have been known to the human beings for more than 200 years since the time William Herschell identified them in 1785 as observationally distinguished class of objects. These objects were so named by Herschell due to their greenish disk-like appearance when looked through small telescopes. The first scientific investigation on the nature of this fascinating class of objects was done by Herschell himself by his discovery of NGC 1514 in 1791 (as quoted in Hoskin, 1963). PNe have since occupied a special place and continue to do so in the present era of modern astronomy. PNe have attracted the interest of amateur astronomers because of their colourful, symmetrical (?) appearance and of physicists and astrophysicists due to the information that they provide as to the atomic transitions, hydrodynamics, ionization physics, stellar evolution, galactic chemistry etc. The PN phase occurs for a very short duration (~ $10^4$ years) compared to the main sequence (core H-burning) lifetime (~ $10^{10} - 10^9$ years) of a low/intermediate mass star of mass between $0.8 M_\odot$ to $8 M_\odot$ when it evolves in its late giant phase. The physical mechanisms that give rise to a PN are not yet well understood in the star's journey from the main sequence to the final white dwarf stage. It is believed that the study of PN shells, in general, should throw light on the progenitor evolution.
### 1.1.1 Post Mainsequence Stellar evolution

Evolution beyond the mainsequence stage occurs for a star once its central core hydrogen is completely burned (Renzini & Voli 1981; Iben & Renzini 1983; Iben 1985; Iben 1995) and the nuclear energy generation ceases in the central core. Hydrogen is now ignited in a thin shell surrounding the core and the products of hydrogen burning are added to the core thereby increasing its mass. For stars which are less massive than 2.3\(M_\odot\), the core does not attain the temperature sufficient to ignite helium soon after the hydrogen burning ceases in the core. However, being in the partially degenerate state, it needs to contract first to reach the required central temperature and the helium burning occurs in a thermal runaway process called the **core helium flash**. Stars of initial mass in the range 0.8\(M_\odot\) to 2.3\(M_\odot\) follow this track of evolution. These stars are classified as the **low mass stars**. The contraction of the core is accompanied by a dramatic expansion of the atmosphere which happens until the core helium flash starts. This phase of a star from the end of hydrogen burning to the helium flash is called the **Red Giant Branch** (RGB). If the star is more massive than 2.3 \(M_\odot\), then the core helium burning occurs in non-degenerate condition soon after the exhaustion of the core hydrogen (shortly after reaching the RGB phase). Stars having initial masses in the range 2.3\(M_\odot\) to 8\(M_\odot\) follow this evolutionary track and are called **intermediate mass stars**.

Once helium is completely burned in the core, both low and intermediate mass stars develop C/O cores which are partially degenerate where the temperature is insufficient to ignite carbon. At this stage the core contracts due to the absence of energy production and the envelope expands further. This phase of stellar evolution is called the **Asymptotic Giant Branch** (AGB). During the Early AGB (E-AGB) phase, a star has an inert C/O core, surrounded by a thin shell of helium now burning quiescently and an extended hydrogen rich envelope. This phase lasts for a period of about \(10^7\) years for a star of mass \(\sim 2.3M_\odot\). The helium exhausted core grows in mass until its outer edge nearly reaches the hydrogen-rich envelope. Hydrogen is subsequently re-ignited and the E-AGB evolution is then
followed by a thermally pulsating AGB (TP-AGB) phase wherein helium and hydrogen burn alternately in two thin shells surrounding the core. The TP-AGB phase lasts for a few \( \times 10^6 \) years. The helium shell is thermally unstable and any small increase in temperature will result in a thermo-nuclear runaway called \textit{helium shell flash} which in turn triggers a thermal pulse. The envelope expands and consequently, shell hydrogen burning is extinguished. Once the runaway reactions end, the helium shell burns quiescently and hydrogen is re-ignited adding mass to the helium shell. When the mass of the helium shell crosses a critical value, another thermal pulse will occur and this process continues till the end of the AGB phase. During this thermal pulsation phase, the convection in the atmosphere extends up to the shell and the freshly processed elements in the shell are brought up and mixed with the atmosphere (dredge-up process). More theoretical investigations of the TP-AGB phase were discussed by Boothroyd & Sackmann (1988a-d); Vassiliadis & Wood (1993); Groenewegan & de Jonk (1993; 1994a,b); and Mariago, Bressan & Choisi (1996). The AGB evolution could, in principle, continue until the partially degenerate core burns carbon when the density is sufficiently high \((10^{9.5}\text{cm}^{-3}; \text{Paczynski 1970})\) at the center. However, the mass loss that occurs during the AGB phase upsets the evolution of the core beyond the C/O stage for stars of mass below 8\(M_\odot\). The evolutionary tracks of low and intermediate mass stars are shown in the HR diagram (Fig. 1), where the thick lines represent the locations of the major core nuclear burning phases.

