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Large dust grains in the dark cloud B5

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Summary. Polarization measurements of stars in the region of the dark cloud B5 indicate that the average dust grain size in the cloud is much larger than the mean interstellar grain size. Within the cloud, the average grain size is found to increase with decreasing distance from the cloud core where *IRAS* detected a compact infrared source IRS 1. Dust grains with an average size as large as about twice the mean size of the interstellar grains could be present in the inner regions of the cloud. It is suggested that dust grains in B5 grew in size by the accretion of condensable heavy elements from the gas on a time-scale of $\sim 10^6$ yr, and gravitational segregation of the larger grains towards the cloud core on a longer time-scale ($\sim 3\times 10^7$ yr) caused the observed radial variation in grain size and the lower than expected extinction in the region outside the core.

1 Introduction

B5 (L1471; Lynds 1962) is a dark cloud in Perseus, about 5° NE of NGC 1333. The cloud is elliptical in appearance, with an angular size of $\sim 1^\circ \times 0.5^\circ$. The cloud centre (the position of maximum visual obscuration) is at RA (1950) $= 3^{\mathrm{h}}\,44^{\mathrm{m}}\,20^{\mathrm{s}}.6$, Dec (1950) $= 32^\circ\,42'\,44''$ (Cernicharo & Bachiller 1984). Close to the cloud centre the *Infrared Astronomical Satellite* (*IRAS*) detected a compact far-infrared source IRS 1 [at RA (1950) $= 3^{\mathrm{h}}\,44^{\mathrm{m}}\,31^{\mathrm{s}}.9$, Dec (1950) $= 32^\circ\,42'\,30''$] which may be a newly born low-mass star (Beichman *et al.* 1984). Young *et al.* (1982) made an extensive study of B5 in the microwave emission lines of carbon monoxide. They found that the cloud is rotating with its projected axis of rotation in the NE–SW direction. The core of the cloud is rotating in opposite sense to that of the outer regions about the same rotation axis. This peculiar rotation of B5 was suggested by Young *et al.* (1981) to be a result of magnetic braking by means of a frozen-in magnetic field. In order to probe the magnetic field structure in the cloud we made measurements of linear polarization for stars in the region of B5 and presented a polarization map (Joshi *et al.* 1985, hereafter Paper I). The field geometry in the cloud was found to have a disturbed appearance, in the sense that across the cloud the field is far from being unidirectional.

The polarization measurements presented in Paper I also indicated that the wavelength $\lambda_{\max}$, at which the linear polarization attains its maximum value $P_{\max}$, for B5 is larger than the mean interstellar value. Since $\lambda_{\max}$ is a measure of the average grain size of the dust grains causing the polarization (e.g. McMillan 1978) this suggests that the dust grains in B5 are, on average, larger than the mean interstellar grain size. In this paper we present the results of a study of the wavelength dependence of polarization for B5. The values of $\lambda_{\max}$ for stars at various angular distances from the cloud centre are evaluated and it is shown that $\lambda_{\max}$ increases progressively as one approaches from outside the cloud-boundary towards the cloud centre where *IRAS* detected the protostar IRS 1. Implications of the observed variation of $\lambda_{\max}$ (and hence of the grain size) with radial distance from the cloud centre for the grain growth and gravitational segregation of dust grains in B5 are discussed.

2 The wavelength dependence of polarization and the dust grain size

Polarization measurements of 24 stars in the region of B5 taken in the Minipol filters G, R(old), and I with effective wavelengths $\lambda_{\rm eff}=0.52$, 0.74 and 0.94 μm respectively (Coyne, Gehrels & Serkowski 1974), and a map showing the stars observed have been presented in Paper I. For star 18 the value of the polarization P(I) was misprinted in Paper I. The correct value is $P(\mathrm{I})=0.60$ per cent. Star 6 was measured for polarization also in the B filter ($\lambda_{\rm eff}=0.43\,\mu$m) with the result $P(\mathrm{B})=2.15$ per cent and the error $\varepsilon_p(\mathrm{B})=0.74$ per cent. Of the 24 stars in Paper I, polarization measurements in more than one filter are available for 10.

