CHAPTER 1
INTRODUCTION

1.1 Importance of Abundance Determination in Astrophysics

The motivation for a study of abundances in astrophysical objects comes both from a desire to make sure that one understands the physical processes leading to the absorption and emission features and from the role played by abundance studies in understanding the origin of elements and the evolution of stars, galaxies and the universe.

An inspection of the abundances derived in various investigations can be used as a test of our understanding of line-forming processes through the principles of consistency and uniformity. The consistency principle is a truism; if an understanding of the line-formation process is complete, then the different lines of the same object should lead to identical abundances. The classical examples are the permitted and the forbidden lines of various elements, especially iron, in the solar photosphere. The uniformity principle is based on the presence of well-defined cosmic abundance distribution (see Suess and Urey 1956; Cameron 1968), which forms the basis of the theories of origin of the elements. Abundances of C, N, O, Na, Mg, Si, S etc. (well-represented in Fraunhofer spectrum)
relative to H are best determined from a study of the solar spectrum. Many rare-earth elements are best studied in meteorites. Abundances of He and Ne are determined from the corona and solar cosmic rays. According to the uniformity principle, the abundance estimates get better when they look alike in different objects. In spite of the exceptions like Ap stars, it has often proved a useful principle. Solar spectroscopists tend to measure the success of their abundance determinations by the agreement of their results with the Type 1 carbonaceous chondrites. The important work of Auer and Mihalas (1973) on non-LTE effects of Ne I in B stars was partly inspired by the uniformity principle.

Abundance studies are useful tools in the study of stellar evolution. Some years ago very few objects like Wolf-Rayet stars, helium stars, carbon, S and Ba II stars, Ap and Am stars were recognized to have anomalous or unusual abundances. Now almost all classes of stars away from main sequence are recognized as having modified the composition of their surface layers in respect of carbon and its isotopes, nitrogen and sometimes the s-process elements and the isotopes of oxygen. Anomalies in red giants are important because they provide evidence concerning hydrodynamical effects in stellar evolution. In metal-deficient giants in globular clusters, the effects are more drastic. Sweigart and Mengel (1979) explain it in terms of strong mixing effects in their
interiors and so in globular clusters we have a veritable jungle of abundance anomalies usually involving carbon depletion and nitrogen enhancement.

Studies of chemical composition of the interstellar medium (ISM) and the stars of different population groups are very useful in testing the models of the chemical evolution of the Galaxy. The big-bang cosmology predicts that at the time of galaxy formation the universe consisted only of H, He and possibly Li. Heavier elements were synthesized in stars by thermonuclear reactions and the enrichment of the ISM is due to the material ejected by the fast-evolving stars. Studies of the abundances in ISM and stars at different parts in the galactic disc would provide valuable clues to the evolution of the Galaxy.

In the present investigations, we would be interested in determining the chemical abundances of long-period Cepheids in order to study the large-scale inhomogeneities and trends in the abundance distribution in the Galaxy as a probe into its chemical evolution.

1.2 Chemical Evolution of Galaxies

The chemical inhomogeneity of the interstellar medium at a given time is an important factor to be explained by the models of galactic chemical evolution. The observations
which are relevant to the problem of the enrichment of the ISM in heavy elements are the following:

1) The stellar metallicities in the solar neighbourhood show an age dependence, in the sense that older stars are metal poor and younger stars are metal rich (Mayor 1976). This is inferred from the metal deficiency of the globular clusters and the ultra-high-velocity stars of the galactic halo population which are certainly old (Eggen, Lynden-Bell and Sandage 1962).

2) Long-lived stars of one solar mass or less in the solar neighbourhood have a narrow range of heavy metal abundance. Simple models of galactic evolution predict more metal-poor stars than observed. This discrepancy is called the G-dwarf problem (Schmidt 1963).

3) There is a large-scale radial abundance gradient in the Galaxy, as deduced from the metallicity and kinematics of nearby stars (Mayor 1976; Janes 1977) and from the oxygen abundances in H II regions (Peimbert 1979 and references therein).