All stars on or close to AGB phase are intrinsic variables. This variability has a dynamical time scale of 100 to a few 100 days with a light amplitude change of at least 2.5 mag in the visual (Pottasch 1984, p.242) and is generally caused by the large scale motion of the stellar envelope. This variable behaviour is called the stellar pulsation. Such pulsations cannot influence the nuclear burning regions of the star, yet they affect most of the volume of its extended stellar envelope. The pulsations cause the expansion of the envelope and hence increase the stellar luminosity which in turn leads to enhanced mass-loss during the RGB and AGB stages.
Figure 1.1: HR diagram indicating the evolutionary path of intermediate mass stars (reproduced from Iben Jr. 1984)
1.1.2 Mass-loss from giant stars

A star suffers substantial mass-loss when it reaches the RGB phase and once more during the AGB phase. Low and intermediate mass stars having masses in the range of $\sim 0.8$ to $\sim 8M_\odot$ finally end their lives as white dwarfs having masses in a narrow range of $0.55$ to $0.85M_\odot$ (Zhang & Kwok 1993) indicating that enormous mass is lost to the interstellar medium during the post mainsequence stage. Two important processes which are happening in a star during the AGB evolution are the thermal pulses and the mass-loss. The mass-loss process is a two-step mechanism (Jura 1986; Bowen 1988; Anandarao, Pottasch & Vaidya 1993) which involves the levitation of the stellar atmosphere by the shocks driven by the envelope pulsation (Jones et al. 1991; Jura 1986; Sedlemyer 1990; Schonberner & Blocker 1992) followed by the action of pressure due to the large radiation field from the star which impinges on the dust causing a momentum transfer (Krishnaswamy & Stecher 1969; Salpeter 1974a,b; Kwok 1975; Tielens 1983). The dust particles then transfer their momentum in turn to the gas particles of the envelope by collisions and drive the mass-loss. The mass-loss rate increases rapidly to a value of $\sim 10^{-4}M_\odot/yr$ (Baud & Habing 1986) and the velocity of $\sim 20$ km/s (Sivagnanam et al. 1989) in the TPAGB phase (superwind, Iben & Renzini 1983) from the radiation driven Reimers mass-loss rate (Reimers 1975) value of $\sim 10^{-6}M_\odot/year$ (Renzini 1981) and the velocity of $\sim 10$ km/s (Pottasch 1984) in the AGB phase (slowwind). The superwind was first introduced as a hypothesis by Renzini (1981), in order to explain the observed nebular mass ejected during the AGB life time of $\sim 10^6$ yrs. However, observational evidences were found later for mass-loss rates as high as $3 \times 10^{-4}M_\odot/yr$ in some late type stars (Knapp & Morris 1985). Theoretical models on the dynamical evolution of AGB stars (pulsations driven in the fundamental mode) were developed by Schonberner (1979, 1981, 1983) and Boothroyd & Sackmann (1988a-d); however, they do not take into account the superwind effect. More accurate models have been developed by Bowen & Wilson (1991) and Vassiliadis & Wood (1993) which confirm that the superwind phase is inevitable for low
and intermediate mass stars during their thermally pulsating stage. They find an exponential growth in the mass-loss rates before the superwind phase. Bowen & Wilson showed that this effect occurs for all possible combinations of the parameters that they have tested and the existence of dust promotes the mass loss but is not essential. They explain the superwind phase as the result of the rapid increase in density with the scale height in the wind region (where the mass is driven out). The high mass-loss rate decreases the mass of the envelope significantly and hence increases the scale height. This in turn increases the density in the wind region and leads to a more rapid mass-loss. The quiescent luminosity of the star is the highest immediately prior to the helium shell flash and the superwind ejection occurs preferentially during this phase (Vassiliadis & Wood 1993).