The wavelength dependence of linear polarization is a function of the optical properties of the dust-grain material and the grain-size distribution. In particular, the wavelength of maximum polarization $\lambda_{\max}$ is a direct measure of the mean grain size: $\lambda_{\max}\propto\langle a\rangle$ where $\langle a\rangle$ is the mean grain radius of dust grains along the line-of-sight that cause the polarization (McMillan 1978 and references therein). The multicolour measurements of the interstellar polarization are well represented by the relationship

$$\ln(P_{\max}/P_\lambda)=1.15\ln^2(\lambda_{\max}/\lambda), \qquad (1)$$

where P_λ is the polarization at the wavelength λ (Serkowski 1973; Serkowski, Mathewson & Ford 1975). The mean value of $\lambda_{\max}$ for the normal interstellar medium is 0.545 μm (Serkowski *et al.* 1975).

We can use equation (1) to evaluate $\lambda_{\max}$ (and make a relative estimate of the grain size) provided our multifilter polarization measurements do fit this equation. That this is so is shown in

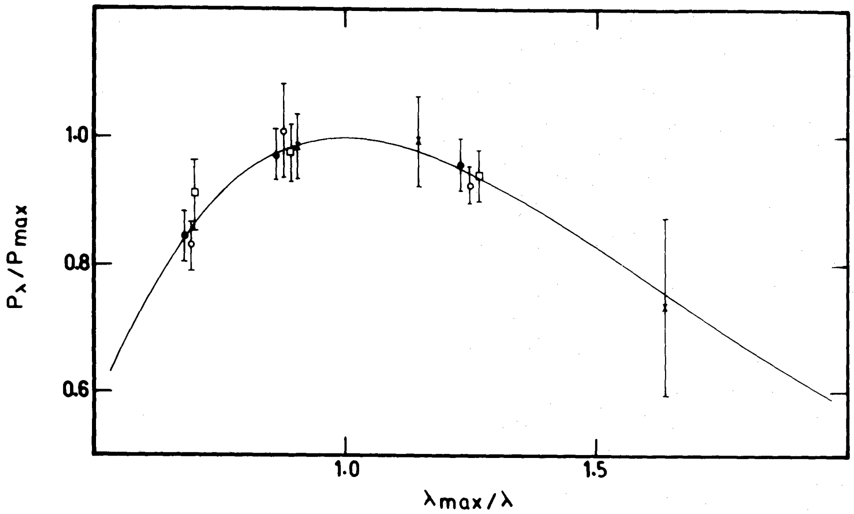

Figure 1. The wavelength dependence of linear polarization for stars in the region of B5. The symbols are: ● star 18, ○ star 9, □ star 23 and × star 2. The solid curve represents equation (1).

Table 1. Results: $\lambda_{\max}$ and $P_{\max}$ for stars in the region of B5.

Star no.	Angular distance from IRS 1 r (′)	$\lambda_{\max}$ (μm)	$\delta\lambda_{\max}$ (μm)	$P_{\max}$ (per cent)	$\delta P_{\max}$ (per cent)	Filters used
16	7.4	1.11	0.29	2.25	0.42	R, I
11	10.1	0.66	0.27	0.67	0.25	R, I
10	12.8	1.00	0.33	3.61	0.53	R, I
6	15.5	0.80	0.11	3.90	0.35	B, G, R, I
2	16.4	0.85	0.08	2.30	0.09	G, R, I
1	16.8	0.79	0.06	2.05	0.07	R, I
18	20.3	0.64	0.04	0.71	0.05	G, R, I
24	21.0	0.63	0.05	1.01	0.08	R, I
9	26.1	0.65	0.03	0.77	0.06	G, R, I
23	26.5	0.66	0.05	1.96	0.13	G,R, I
HD 24398	97	0.54	0.04	1.23	0.03	*multifilter

*Serkowski *et al.* (1975).

Fig. 1. In Fig. 1 the observations for stars 2, 9, 18 and 23, for which multifilter measurements with relatively small errors are available, have been plotted. The solid line curve represents equation (1). The values of $\lambda_{\max}$ and $P_{\max}$, and the errors in their determination $\delta\lambda_{\max}$ and $\delta P_{\max}$ resulting from the errors $\varepsilon_{\mathrm{p}}(\lambda)$ in the polarization measurements, are given in Table 1. These values are determined by the method of least squares.