4) Similar large-scale abundance gradients are found in other large galaxies, both elliptical and spiral. Faber (1977) reported gradients in a large number of normal E and SO galaxies using CN absorption features at 4160Å, MgH + Mg I 'b' band at 5178Å and Na I 'D' at 5893Å. The observations
of H II regions in seven Sc galaxies by Searle (1971) also indicated the presence of an abundance gradient across the disc of these galaxies. Most large galaxies share the property of having greater metallicity (heavy-element abundance) in their central regions than in the outer parts. These gradients in the Galaxy as well as in external galaxies imply that inhomogeneities over a large length scale are created and survive during galactic evolution.

5) There is an abundance difference between the giant and dwarf elliptical galaxies in the sense that the metallicity in the central regions increases steadily with the mass or luminosity of the parent galaxy (e.g. Faber 1973, 1977). This effect and the large-scale gradient in elliptical galaxies probably results from the systematic flow of enriched gas from newly-formed stars towards the centre during the formative stages (Larson 1974).

The basic postulates of models for the chemical evolution of galaxies are that the galaxies are formed by the collapse of protogalactic clouds of gas accompanied by star formation. The protogalactic gas cloud is initially lacking in the heavy elements from carbon upwards, since the nucleosynthesis during the big-bang is expected to result only in hydrogen, deuterium, helium and possibly lithium in detectable quantities. The interstellar gas, then, is believed to be gradually
enriched in heavy elements by the matter coming out of the stars that have completed their own evolution and eject the products of nucleosynthesis in the course of their violent or slow deaths. In elliptical galaxies and the bulge of spirals, stellar relaxation times are longer than the age of the universe. This implies that the spheroidal shape of these components could not have resulted from the relaxation of stars. Hence, it has been proposed that these components assumed their shape at the time of their formation itself. This is possible through 'violent relaxation' proposed by Lynden-Bell (1967), which takes place if the star formation occurred on a timescale shorter than the collapse of the system as a whole. This implies that the star formation was largely completed a long time ago so that little gas is left. On the other hand, in the disk-like systems the star formation has evidently been delayed for some reason so that substantial amounts of gas are still there and we can see the star formation that is going on at the present time.

1.3 Models of Chemical Evolution

The important ingredient for the construction of models of galactic chemical evolution is the local stellar birthrate. The stellar birthrate is defined as the number of stars $b(m,t)$ in the mass interval $(m, m + dm)$ born per pc$^2$ in the time interval $(t, t + dt)$. To the first approximation, the
mass-dependence and the time-dependence of the stellar birthrate can be separated.

\[ b(m, t) \, dt = \phi(m) \, \psi(t) \, dt \]

where \( \psi(t) \) is the total star formation rate in mass per \( \text{pc}^2 \) per unit time and \( \phi(m) \) is the initial mass function which is the distribution of stellar masses at birth.

The simple models of galactic chemical evolution are based on the following assumptions:

1) The evolution takes place in a cylindrical shell coaxial with the galaxy and passing through the Sun, in isolation with the rest of the galaxy. The models which make this assumption are known as the closed models.

2) The gas is initially unenriched and is gradually depleted by star formation.

3) The rate of star formation \( \psi \) varies as a power of the surface density \( \mu \) of the gas (the surface density being the projected volume density of the gas on the galactic plane).

\[ \psi = \psi_0 \mu^n \]
4) The interstellar medium is well mixed at all times and in particular, new stars formed at time \( t \) have the average heavy element abundance of gas, \( Z(t) \).

5) Initial mass function \( \phi(m) \) has a constant form.

The two important parameters of the models of galactic evolution are firstly the fraction of mass in each generation that is returned to ISM which we shall call as \( \beta \) and secondly the yield of heavy elements which we will call \( p \), defined as the total mass fraction of primary synthesis products ejected in each generation relative to the fraction that remains locked up in long-lived stars or collapsed remnants. In instantaneous recycling approximation where one assumes the evolutionary processes to take place instantaneously compared to the timescale of galactic evolution, these two quantities are constants characteristic of IMF adopted. From the above considerations, the heavy metal abundance \( Z \), in the gas or in newly formed stars, at a given time is given by

\[
Z = p \ln \left(1 + \frac{s}{g}\right)
\]

where \( s \) is the mass locked up in stars or compact remnants and \( g \) is the mass of gas that is left. Searle and Sargent pointed out that this equation predicts a large scale radial abundance gradient in the galactic disc such as already established observationally by Searle (1971).
The simple model of galactic evolution runs into difficulties because of its incapability to explain the narrow range of metallicity of G dwarfs.