The superwind phase stops when the envelope mass drops below a critical value (remnant envelope of mass $\sim 10^{-4} M_\odot$; Renzini 1989). Once the bare C/O stellar core is exposed after this mass-loss, the core shrinks by its own gravity resulting in the increase in its surface temperature. At this stage the fast stellar wind of $M \sim 10^{-8} M_\odot/yr$ emerges from the core with a terminal speed of $\sim 2000$ km/s (Perinotto 1993 and the reference therein). The statistical study of the occurrence of fast wind can be seen in Patriarch & Perinetto (1991). Fast wind is driven by the stellar radiation pressure which is acting on the ionic particles of the thin remnant envelope situated around the core (Paulrach et al. 1988).

1.1.3 Planetary Nebulae Formation

As discussed in the previous sections, Planetary Nebulae are formed from episodic mass ejections during the late stages of the low and intermediate mass stars, which form the majority of the stellar populations in the galaxy. The study of the physical structure and chemical enrichment of PNe is essential for understanding the evolution of this class of stars from the RGB phase to the white dwarf stage. Mass-loss plays a key role in determining the properties of AGB populations, distribution of white dwarf masses, the maximum mass of the white dwarf progenitor (and
hence the minimum mass required for the supernova event), composition of the interstellar medium and the chemical evolution of the galaxy. PNe are expected to retain signatures of mass-loss and hence play a crucial role in understanding the underlying physical mechanisms.

PNe are the shells formed by the interaction of the fast wind from the central star with the previously emitted progenitor wind (Interacting Stellar Wind models, first proposed by Kwok et al. 1978). However, Kwok et al.'s model is Two Wind model which does not include the superwind. Further, the interaction between fast and progenitor wind was treated in the momentum conserving case. However, estimates by Kwok (1983) show that the interaction of winds should occur in the energy conserving case (where the radiation loss in the interacting region is negligible) in order to understand the dynamical evolution of PNe. The analytical model of Kwok et al. was extended by Kahn (1985) and Kahn & Breitschwerdt (1990). Numerical models on this problem were proposed by Volk & Kwok (1985), Bobrosky & Zipoy (1989), Schmidt-Voigt, Koppen (1987a,b) and Marten & Schonberner (1991).

The most recent models overcome the above mentioned discrepancies in Kwok et al.'s model. The progenitor wind was considered as having two parts, namely, the slowwind and the superwind. Frank (1994) defines the PNe gas dynamics problem by the interaction of three winds of different initial velocities and densities where, the fast wind interacts with the superwind (conserving energy) and the superwind is surrounded by the slowwind. The energy conserving interaction creates a bubble of hot shocked gas (of kinetic temperature $T_e \sim 10^8$ K) which fills the central cavity of PNe (Marten & Schonberner 1991 and references therein). This hot bubble (which is unobservable in optical and UV regions) expands into the superwind, driving a forward shock into it and compressing it. The region of hot gas is assumed to be separated from the PN shell by a contact discontinuity, across which neither matter nor heat passes as described by Courant & Fredricks
(1948). The schematic picture of IWM is given in Fig. 2. The compressed progenitor wind is then ionized by the hard UV photons from the central star. More detailed physical treatments, which include the photo-ionization processes decided by the central star evolution intercoupled with the nebular gas dynamics, have been able to largely reproduce the observed nebular features to the microscopic level (Frank 1992; Frank 1994; Frank & Mellema 1994). Frank (1994) developed a model that evolves with time through four different phases with distinct observational characteristics. The character of each phase is determined by the evolution and the interaction of discontinuities of the gas dynamics (shocks and rarefaction fronts) with radiation (ionization fronts). Two nebulae which are having the same physical conditions during their formation phase may be observed differently if they are at different evolutionary phases. This minimizes the diversity observed among the PNe. Nebular shells are, in general, thick in size because the pressure of the ionized nebular material is comparable and hence competes with the thermal pressure given by the hot bubble as well as with the ram pressure of the fossil AGB wind.