For stars for which measurements with small errors are available in only two filters (R and I), $\lambda_{\max}$ is determined by using the following relation (Serkowski *et al.* 1975) resulting from equation (1)

$$\lambda_{\max}=(\lambda_{\mathrm{R}}\lambda_{\mathrm{I}})^{1/2}\exp\left\{\frac{\ln[P(\mathrm{I})/P(\mathrm{R})]}{2.3\ln(\lambda_{\mathrm{I}}/\lambda_{\mathrm{R}})}\right\}, \tag{2}$$

where $\lambda_{\mathrm{R}}(0.74\,\mu\mathrm{m})$ and $\lambda_{\mathrm{I}}(0.94\,\mu\mathrm{m})$ are the effective wavelengths of the R and I filters respectively. Equation (2) can be written as

$$\lambda_{\max}=0.83[P(\mathrm{I})/P(\mathrm{R})]^{1.82}\,\mu\mathrm{m}. \tag{3}$$

The value of $P_{\max}$ then follows from equation (1). Corresponding to the errors $\varepsilon_{\mathrm{p}}(\mathrm{R})$ and $\varepsilon_{\mathrm{p}}(\mathrm{I})$ in the measurements, the resulting errors in $\lambda_{\max}$ and $P_{\max}$ are also evaluated. The results are presented in Table 1 and discussed later in this paper. In these calculations we have ignored the very weak dependence of the effective wavelengths of the filters on the star colours. Any additional errors in $\lambda_{\max}$ and $P_{\max}$ resulting from the uncertainties in the effective wavelengths of the filters are negligibly small.

3 Results

The results on the values of $\lambda_{\max}$ and $P_{\max}$ together with the errors $\delta\lambda_{\max}$ and $\delta P_{\max}$ for the 10 stars are listed in Table 1. The projected angular distance (r, in arcmin) of the stars from the central protostellar *IRAS* source IRS 1 are given in the second column. The last column gives the filters used in the determination of $\lambda_{\max}$ and $P_{\max}$. Also included in Table 1 is the star HD 24398 [RA(1950) = $3^{\mathrm{h}}50^{\mathrm{m}}59^{\mathrm{s}}.0$, Dec(1950) = $31°44'12''.5$] at $r=97$ arcmin (B5 extends to

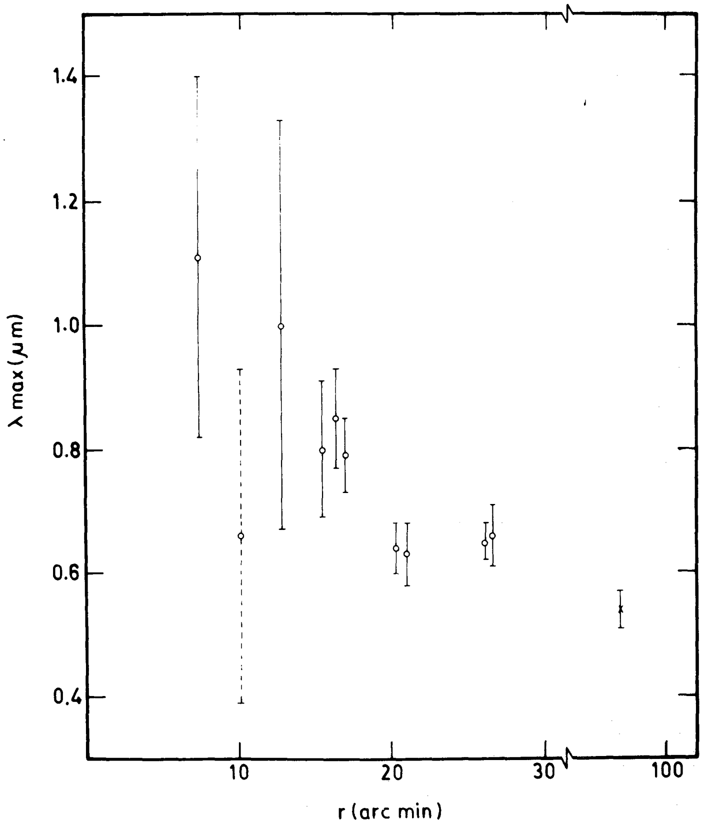

Figure 2. Plot of the wavelength of maximum linear polarization λ_{max} against the angular distance r from the central *IRAS* source IRS 1. Star 11, which is probably a foreground star, is shown with a broken-line error bar. The data for the star HD 24398 (shown with ×) have been taken from Serkowski *et al.* (1975).