As we look across the galaxy at a particular moment of time, more of the gas has been changed into stars in the inner region than in the outer region. Some authors have considered the rates of star formation varying with a power law of the average gas density, with an exponent greater than one, which can arise from a variety of reasons like the free-fall timescale, the rate of collisions of clouds and so forth. Such law, when applied to the past history of the solar neighbourhood using the Simple Model, comes into conflict with an attempt to reconcile the relative number of large-mass and low-mass stars seen today with a constant and smooth IMF; there are too few long-lived dwarf stars, compared with the number of short-lived O and B stars, to permit the average past rate of star formation to have exceeded the present rate by as much as would be required by a power law in the gas density with an exponent of even one, let alone more than one. To solve this problem one can propose that the IMF could have varied or it could be discontinuous, with low-mass and high-mass stars being born in quite separate sets of events (Eggen 1976). More simply, the mass of the gas could have had a phase in the past when it was increasing owing to infall (Larson 1974; Lynden-Bell 1975; Larson 1976)
so that one can have a power law in the gas density for the rate of star formation, combined with a non-monotonic dependence on time. This form of departure from Simple Model provides a natural explanation for the narrow range of abundance in G dwarfs; further, it can also account for the indication that the past rate of star formation has been fairly uniform. Thus Larson's (1976) model with decaying infall, and the closely related analytical model of Lynden-Bell are the most reasonable models for the evolution of disk-like galaxies.

1.4 The Radial Abundance Gradient

1.4.1 Abundance Gradient in Lighter Elements

Observations of H II Regions:

The presence of an abundance gradient of O/H, N/H and N/S in external galaxies has been reported by various observers from the observations of the ISM (Searle 1971; Peimbert 1968; Benvenuti, D'Odorico and Peimbert 1973; Shields 1974; Comte 1975). For our galaxy, Peimbert et al (1978) derived an abundance gradient for O/N, N/H, N^+ /S^+ and He/H from the photoelectric observations of five H II regions covering a galactocentric range from 8.4 to 18.9 kpc. Hawley (1977) observed thirteen H II regions and found smaller gradients in O/H and N/H than those found by Peimbert et al and no gradients in the He/H, S/H and Ne/H abundance ratio.
Barker (1974), D'Odorico, Peimbert and Sabbadin (1976), Aller (1976) and Torres-Peimbert and Peimbert (1977) have studied the abundance gradient in the galaxy from the observations of Planetary Nebulae (PN). The abundance gradient can be studied only through type II PN which are of population I and which have apparently not been affected by considerable helium enrichment due to their own stellar evolution.

Periods of Cepheids:

It is known that in the Galaxy as well as in M31 and the Magellanic Clouds, short period Cepheids are concentrated towards the outer regions and long-period Cepheids towards the inner regions (Shapley and McKibben 1940; van den Berg 1958; Baade and Swope 1965; Fernie 1968). A possible explanation is that this effect is due to a radial gradient in the chemical composition of these galaxies.

It is possible to obtain a crude estimate of the O/H abundance gradient in the Galaxy by assuming that the O/H abundance is directly proportional to the Cepheid period (at a given mass of the Cepheid). Such a relationship has been identified through a comparison of the observations of the H II regions and Cepheids in the Small Magellanic Cloud (SMC) and the solar neighbourhood. The assumption that the Cepheid periods are related to the metal abundances is
supported by the results of Gascoigne (1969) and Madore (1974) who found that the SMC Cepheids are 0.1 mag bluer in B-V than the Cepheids in the galaxy. Bell and Parsons (1972) have explained this difference as due to reduced line-blanketing in SMC Cepheids or in other words, the reduction in metal content in SMC Cepheids by a factor of four relative to the galactic Cepheids. Fernie (1968) found for the galaxy a relation between the galactocentric distance R and the Cepheid period given by