When PNe are ejected, the nebular density and hence the emissivity decrease by the shell expansion (typically with a velocity of \( \sim 25 \text{km/s} \)). For a PN to be observable, the dispersion timescale for the nebular gas should be longer than the timescale for the central star to become hot enough by its own contraction to emit significant hard UV flux. The latter is a very sensitive function of the mass of the core (Iben & Renzini 1983). A PN core of mass \( 0.6 M_\odot \) takes 9000 years to emit hard UV flux where as a core of mass \( 0.644 M_\odot \) takes only 3000 yrs (Schonberner 1983). The schematic representation of the structure of a classical PN is shown in Fig. 3.
A: Shocked stellar wind region, B: Ionized PN shell
C: The neutral Shell, D: Remnant red giant wind region

Figure 1.2: Schematic representation of the Interacting Stellar Wind Model
Figure 1.3: PN components and their hydrodynamic interpretation (Fig. reproduced from Balick 1993)
1.1.4 Nebular Ionization

The principal source for the emission from PN gas is the photoionization process due to the ultraviolet radiation from the central star. Hydrogen, forming the overwhelming concentration of the nebula, is ionized by the Lyman continuum radiation of wavelengths $\leq 912$ Å (energy of the photon $\geq 13.6$ eV). If a photon is more energetic than 13.6 eV then the rest of the energy after ionizing a hydrogen atom will be supplied as the kinetic (thermal) energy to the electron. A balance between the nebular photoionization and the recombination of ions with electrons establishes the photoionization equilibrium in a PN (Osterbrock 1989). If the density distribution is isotropic in the nebula, then the radius of the sphere within which the nebula is completely ionized (Stromgren sphere; Stromgren 1939) can be derived as (Spitzer 1978)

$$R_s = \left(\frac{3}{4\pi}\right) \times \left(\frac{S}{n_e^2 \beta_2}\right)^{1/3}$$

where, $S = J \times 4\pi r^2$, $J$ is the total number of ionizing photons per unit area per sec at a distance $r$ and $\beta_2$ is the total recombination coefficient of hydrogen at level 2. The radius $R_s$ is called the Stromgren radius. The thickness of the transition region from Stromgren sphere to the neutral zone is approximately one mean free path of the ionizing photon (since it is due to resonance absorption) which is

$$d \sim 1/(N_H a)$$

where $a$ is the ionization cross section for hydrogen and $N_H$ is its density. For typical nebular conditions, the value of $d$ is $\sim 0.01$ pc which is much less than the size of the Stromgren sphere ($\sim 0.2$ pc). Hence the transition zone can be treated as an ionization discontinuity. This ionization discontinuity (Ionization front) moves into the surrounding neutral region, ionizing and heating it.

Though there exist inelastic collisions between the electrons and the ions (for example, recombination), these processes are very less frequent in the typical nebular conditions ($\sim 10^7$ times smaller) compared to the elastic collisions. This establishes a Maxwellian distribution of velocities, the nebula being in kinetic
equilibrium. Therefore, a unique temperature can be defined for both electrons and ions. The ionized nebular region gives rise to a spectrum of emission lines and shines as a PN (Schmidt-Voigt & Koppen 1987). The typical mass of the ionized PN is between $\sim 0.1 \, M_\odot$ to $1M_\odot$ indicating the presence of a large amount of neutral matter surrounding the nebula which represents the extensive mass-loss during the AGB phase. This indicates that the nebular shell may not always be expanding into the vacuum-like interstellar medium.

1.1.5 Radiations from PNe

Radiations from PNe come in the form of line emissions and continuum emission. However, line emissions play the role of the main cooling agent for the nebula. A large fraction of nebular radiations, especially in the optical window, are in the form of line emissions. These emission lines are the main source for the study of nebular parameters viz. electron density and temperature, elemental abundances, and the kinematics. Continuum emission is also present in the entire electromagnetic spectrum. Though in optical wavelengths it is very weak, in far-infrared region it is significant and is dominated by the emission from the heated dust grains. Continuum emission in optical and radio regions can also be used in finding the nebular temperature and density (Osterbrock 1989).