only about 30 arcmin from IRS 1) from IRS 1, for which the values of λ_{max} and P_{max} have been taken from Serkowski *et al.* (1975). The value of $\lambda_{max}(=0.54\pm0.04\,\mu m)$ for HD 24398 is close to the mean interstellar $\lambda_{max}=0.545\,\mu m$ (Serkowski *et al.* 1975). Stars in Table 1 have been arranged in order of increasing angular distance (r) from IRS 1. From Table 1 we see that for stars in the region of B5 the values of λ_{max} show a large range, the trend of variation in λ_{max} being such that larger values are found closer to the cloud centre. This is shown in Fig. 2 where λ_{max} is plotted against r, the angular distance from IRS 1. For comparison HD 24398 is also included in Fig. 2.

4 Discussion

4.1 RADIAL VARIATION OF λ_{max} AND THE DUST GRAIN SIZE IN B5

It is evident from Fig. 2 that λ_{max} increases as one approaches the central regions of the cloud. Outside the cloud boundary HD 24398 shows $\lambda_{max}=0.54\pm0.04\,\mu m$, the typical normal interstellar value. In the outer parts of the cloud at $20'<r<30'$ the average value of $\lambda_{max}=0.65\pm0.03\,\mu m$ (stars 18, 24, 9 and 23). At distances $15'<r<20'$ the mean value for stars 6, 2 and 1 is $\lambda_{max}=0.81\pm0.06\,\mu m$. For stars at $r<15'$ the values of λ_{max} have large errors, but they are not inconsistent with a further rise in λ_{max} to $\simeq 1\,\mu m$. Star 11 (shown in Fig. 2 with a broken-line error bar) is probably a foreground star. Its projected angular distance from the cloud centre is small ($r=10'.1$) but it shows a low level of polarization ($P_{max}=0.67\pm0.25$ per cent). At $r\lesssim 20'$ the dust in B5 causes an extinction $A_V\sim 3$ mag to background stars (Young *et al.* 1982) and the polarization to extinction ratio shown by stars in this region $P_{max}/A_V\sim 1$ per cent per magnitude. If star 11 were background to the cloud it should have shown a polarization a factor of ~4 larger than what is observed. The low values of $P_{\max}$ and $\lambda_{\max}$ would be consistent with the possibility that it is a foreground star. If we exclude star 11, then near the central core of B5 at $7'<r<15'$ (stars 16 and 10) the mean value of $\lambda_{\max}=1.06\pm0.12\,\mu$m. Unfortunately we have no measurements for stars at $r<7'$, the core region of B5 which Young *et al.* (1981) found to be rotating in a direction opposite to the outer bulk of the cloud, and where the extinction rises steeply. In Fig. 2 it is interesting to note that $\lambda_{\max}$, before attaining a roughly constant but lower value of $\simeq 0.65\,\mu$m in the outer region ($20'<r<30'$), decreases sharply from $\simeq 0.80\,\mu$m at $r\simeq 17'$ which coincides with the rapid fall in the ^{13}CO column density observed by Young *et al.* (1982).