$$\Delta \log P / \Delta R = -0.05 \, \text{d kpc}^{-1}$$

and an average value of $\log P(d) = 0.97$ for the Cepheids of solar neighborhood. Arp and Kraft (1961) found an average value of $\log P(d) = 0.5$ for the SMC Cepheids. Peimbert and Torres-Peimbert (1976) have found a difference of 0.76 in the log \((O/H)\) between the solar vicinity and the SMC H II regions. One obtains from these results $\Delta \log (O/H) / \Delta \log P(d) = 1.6$ and thus a radial gradient in the galaxy of $d \log (O/H) / dR = -0.08 \, \text{kpc}^{-1}$.

1.4.2 Abundance Gradient in Heavier Elements:

Grenon (1972), from the Geneva photometry of G and K dwarfs, found $d \log (Fe/H)/dR = -0.07 \, \text{kpc}^{-1}$. Mayor (1976), from an analysis of the kinematic and photometric properties of about 600 F-type main-sequence stars and 600 G and K
giant stars, has derived two values of the metallicity
gradient, one for all the objects with eccentricity of their
galactic orbit in the range 0.05 - 0.40 and another for the
subset of statistically younger objects with eccentricity
0.05 - 0.15. From the observations of Hansen and Kjærgaard
(1971), Mayor has derived gradients in the sodium abundance
corresponding to the two eccentricity groups described above.
Sodium and iron gradients are steeper for the younger subset
than for the complete sample. This result is in agreement
with the absence of a gradient for halo stars derived by
Grenon (1972), but is apparently in contradiction with the
radial metallicity gradient derived from globular clusters in
the solar neighbourhood which amounts to $d \log (Fe/H)/dR = -0.1$
(Kinman 1959; Mayor 1976). Janes and McClure (1972), from
the DDO photometry of 799 K giant stars, presented the
evidence for a radial gradient in CN strength. The CN
strength is correlated with Fe/H. Janes (1977) covered a
still larger sample of G and K giant stars and measured the
CN strengths from DDO photometry; he also incorporated the
UBV photometry of 41 open clusters to estimate the variation
of metallicity across the galactic disk.

Williams (1966), from the narrowband photometry of 52
Cepheids with periods longer than 13 days, found that the
Cepheids in the Sagittarius arm appear to be somewhat
metal-rich as compared to those within 1.5 kpc of the Sun;
the Cepheids in the Cygnus arm, on the other hand, appear to be somewhat metal-deficient. Harris (1981), using the Washington system colours which are designed specifically to determine stellar abundances in the temperature range of Cepheids (Canterna 1976; Harris and Canterna 1979), determined photometric abundances for 102 Cepheids with a wide range of positions in the disk of the galaxy. He found a gradient in the metal abundance \( \frac{d(A/H)}{dR} = -0.07 \text{ kpc}^{-1} \) for the galactic disk, approximately linear over 10 kpc.

Apart from the photometric attempts to determine the abundance gradient in the galactic disk, accurate spectroscopic abundance determinations have also been tried in the past. The analysis of Luck (1977a,b, 1978, 1979), Luck and Lambert (1981), and Luck and Bond (1980), based on high dispersion spectra of F and G supergiants, suggests somewhat greater gradient than other studies. Though their relatively small range of 3 kpc in distance increases their uncertainty in the gradient, such an analysis should ultimately yield more accurate results as the sample is enlarged to larger distances. Besides, such detailed analyses are indispensable for the calibration of a photometric reddening-free abundance index. Various estimates of the abundance gradients in the galactic disk are summarized in Tables 1.1 and 1.2.
Table 1.1
Summary of different estimates of Fe abundance gradients in the Galaxy