The emission lines are classified into recombination lines and collisionally excited lines. Recombination lines are formed by the capture of an electron by an ion into one of the excited states followed by a transition from the upper level to a lower level. These lines are mostly formed from hydrogen and helium ions. Collisionally excited lines originate from the heavier ions like oxygen, nitrogen, sulfur etc. The ground level configuration of such ions (for example $^1S_0$, $^1D_2$, $^3P$) have energy levels separated by a small difference which is of the order of the electron thermal energy. Hence the thermal electrons in the nebula populate these levels by collisions and the electronic transition from the excited levels give radiation in optical and near UV as well as in near and far infrared regions. However, these lines
mostly occur in the visible spectrum. Collisionally excited lines may appear either in the electric dipole induced permitted transition or in the electric quadrupole or magnetic dipole induced forbidden transition. Most of the visible spectrum of PNe consists of collisional lines, especially the forbidden lines. These forbidden lines are observed from PNe since the collisional de-excitation does not suppress the radiation transition because of the low nebular density. Another speciality of the forbidden lines is that they are optically thin, where the emitted radiation escapes the nebula with negligible absorption and hence they play a main role in understanding the nebular kinematics. Since the forbidden lines are formed from heavier ions, the thermal width of the emission lines is smaller than the recombination lines like $\text{H}_\alpha$ and hence the kinematics can be probed with better velocity resolution. Different forbidden lines arise from different zones of the PN due to ionization stratification and hence they are useful in studying different zones of different depths. As an example, the doubly ionized oxygen (ionization potential of 35.12 ev) occurs in the inner nebula whereas the singly ionized nitrogen (ionization potential of 14.5 ev) is present in relatively outer nebular region. The energy level diagram of one of the most important as well as the most intense forbidden lines of PN originating from the doubly ionized oxygen is shown in Fig. 4.

1.2 Morphological classification of PNe

Most of the observed PNe show axi-symmetric morphologies with many structural components (knots, filaments, ansae etc) embedded inside. Statistical survey shows that among the observed PNe in our galaxy, only $\sim 10\%$ are round in shape. The shapes and the structural components of PNe provide paleontological clues about the origin and the evolution of the gas expelled from their progenitors. Balick et al. (1987) suggested (see also Balick 1989, 1993) that the concepts underlying the interacting wind model, if generalized to two dimensions, might explain the morphologies of nearly all the PNe. Balick (1987) gives a two parameter qualitative analysis to classify the PNe morphologies. One is the degree of departure from
Figure 1.4: Energy level diagram of [OIII] for three lowest levels. (Transition probability co-efficients are given in the brackets)
roundness, from round to elliptical to bipolar (bilibal, butterfly). The second parameter is related to the overall physical size which indicates the age of the nebular evolution (assuming the nebular distance is known accurately) through the interacting wind models. PNe are designated into early, middle and late types using the second parameter and most of the observed PNe can be accommodated in this classification. PNe generally exist in elliptical morphology (~ 80%; Soker 1997), and only ~ 11% PNe show bipolar morphology (Corradi & Schwarz 1995). Fig. 5 shows a schematic representation of observed PNe morphologies as classified by Schwarz et al. (1992).

Kahn & West (1985) hypothesised that the mass loss from PNe progenitor is not isotropic and more mass is preferentially expelled in the equatorial regions than in the polar regions. The degree of departure from roundness is initiated by such an axi-symmetric mass ejection, which leads to the latitudinal variation of the density of the progenitor wind from polar to equatorial regions and is called the density contrast. For a spherical nebula there is no density contrast, while a mild density contrast leads to an elliptical PN and the bipolar PN requires a large density contrast. By assuming a density contrast in the progenitor wind, different morphologies of PNe can be explained by the IWM (Kahn & West 1988; Soker & Livio 1989). Further, Balick, Preston & Icke (1987) conjectured that the focusing of the fast wind by the progenitor wind towards the polar regions causes the formation and the acceleration of ansae observed in PNe. However, Soker & Livio (1989) show that such an effect is not efficient for the production of ansae. The interacting stellar wind models do not explain the density contrast or occurrence of the structural components (internal structures); they just assume the density contrast (Soker 1997). Although most of the observed PNe come under the morphological classification of Balick, a little fraction of PNe does exist in morphologies other than Balick’s classification. A new morphological class of PNe, the Quadrupolar PNe (QPNe) having two pronounced pairs of lobes was discovered by Manchado, Stanghellini & Guerrero (1996). Therefore, the nature of the progenitors which are
Figure 1.5: Observed Morphological types of PNe (as classified by Schwarz et al. 1992)
responsible for the formation of different morphologies PNe as well as their internal structures should be well established.