Since $\lambda_{\max}$ is linearly proportional to the mean grain radius $\langle a\rangle$, the observed variation of $\lambda_{\max}$ presented above indicates that the dust grains in B5 are larger in size than the mean interstellar dust grains and within the cloud the mean grain radius $\langle a\rangle$ increases as the line-of-sight passes closer to the cloud core. Since $\lambda_{\max}$ measures the average grain size along the line-of-sight, and along any line-of-sight through the cloud there are grains smaller than the mean in the outer parts of the cloud, the actual grain size in the inner regions will be larger than the line-of-sight mean. As an example, for the observed $\lambda_{\max}\simeq 0.65\,\mu$m (and $P_{\max}\simeq 1$ per cent) in the region $20'<r<30'$, the value $\lambda_{\max}\simeq 0.80\,\mu$m (and $P_{\max}\simeq 2$ per cent) found at $r\simeq 16'$ can arise provided there are grains within $16'<r<20'$ which would have given $\lambda_{\max}\simeq 1.0\,\mu$m if the lowering of the average due to the smaller grains in the outer regions could be avoided. This follows from the definition of averages. As the mean interstellar $\lambda_{\max}=0.545\,\mu$m, the value of $\lambda_{\max}\simeq 1.0\,\mu$m for dust in the inner regions of B5 requires the existence of dust grains there which are ~1.8 times larger in size and ~6 times more massive than the typical interstellar dust grains. In the central core the grains might be even larger.

Since B5 is a nearby (~160 pc) high galactic latitude ($b=-17°$) dark cloud, the observed polarization for background stars should be caused mainly by the dust in the cloud (Paper I). Any interstellar contribution to the observed polarization would tend to lower the observed value of $\lambda_{\max}$.

4.2 GROWTH AND SEGREGATION OF DUST GRAINS IN B5

As discussed above, the mean dust grain size in B5 is larger compared with the mean interstellar grain size, and within the cloud the grain size increases with decreasing radial distance from the cloud centre. Clearly, the grains have grown in size. But the mechanism of grain growth should be such that the observed radial variation in grain size is produced.

Larger values of the mean grain size (and hence $\lambda_{\max}$) in a dense cloud could be realized by: (i) grain growth due to the accretion of condensable heavy elements on to the grains (e.g. Greenberg 1968), (ii) coagulation of grains due to grain–grain collisions (e.g. Lefevre 1974) and (iii) gravitational segregation of grains (e.g. McCrea & Williams 1965; Flannery & Krook 1978) which gives rise to the preferential settling of larger grains towards the cloud centre (Bhatt & Desai 1982) since the settling time-scale is inversely proportional to the grain size. We now examine these processes for the case of B5.

4.2.1 *Grain growth by accretion*

Grain growth by accretion from the gas increases the size of individual grains. Grains can grow in size by a factor at most ~1.8 compared to the mean interstellar size (Greenberg 1978) when the supply of condensable elements (like O, C, N) from the gas is exhausted. The rate of growth of the grain radius '*a*' is given by

$$\frac{da}{dt}\simeq 3.4\times10^{-23}n(\mathrm{H})\,T^{1/2}\,\mathrm{cm\,s^{-1}}, \tag{4}$$

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where $n(\mathrm{H})$ is the number density of hydrogen atoms in the gas and T is the gas temperature (Greenberg 1978). For B5, the density is uniform across the cloud with $n(\mathrm{H_2}) \simeq 2\times10^3\,\mathrm{cm^{-3}}$ and the temperature varies from $T \simeq 15\,\mathrm{K}$ in the inner regions ($r \lesssim 15'$) to $T \simeq 40\,\mathrm{K}$ in the outer regions (Young *et al.* 1982). The time Δt needed for a fractional increase $\Delta\lambda_{\max}$ in $\lambda_{\max}$ can be written as

$$\left(\frac{\Delta\lambda_{\max}}{0.545\,\mu\mathrm{m}}\right)=\left(\frac{\Delta a}{0.15\,\mu\mathrm{m}}\right)\simeq 4.6\times10^{-14}[n(\mathrm{H_2})/2\times10^3\,\mathrm{cm^{-3}}](T/25\,\mathrm{K})^{1/2}\,\Delta t, \tag{5}$$

where $0.545\,\mu\mathrm{m}$ and $0.15\,\mu\mathrm{m}$ are the mean interstellar values for $\lambda_{\max}$ and 'a'.

