CHAPTER I
INTRODUCTION

The immense space between stars is not empty. It is filled with gas, dust and electromagnetic radiation together with high energy particles and weak interstellar magnetic field. The first evidence for such a pervasive interstellar medium came from observations of interstellar absorption lines (Hartmann, 1904) caused by gas, interstellar extinction (Trumpler, 1930), reddening (Stebbins et al, 1940) and polarization (Hall, 1949 and Hiltner, 1948) caused by dust. More recently observations in radio, microwave, infrared, ultraviolet and X-ray wavelengths have greatly improved our knowledge of the distribution and state of interstellar matter.

The distribution of the components of the interstellar medium is far from uniform. There are thus concentrations of gas and dust; the cosmic clouds or nebulae; that reveal their presence in the interstellar space in a variety of ways, and are known by different names.

I.1:1 Dark Nebulae

These are relatively dense clouds of gas and dust often detected optically as dark areas in the midst of rich star fields. They appear dark against a bright background because the dust in these clouds absorbs the light from background stars and
reduces the number of stars seen through the cloud in relation to the density of stars in adjacent areas. The "Coal Sack" near the Southern Cross is one of the most striking examples of a dark cloud visible to the naked eye. The "Great Rift" in the constellation of Cygnus is a result of the overlapping of numerous dark clouds in the galactic equatorial plane.

Dark clouds exhibit a variety of shapes and a large range of sizes. Many smaller dark clouds appear on the telescopic photographs of the Milky Way such as the ones taken by E. E. Barnard at the turn of the century. Some of these dark nebulae of small dimensions, catalogued by Barnard (1927) and also called "Barnard Objects" display compact, quasi-spherical shapes. These compact clouds and the still smaller dark nebulae seen projected against bright nebulosities like M8, are known as "Bok globules" after B. J. Bok who first drew attention to them and suggested that they may represent an early stage of condensation of the interstellar medium leading to the formation of stars (Bok and Reilly, 1947). The most complete catalogue of dark nebulae has been compiled by Lynds (1962) from a study of the Palomar Observatory Sky Survey photographs.

L.1:2 Reflection Nebulae

Dusty clouds that become luminous by reflecting the light from a nearby star or some other source of light are called "Reflection nebulae". There are three main types of them. The
'interstellar' reflection nebulae are produced by the illumination of the surrounding interstellar matter by intrinsically luminous stars, as the nebulosity in the Pleiades cluster. The Hubble's variable nebula NGC 2261 is an example of a 'compact' reflection nebula where the dust cloud is more intimately related to the illuminating star, in this case R Mon. The third type of reflection nebulae are the ones that are found at high galactic latitudes and reflect the integrated light of stars in the Galactic disk.

I.1:3 Emission Nebulae

Emission nebulae are gas clouds that absorb ultraviolet radiation from nearby hot stars and reradiate it in emission lines. The great nebula M42 in Orion is an example visible to the naked eye. Dark dust clouds are often found in the company of such nebulosities. However, the central stars seem to have driven the dust away from their immediate surroundings by means of radiation pressure, stellar wind or some other cause. The hydrogen gas in these nebulae is ionised in a roughly spherical volume around the hot star forming the H II region.

There are other kinds of emission nebulae like the supernova remnants and the planetary nebulae. The high velocity gas expelled in supernova explosions collides with the low density gas of the interstellar medium and produces shocks.
Hydrogen in these shocks is collisionally excited and gives rise to the luminescence observed, for example in the "Loop Nebula". Planetary nebulae such as the "Ring Nebula" in the constellation Lyra appear roughly spherical or ellipsoidal shells of luminous gas, with faint but very hot nuclear stars at the center. They are believed to result from gas ejection from the central stars probably at a late stage of stellar evolution.

I. 1:4 Molecular Clouds and H I Clouds

The term 'molecular cloud' is frequently used for the very large clouds in which hydrogen is almost all in the molecular form. The molecular clouds are often associated with the sites of current star formation. There are also less dense clouds of various sizes in which hydrogen is mainly in the atomic form and visual absorption is not large enough for them to be observable as dark clouds. They are called 'H I clouds' or 'Diffuse clouds'.

I. 2 Interstellar Clouds and Star Formation

The interstellar medium with its clouds of various kinds is an important structural and dynamical component of the galaxy. It is generally believed, with considerable observational evidence, that stars form out of the interstellar
matter and have their birth place within interstellar clouds of gas and dust, though the details of the star formation process are as yet unclear. And, stars at various stages of evolution throw out matter back to the interstellar medium where again it condenses into clouds. Studies of interstellar clouds are thus of obvious importance for a better understanding of the problems of star formation. Under the diverse environmental conditions and states of matter, interstellar clouds provide a tremendous variety of physical processes and phenomena. By studying the interactions between the gas, dust, radiation, magnetic field, high energy particles and other components of the interstellar medium under different astronomical situations, we may hope to better understand the behaviour, structure and evolution of the interstellar medium and the detailed steps in the star formation process.