Furthermore, it is possible that PNe which are old and/or have a large space velocity could significantly interact with the interstellar medium (ISM). The intrinsic morphology of PNe (decided by the nebular formation process) can be altered by such an interaction during their later stages of evolution. Hence, it is essential to consider the manifestations of the PNe in relation to their interaction with ISM while studying their morphologies. A case study of such an interaction forms the subject matter of chapter 4.

1.3 Single and binary star hypotheses for PNe morphologies

1.3.1 Single star hypothesis

Rotation of a single star can, in principle, give rise to an axi-symmetric mass ejection (Friend & Abbot 1986). The mass driven out by the expansion of the stellar atmosphere is enhanced to a larger radius in the equatorial regions than in the polar regions. Can such a density contrast produce a bipolar PN (BPN)? Observationally, BPN are found to have the hottest central stars, their distribution is concentrated towards the galactic plane and they are chemically enriched in comparison to the other morphological classes. These observed facts combinedly suggest that the progenitors of BPN are massive stars (Greig 1972; Acker 1980; Kaler 1983; Corradi & Schwarz 1995). Following this, the massive single star progenitor concept has been taken to explain the BPN morphology. The argument is that the massive progenitors can determine the final morphology of the descendant PN due to their rotation, and hence no binary companion is required to produce bipolar morphology (Pottasch 1995). The mass ejection in the superwind phase is more aspherical and extremely flattened for progenitor of large intermediate mass (Corradi & Schwarz 1995). Apart from stellar rotation, the magnetic fields (Pascoli et al. 1992), non-radial stellar pulsations (Soker & Harpaz 1992) and even the existence
of fossil protostellar disks around the fast evolving massive progenitors (Balick & Preston 1987) were also proposed to explain the asymmetric mass ejection from the single star progenitor. However, these models were found to be inadequate because of the modest rotation velocity of the progenitor during the giant phase and extremely small magnetic fields in AGB stars as shown by Soker & Harpaz (1992). Additional spinning-up of the envelope is essential in order to allow the above models to act efficiently (Livio 1995; Soker 1997). There is no observational evidence to support the possibility of the presence of fossil protostellar disks.

However, the required density contrast for elliptical PNes can be obtained by taking stellar rotation or magnetic fields into account though they are small. The occurrence of ansae, significantly in elliptical PNes, has been observed (Soker 1996). Eventhough Balick, Preston & Icke (1987) suggested that the ansae can be produced by the focusing of the fast wind by the progenitor wind, the hydrodynamical study of Soker & Livio (1989) showed that such an effect is not efficient in the production and the acceleration of ansae. Further, the ansae are believed to be formed in the transition from AGB to PN phase (Soker 1990; Soker & Livio 1994). Several BPNe and even some proto-PNes show bipolar, rotating, episodic jets (BRETS, Lopez et al. 1997; Phillips & Cuesta 1996; Trammell & Goodrich 1996). The occurrence of point symmetric PNes (Corradi & Schwarz 1993; Cliffe et al. 1995) and the PNes with pairs of bipolar lobes (QPNe; Manchado, Stanghellini & Guerrero 1996; Guerrero & Manchado 1998) were also reported increasing the complexity in the PNe morphologies. Point symmetric PNe and QPNe require the precession of the axis of symmetry of their progenitor. However, there are no convincing models for the precessing jets present in the single star progenitor models (Soker 1998).

The central stars of BPNe are massive and they evolve faster than the low mass cores. Mellema (1997) suggested that such slowly evolving central star allows the ionization front to smooth out the density contrast whereas the massive central star does not permit this and hence they have BPNe around them. However, Soker (1998) argues that a flat distribution of the masses of the central stars contradicts
the proposed scenario of Mellema. Hence, the single star hypothesis is inadequate to explain many of the observed facts of PNe; though, the chemical enrichment of BPNe and their concentration towards the galactic plane can easily be understood by their massive single star progenitors.