<table>
<thead>
<tr>
<th>Objects</th>
<th>Method</th>
<th>-d Fe/H / dR</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Old disk stars</td>
<td>1</td>
<td>0.04 ± 0.03</td>
<td>1</td>
</tr>
<tr>
<td>gK and old open clusters</td>
<td>1</td>
<td>0.05 ± 0.01</td>
<td>2</td>
</tr>
<tr>
<td>Young disk stars (dF and dG)</td>
<td>1</td>
<td>0.10 ± 0.02</td>
<td>1</td>
</tr>
<tr>
<td>Young clusters *</td>
<td>1</td>
<td>0.098± 0.015</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.093± 0.034</td>
<td>4</td>
</tr>
<tr>
<td>Cepheids *</td>
<td>1</td>
<td>0.07 ± 0.01</td>
<td>5</td>
</tr>
<tr>
<td>Supergiants and Cepheids</td>
<td>2</td>
<td>0.13 ± 0.03</td>
<td>6</td>
</tr>
<tr>
<td>Cepheids</td>
<td>2</td>
<td>0.06 ± 0.01</td>
<td>7</td>
</tr>
</tbody>
</table>

* -d log (Z/X)/dR

Method: 1. Photometry 2. Spectroscopy

7. Present study
### Summary of different estimates of O and N abundance gradients in the Galaxy

<table>
<thead>
<tr>
<th>Objects</th>
<th>Method</th>
<th>(-d \log(O/H)/dR)</th>
<th>(-d \log(N/H)/dR)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cepheids</td>
<td>1</td>
<td>0.08</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>O stars (local gradient in Sagittarius arm)</td>
<td>2</td>
<td>0.13 ± 0.06</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>H II regions</td>
<td>3</td>
<td>0.06 ± 0.02</td>
<td>0.08 ± 0.02</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.13 ± 0.04</td>
<td>0.23 ± 0.06</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.05 ± 0.03</td>
<td>0.10 ± 0.03</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.09 ± 0.02</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>H II regions (Sagittarius arm) (Persius arm)</td>
<td>3</td>
<td>0.24</td>
<td>0.16</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.18</td>
<td>0.15</td>
<td>3</td>
</tr>
<tr>
<td>Planetary nebulae</td>
<td>3</td>
<td>0.06 ± 0.02</td>
<td>0.18 ± 0.04</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.10 ± 0.03</td>
<td>0.27 ± 0.08</td>
<td>8</td>
</tr>
<tr>
<td>H II regions</td>
<td>4</td>
<td>0.05 - 0.08</td>
<td></td>
<td>9</td>
</tr>
</tbody>
</table>

**Method:**
1. Period calibration
2. Photometry
3. Spectroscopy
4. Radio electron temperature

**Source:**
1. Peimbert (1979)
3. Talent and Dufour (1979)
4. Peimbert, Torres-Peimbert and Rayo (1978)
5. Hawley (1978)
6. Peimbert and Torres-Peimbert (1979)
7. Torres-Peimbert and Peimbert (1977)
The O/H abundance gradient obtained from H II regions is steeper than that given by PN. This difference, if real, could be due to at least three causes: (a) a different O/H distribution in the interstellar medium at the time of formation of the parent stars of PN; (b) a different O/H in the shell from that of the original cloud from which the parent stars of PN are formed; (c) the effect of non-circularity of the PN orbits around the centre of the galaxy.

The Fe/H and Na/H gradients derived from the intermediate age stars are similar to the O/H gradients derived from PN which supports the possibility (a). On the other hand, there is some observational evidence that suggests that the rate of enrichment of Fe has been different from that of O, S and Ar and consequently that the Fe/H and O/H are not directly comparable (Peimbert 1973; Barker 1974; Chevalier 1976a; Chevalier and Kirshner 1978). Furthermore, based on the observational evidence, Chevalier has suggested that the Fe enrichment is due to SN of type I while that of O, S and Ar is due to SN of type II.