From equation (5) we find that $\lambda_{\max}$ as large as $\simeq 1\,\mu\mathrm{m}$ can be achieved in a time $\Delta t \simeq 6\times10^5$ yr. However, the grain growth by accretion increases the size of the grains while the number of grains remains unchanged. Since the extinction $A_V = \pi a^2 Q(a) n l$ where n is the number density of grains, l is the path length along the line-of-sight and $Q(a)$ is the extinction efficiency, $Q(a)/a$ is a slowly increasing function of a, so that an increase in grain size with the number of grains unchanged would give rise to a large increase in the extinction ($A_V \underset{\sim}{\propto} a^3$). The dust mass also ($\propto a^3$) grows. Therefore, the dust to gas mass ratio in the cloud as measured by the ratio A_V/N_H, where $N_\mathrm{H}[=n(\mathrm{H})\,l]$ is the column density of hydrogen along the line-of-sight through the cloud, should be much higher than the interstellar value. For $\lambda_{\max} \gtrsim 0.80\,\mu\mathrm{m}$ (possibly as large as $\simeq 1\,\mu\mathrm{m}$) for B5 as compared to $\lambda_{\max} = 0.545\,\mu\mathrm{m}$ for the interstellar medium, the ratio A_V/N_H for B5 should be at least $3.2[=(0.80/0.545)^3]$ times larger compared to the normal interstellar value. However, Young *et al.* (1982) find that this ratio is not larger, but a factor of ~ 2 smaller than the normal value, except for the innermost core of B5 where the derived A_V is a lower limit. This discrepancy could be understood if grains are gravitationally segregated towards the cloud core. We will return to this possibility later.

4.2.2 Grain growth by coagulation

Grain growth by coagulation increases the grain size, but decreases the number of grains. The total mass of the grains remains the same. The ratio of the initial number of grains n_0 to the number of grains 'n' at time 't' is related to the ratio of the grain size 'a' at 't' to the initial size 'a_0' as: $(n_0/n) = (a/a_0)^3$. The coagulation process is governed by the relation (Lefevre 1974)

$$\frac{dn}{dt} = 4\gamma(3kT_\mathrm{d}a/\varrho_\mathrm{d})^{1/2} n^2 \tag{6}$$

where k is the Boltzmann constant, $\gamma(\simeq 2)$ is a coefficient which takes into account the van der Waals forces, T_d is the dust temperature and ϱ_d is the dust material density.

With $T_\mathrm{d} \simeq 15\,\mathrm{K}$ and $\varrho_\mathrm{d} \simeq 1\,\mathrm{g\,cm^{-3}}$ the time Δt required to attain $\lambda_{\max} \geqslant 0.80\,\mu\mathrm{m}$, starting from the interstellar $\lambda_{\max} = 0.545\,\mu\mathrm{m}$, follows by using $(n_0/n) = (a/a_0)^3 = (0.80/0.545)^3 = 3.16$ in equation (6) which can be written as

$$(n_0 - n)/n = 4\gamma(3kT_\mathrm{d}\bar{a}/\varrho_\mathrm{d})^{1/2} n_0 \Delta t, \tag{7}$$

where the grain size is assumed to be roughly a constant and a mean value $\bar{a} = 0.2\,\mu\mathrm{m}$ is used. The value of n_0 is estimated to be $\sim 2\times10^{-8}\,\mathrm{cm^{-3}}$ from the observed gas density [$n(\mathrm{H_2}) \simeq 2\times10^3\,\mathrm{cm^{-3}}$, Young *et al.* 1982] and a gas to dust mass ratio ~ 100, the initial grain radius being $a_0 = 0.15\,\mu\mathrm{m}$. We find from equation (7) that grain growth by coagulation to attain $\lambda_{\max} \gtrsim 0.80\,\mu\mathrm{m}$ requires a time $\Delta t \simeq 1.3\times10^9$ yr. This is too slow a process for grain growth to large sizes.

In both the processes of Sections 4.2.1 and 4.2.2 of grain growth described above, the radial variation in $\lambda_{\max}$ can arise due to grain growth if the cloud density increases towards the cloud centre. This is because in both processes the growth rate increases with increasing density. For the observed change $\lambda_{\max}$ from $\simeq 0.65\,\mu\mathrm{m}$ at $r \simeq 21'$ (where $T \simeq 40\,\mathrm{K}$) to $\simeq 0.80\,\mu\mathrm{m}$ at $r \simeq 16'$ (where

$T\simeq15$ K) a density enhancement by a factor of $\simeq4$ is needed for which Young *et al.* (1982) find no clear evidence.