1.3.2 Binary star hypothesis

In comparison to the single star hypothesis, the interacting binary progenitor hypothesis presents the most natural environment for the production of strong axi-symmetric mass-loss as well as for the formation of structural components. Most of the key observations on PNe can be understood if it is assumed that the progenitor was a binary. Soker (1997) argues that a PN can be formed in an interacting binary system if (i) the existence of the secondary had influenced the primary's evolution on its mass-loss geometry or (ii) the envelope had been spun-up by the secondary by transferring the angular momentum through tidal effects. Spinning up by the tidal mechanism will lead to an oblate envelope which eventually would cause an enhanced axi-symmetric mass-loss. The companion required for such a spinning up can either be a stellar or a sub-stellar component like a brown dwarf or a massive planet like Jupiter (Soker 1997). The presence of a companion forms a natural environment for the formation of the disks and the jets also (Soker & Livio 1994). The presence of precessing jets (and the formation of point symmetric PNe and QPNe) can more easily be understood if the progenitor is assumed to be an interacting binary (Soker 1997). Soker (1998) finds, through his statistical study, that the fraction of massive progenitors which are responsible for the BPNe is similar to the fraction of progenitors that interact with close stellar companion. Further, he points out that the massive progenitors are most likely to be formed in the binary system and only those binary systems with massive progenitors will form BPNe. This explains several observed facts as to the BPNe having hotter central stars, their galactic distribution and their larger chemical enrichment. However, Corradi & Schwarz (1995) find that among the 43 BPNe that they have observed, only 3
were found to have binary nuclei. They point out that one reason for this discrepancy could be the difficulties of observing the inner region of BPNe which suffers from strong internal extinction. The similarities observed in the morphologies and kinematics of BPNe with the symbiotic nebulae (Corradi 1995; Corradi 1993, 1995; Schwarz & Corradi 1992, 1995) support the hypothesis of the binary progenitor for the formation of BPNe. Symbiotic nebulae are formed from a binary system where the primary is in RGB or AGB phase and the secondary is a white dwarf. More discussion on the binary progenitor models and their usefulness in explaining the PNe morphologies can be found in Soker (1998).

1.3.3 PNe formed in the Common Envelope (CE) binary system

An interacting binary system having primary as an evolved giant star and the secondary as a main sequence star or a sub-stellar object may go through a CE phase. A CE is formed if the dynamic mass transfer (unstable mass transfer) from the primary to the secondary leads to the overfilling of Roche lobes of both the components (Bond & Livio 1990). The secondary spirals into the envelope by the frictional dissipation of orbital energy. This causes the deposition of gravitational energy as well as the transfer of angular momentum from the secondary to CE which eventually leads to the ejection of the envelope under favourable conditions. The formation, the evolution and the ejection of CE have been discussed elaborately in the reviews by Iben & Livio (1993), Iben & Tutukov (1993) and Iben (1995). The envelope is ejected mostly in the equatorial regions leading to the formation of a density contrast. Bond & Livio (1990) argue that if the primary encounters the companion during its RGB phase, then the density contrast produced is expected to be much larger leading to the formation of a bipolar PN. Further, if the primary happens to be in the AGB phase during the formation of CE, then the density contrast will be mild giving rise to an elliptical PN. In both the cases the density contrast increases with the mass of the secondary. However, it was suggested by Soker (1997) that in the case of an early encounter the secondary is less likely to survive inside the
CE (unless it is massive) which may lead to an elliptical rather than a bipolar PN. The subsequent evaporation of the companion inside the CE (or the coalescence with the core) may form a disk and jets. The primary is more likely to form a CE if it interacts with the substellar companion. Further, coalesce with the core is also most likely in this case (Livio & Soker 1984). Soker (1997) suggests from the above arguments that most of the elliptical PNe are expected to end up having single central stars. The study of the morphology of 13 PNe with close binary nuclei (an obvious product of CE) by Bond & Livio (1990) shows 8 elliptical PNe. Hence, the most likely outcome of a CE is an elliptical PN inspite of the enhancement in the mass-loss rate in the equatorial regions (Soker 1996). Soker (1998) suggests the formation of bipolar PN in an interacting binary system which had avoided a CE formation for a large fraction of time.