1.5 Local Chemical Inhomogeneities

One of the important mechanisms that can produce local inhomogeneities is the sequential star formation in associations, the first generation of supernovae enriching the material out of which further stars immediately form.
There is considerable evidence that supernova explosions may induce further star formation. Sansi (1974) and Knapp and Kerr (1974) found shells of cold H I, dust and molecules around supernova remnants; Berkhuijsen (1974) and Herbst and Assousa (1978) found young stellar associations on the edge of supernova remnants. It has been suggested that the formation of our own solar system was induced by a supernova. Even if the star formation is not actually triggered by supernova explosion, the synthesised material from a supernova could still be incorporated, provided the formation happens soon afterwards (e.g. instigated by photoionized H II region formations; Elmegreen and Lada 1977) before the inhomogeneity is destroyed by mixing. If the products of several supernovae are mixed into the mass of a typical observed shell \( (3 \times 10^{-3} \text{M}_\odot) \), then the excess over the surrounding metallicity, \( dZ = 3 \times 10^{-3} \) would be possible, resulting in \( \sigma \sim 0.1 \) for the present mean disk abundances. Ögelman and Maran (1976) suggest a repetative cycle of star formation—supernova may operate within OB associations, but the extent of homogeneity will depend on how well and quickly the supernova mixes into the interstellar medium before new star formation takes place. The expanding remnants will probably break up into knots (Chevalier 1975, 1976b; Gull 1974) which may be metal rich. It is not clear whether induced star formation occurs in these knots before they mix into outer material, or by the
supernova shocking of previously existing cool clouds of normal abundance.

1.6. Nucleosynthesis in Stellar Interiors

The theory of the synthesis of elements in stellar interiors is developed by Cameron (1955) and by Burbidge, Burbidge, Fowler and Hoyle (1957, B2FH). Starting with the hypothesis that all elements have been built from primordial hydrogen and helium, B2FH postulated as much as eight different nuclear processes to account for the observed features of the cosmic abundance distribution:

1) hydrogen burning to produce helium;
2) helium burning to produce C, O, Ne and perhaps Mg;
3) $\alpha$-processes in which Mg$^{24}$, Si$^{28}$, S$^{32}$, Ar$^{36}$ and Ca$^{40}$ are produced by successive addition of helium nuclei to O$^{16}$ and Ne$^{20}$, the $\alpha$-particles being freed by decomposition of heavy nuclei;
4) the equilibrium $\epsilon$-process which was suggested to account for the iron peak elements;
5) $s$-process in which neutrons are captured at long timescales ranging from 10 yr to $10^5$ yr for each neutron capture. This mode of synthesis is responsible for the production of the majority of isotopes in the range $23 \leq A \leq 46$ and for a considerable
6) r-process in which neutrons are captured on a fast timescale $\sim 0.01$ s to 10 s;
7) the p-process in which proton-rich isotopes are formed;
8) x-process which is invoked for the production of the temperature-vulnerable light elements.

These nuclear processes operate in different stages of star's evolution. It is known that when the stars first form out of a gas of hydrogen and helium, the hydrogen burns in the core to produce helium and the star is then called a main-sequence star. When the hydrogen burning in the core is exhausted it begins to contract gravitationally until the temperature and density are large enough for helium to burn in the core. During this core-contraction stage, the outer envelope expands and the star becomes a red giant. When helium burns in the core, it creates carbon and oxygen via the triple-alpha reaction. At higher internal temperatures, a succession of x-processes may set in to form $^{16}$O, $^{20}$Ne and $^{24}$Mg. After depletion in the core, helium may continue to burn in a shell surrounding the depleted core. This shell is surrounded by a hydrogen-burning shell. At temperatures of $\sim 10^9$ K, reactions may take place among the $^{12}$C, $^{16}$O and $^{20}$Ne nuclei. Helium particles can be made
available through a (γ, α) reaction. Mg24 can capture alpha particles to form Si28, S32, Ar36 and Ca40. The chain eventually terminates in the iron group of nuclei that have larger stability. During this time an equilibrium concentration is being reached between these even-even nuclei, this process is called the equilibrium process. If the star is a second generation star, i.e. it contains heavier elements, neutrons are produced via exergonic reaction Ne21 + He4 → Mg24 + n or C13 + He4 → O16 + n. Heavier elements are formed via the process of slow and fast neutron captures.

It is useful to classify the elements according to the number of stellar generations required for their nucleosynthesis. Primary elements are those that can be formed directly from H and He inside the star (C12, O16, Ne20, Fe56 etc.). Secondary elements are necessarily formed from the primary seeds which must have existed in the interstellar matter when the star was formed. Examples of such secondary elements are C13, N14 and the s-process elements.