1.3 Methods of study and Properties of Dark Clouds

A large number of techniques are used to gather information about the objects of our study. Here we briefly review some of the methods of observation and the properties of the dark clouds derived from them. In the optical, the typical methods are the measurement of reddening of background stars and star counts (e.g. Bok and McCarthy, 1974; Schmidt, 1975; Tomita et al., 1979). Reddening is measured by performing multiwavelength photometry, and in the method of star counts
one compares the number of stars per unit area seen through
the cloud and in an adjacent area away from the cloud. From
these observations one derives the magnitude of extinction
caued by the cloud and the amount and distribution of dust
in it. Polarization measurements of the background stars
also give information about the nature of the dust and the
mechanism that aligns the dust grains in the cloud. However,
the very dense regions of the dark clouds cannot be studied
by optical means because of the large absorption in the
visual. At longer wavelengths in the infrared, far infrared,
microwave and radio one can penetrate deeper into the
dark clouds (e.g. Strom et al., 1975; Keene, 1981; Dickman,
1978; Martin and Barrett, 1978; Schell, 1981) and gain
knowledge not only about the dust but also the gaseous
component of the clouds. Radio observations of a variety
of atomic and molecular species (particularly the $^{13}$CO
molecule) help us determine the density, temperature and
the dynamical properties of these objects. Though the dark
nebulae exhibit a range of shapes, sizes and physical pro-
erties, the following characteristics may be considered
to be typical of an average dark cloud like 'B 361'.

Constituents: Dust and gas. Gas mainly molecular
hydrogen $H_2$ with traces of CO, $NH_3$,
$H_2CO$, CS, HCN and others; CO being
the most abundant after $H_2$. The gas
to dust ratio by mass is $\sim 100$. 
Linear size and Mass: \( R \sim 0.5 \) pc, \( M \sim 50 M_\odot \).

Visual absorption: \( A_v \sim 3 \) magnitudes.

Density: \( n(H_2) \sim 10^3 \) cm\(^{-3}\).

Temperature: \( T_{\text{gas}} \sim T_{\text{dust}} \sim 10^5 \) K.

Dynamical state: Microwave spectroscopic observations indicate the presence of rotation and suprathermal gas motions in many of the observed dark nebulae (e.g. Martin and Earrett, 1978).

The dust grains in these clouds may be similar to the ones in the intercloud medium in many ways. Thus the grains may be submicron sized solid particles of similar substances as in the normal interstellar medium. Magnetic field \( B \) in the clouds may be of the order of few tens of microgauss (\( \mu \)G). We note here that in contrast to the clouds, the inter-cloud medium is characterized by \( n(H) \sim 0.3 \) cm\(^{-3}\), \( T \sim 8000 \, \text{K} \) and \( B \sim 3 \, \mu \)G (Field, 1973).
I.4 Scope of the Present Study

The large molecular clouds and the emission nebulae are generally found together and it seems that active star formation is well under way in them. This is clearly evident in the 'Orion Nebula'. Here one finds hot young stars, H II regions, infrared sources obscured in the visible by dust, dense concentrations of molecular gas emitting strongly in microwave lines, high velocity gas flows and other signs of stellar birth, all side by side. However, the status of the smaller dark nebulae is not clear in this regard. Observations in microwave spectral lines (e.g., Martin and Barrett, 1978) and theoretical arguments based on the 'Virial Theorem' suggest (e.g., Bok, 1977) that most of the observed dark nebulae (Bok globules, Barnard objects and Lynds clouds) are gravitationally bound and perhaps collapsing to give rise to the formation of stars. However, there are no convincing examples of these clouds being in association with new-born stars. In this thesis we focus our attention on these nebulae.

We first make a statistical study of a large sample of these objects to determine the frequency distribution of the cloud masses. The form of the mass spectrum would provide an important constraint on any model for the origin and evolution of the dark clouds. We then consider some general physical processes taking place within and around
an individual dark cloud. These processes involve the motion of dust grains relative to the gas under the forces of gravity, radiation pressure and viscosity; and are discussed with emphasis on their relevance to the observed phenomena in dark nebulae. Effects of radiation pressure driving dust grains into dark globules and gravitational settling of dust have been investigated. Polarimetric observations of the Bok globule 'B 361' are presented. These observations were carried out to find the magnetic field geometry in the globule and to look for the effects of dust segregation discussed in this thesis. Implications of the results of these investigations have also been discussed.