The ejection of the envelope is caused mainly by the gravitational energy drawn from the secondary. The PNe resulting from CE differ from those evolving from single stars because of the fact that the physical process of ejection in the two cases are different. A further difference comes from the fact that the time scale of ejection is shorter for CE than in the single star evolution. The nebular chemical structure differs in the two situations since the formation and ejection of the CE lead to the termination of further nuclear evolution in the primary (Iben & Tutukov 1989). This in turn gives rise to the cessation of chemical evolution of the envelope leaving the nebula less chemically evolved in the second dredge-up elements namely nitrogen and helium (for the primary mass larger than 3.3 $M_\odot$; Weidemann & Schönberner 1989). However, since the range in the initial binary separation which will allow a primary component to reach the TP-AGB stage and enhance the third dredge-up elements (carbon and s-process isotopes) is narrow compared to the expected separation for a CE formation, the possibility of close binary core PNe which are having over-abundance in these elements is less likely (Iben & Tutukov 1987). Mass of the primary is also a main factor in deciding the PNe chemical evolution.
1.4 The importance of and the motivation for the present study

Spatio-kinematic study is important in understanding the 3-dimensional structure of a PN. For instance a bipolar PN can show a spherically symmetric structure in its image if it is observed pole on, but the spatio-kinematic structure will be entirely different for spherical and bipolar PNe irrespective of aspect related problems. For an assumed geometry, theoretical emission line profiles at different parts of the nebula can be generated. Matching these profiles with those observed will give the geometrical and physical parameters of the nebula. From this, one can infer the complete 3-dimensional morphology of the nebula and hence the spatio-kinematics plays a crucial role in understanding PN morphologies. However, in the literature, among the known PNe of ~1800 in our galaxy, only ~ 30 are studied spatio-kinematically (Sahu & Desai 1986; Banerjee 1990; Anandarao et al. 1988; Banerjee & Anandarao 1991, Walsh et al. 1990). The motivation for our study comes from the lack of adequate spatio-kinematic observations under near seeing-limited spatial resolution and adequate spectral resolution for the PNe with binary nuclei as well as those interacting with ISM. These observations are essential to verify the theoretical predictions/models.

The aim of our study is two fold. Firstly to find the kinematics of PNe in order to identify their morphologies and to give a scenario for their formation from the binary progenitor origin, based on theoretical predictions, to match with our observational findings. For this purpose we have selected two nebulae : (i) NGC 1514, suspected to have close binary nucleus and (ii) NGC 4361, suspected to have spectroscopic binary nucleus. Spectrographic observations were also taken up in NGC 1514 to derive abundances through which one may be able to predict the evolutionary phase at which the primary encountered the secondary to form the CE.

The second aim is to investigate the kinematics of a PN which is strongly interacting with the ISM and study the evolution of structures in the morphology
due to such an interaction. Detecting the shell deceleration, if any, and deriving the ISM parameters were aimed. The nebula, NGC 246 was selected for this study. Spectrographic observations were also made to derive physical parameters and find out differences due to the ISM interaction.

1.5 The plan and content of the Thesis

The thesis consists of five chapters. An introduction to the subject is given in Chapter 1 (the current chapter). In the second chapter the instrument used for the observations taken for spatio-kinematic study is described in brief, and the selection of objects, the observations and the data analysis procedures are discussed.

In the third chapter the inter-comparison of spatio-kinematic studies of the selected PNe evolved from different progenitors and their spatio-kinematical models have been discussed. The results and discussion of spectrographic observations on NGC 1514 are given in this chapter.

The fourth chapter specifically deals with the PN-ISM interaction in NGC 246, discussing different characteristics of such an interaction. The spatio-kinematic results on NGC 246 and the derived physical parameters along with the spectrographic observations and the results are detailed.

The fifth and final chapter summarizes the important findings and conclusions of the thesis and give suggestions for future work.