Enrichment of the ISM is mostly due to the material ejected by stars in their last stage of evolution. Most massive stars eject so-called primary nucleosynthesis products which can be built up directly from hydrogen and helium in the course of stellar evolution. The elements C, O, Ne and most of the nuclear species up to the iron group are formed
this way. Stars of intermediate mass (between one and few solar masses) eject their excess of material above the white-dwarf residue as gas that may have undergone some processing but without enriching it in oxygen or metals. Stars of about 1 solar mass or less simply form and remain there without significant contribution to the ISM as do the white dwarfs and other compact remnants such as neutron stars left behind by more massive stars after their death.

1.7 Role of $s$-process Elements in the Chemical Evolution of Galaxies

The $s$-process nuclei are an interesting probe of galactic evolution because they are produced via a secondary process. It is not possible to produce $s$-process nuclei in a star unless that star already contains some heavy seed nuclei. The bulk of the heavy element fraction $Z$ is due to primary processes. The heavy primary nuclei which are the products of explosive nucleosynthesis are probably produced by explosions of massive stars $M > 7 \, M_{\odot}$. The source of $s$-process nuclei is normally taken to be in the interiors of red giant stars ($\beta^2$TH). However, the details of how the $s$-process actually might work in such an astronomical site is only beginning to be understood. Ulrich (1973) investigated what happens during the double-shell-source phase of the evolution of certain stars. He finds that a reasonable
s-process environment occurs between the two shells whenever a flash mixes down hydrogen-burning material into helium-burning region. Ulrich (1974) has estimated that the s-process synthesis in such intershell sources can explain the abundance anomalies observed in FG Sagittae. In Ulrich's model, when the hydrogen is mixed down in the flash, it is captured by $^\text{12}_\text{C}$, the $^\text{13}_\text{N}$ thus formed rapidly decays into $^\text{13}_\text{C}$; at the high temperature inner boundary of the convective cell, the reaction $^\text{13}_\text{C} (\alpha, n) ^\text{16}_\text{O}$ produces neutrons. These neutrons are captured by the iron-peak nuclei that serve as seeds for the s-process. The s-process nuclei built up in the intershell region gradually leak out into the outer envelope where they can be radiated away into the interstellar medium via the red giant's stellar wind. It may also be possible that the intershell region itself gets ejected during the later stages of stellar evolution.

As we have already seen, the iron peak and s-process elements are formed due to two fundamentally different nucleosynthesis processes, former resulting from explosive nucleosynthesis within supernovae and the latter due to slow neutron capture by heavy elements during advanced non-catastrophic evolution. These processes occur in different mass ranges of the star and depend in different ways on the star's initial composition. The abundance ratio of the s-process and iron peak elements may, therefore,
set important constraints on the theories of stellar and galactic evolution.

1.8 **Cepheids as probes for the Chemical Constitution of the Galactic Disk**

As a group, the classical Cepheids (referred to hereafter as Cepheids for the sake of brevity) have five properties which make them perhaps the most suitable class of stars for studying the abundance variations in the galaxy:

1) Cepheids are intrinsically luminous objects. Their high intrinsic luminosity enables one to observe them at considerable range of distances.

2) They comprise of a homogeneous population, their masses, ages and luminosities are closely related to their periods, and the total range in age is much less than the age of the galactic disk.

3) Period-luminosity-colour relationship of Sandage and Tammann (1969) helps one to determine their distances with a sufficient degree of accuracy. The intrinsic luminosity of non-variable supergiants is inferred on the basis of the luminosity class and the spectral type. The accuracy of these estimates is rather low and is only slightly improved by an application of model atmospheres.
4) Cepheids have a temperature range in which the spectra show enough number of metallic lines. Yet their temperatures are not too hot as to make the non-LTE effects very serious, while not too low for the convection to become important.

5) All the Cepheids with periods larger than 10 days are quite young and hence their atmospheric abundances reflect those of the interstellar medium out of which they are born.

Because of these advantages, we choose to study the chemical abundances of selected Cepheids in the present investigation.