4.2.3 *Gravitational segregation*

Dust grains in a cloud acted upon by the forces of gravity and viscous drag acquire a drift velocity relative to the gas directed towards the centre of gravity and thus settle towards the cloud centre (e.g. Flannery & Krook 1978). Bhatt & Desai (1982) have shown that this process gives rise to a preferential segregation of larger grains (from a distribution of grain sizes) towards the cloud centre because the larger grains settle faster. The gravitational settling time-scale τ is inversely proportional to the grain size and is given by

$$\tau=(3W/4\pi G\varrho_{\mathrm{d}}a), \tag{8}$$

where W is the mean thermal velocity of the gas molecules and G is the gravitational constant. For H_2 gas at temperature $T\simeq15$ K the settling time-scale $\tau\simeq10^8$ yr. But the time Δt required by this size dependent segregation of grains to produce a significant variation in the mean grain size $\langle a\rangle$ along the line-of-sight (and hence in $\lambda_{\max}$) passing through the cloud at varying radial distances from the centre is only a fraction ($\sim1/3$) of the time τ (required $\Delta t\simeq3\times10^7$ yr, Bhatt & Desai 1982). However, this mechanism predicts a decrease in the value of $\lambda_{\max}$ in the outer parts of the cloud below the initial value of $\lambda_{\max}$, because the segregation process leaves the smaller grains in the outer regions of the cloud. Therefore, if the gravitational segregation is the cause of the observed radial variation of $\lambda_{\max}$ in B5, the mean grain size in the cloud must have already been larger than the interstellar value and the segregation process is at work on the modified grain size distribution. This is required, for we observe $\lambda_{\max}\simeq0.65$ μm, even in the outer parts of B5, which is larger than the mean interstellar value of $\lambda_{\max}=0.545$ μm.

We now compare the time-scales involved in the different processes discussed above with the probable cloud lifetime. The time Δt required to produce the observed values of $\lambda_{\max}$ in B5 is $\simeq6\times10^5$ yr for grain growth by accretion, $\simeq3\times10^7$ yr for gravitational segregation and $\simeq1\times10^9$ yr for coagulation of grains. The dark cloud B5 is located at one end of the Perseus OB2 molecular cloud (Sargent 1979) and an age of $\sim4\times10^6$ yr was estimated for the stars in the Perseus OB2 association by Blaauw (1964). But the age of the cloud since its formation would be much larger than this. Though for an individual cloud it is not possible to make a precise determination of its age, the mean lifetime of molecular clouds is estimated to be $\sim10^8$ yr (e.g. Bash 1979; Blitz & Shu 1980; Cohen *et al.* 1980; Solomon & Sanders 1980). This is much larger than the time-scale for grain growth by accretion, smaller than the coagulation time-scale by an order of magnitude and comparable to the time-scale for gravitational segregation of grains. Because of the long time-scale required for coagulation we consider this process to be unimportant when compared with the grain growth by accretion and grain segregation in B5.

Since the time-scale for grain growth by accretion is about two orders of magnitude smaller than the cloud lifetime, dust grains in B5 must have grown to the mean size corresponding to the observed $\lambda_{\max}$ in just about 10^6 yr from the time of its formation. However, as mentioned earlier, this would give rise to a large increase in extinction and the dust to gas mass ratio which is not observed (on the contrary Young *et al.* (1982) found extinction and the dust to gas mass ratio in the outer parts of the cloud ($r\gtrsim5'$) to be about a factor of 2 less than normal). We suggest the following possibility.

At the time of its formation B5 could have had a normal dust to gas mass ratio and normal grain size distribution (corresponding to $\lambda_{\max}\simeq0.55$ μm, similar to the mean interstellar value). Dust grains grew rapidly to large size (corresponding to $\lambda_{\max}$ as large as $\simeq1$ μm) on a time-scale of $\sim10^6$ yr. Gravitational segregation of dust grains on a time-scale of $\sim3\times10^7$ yr removed the larger grains (which make up most of the dust mass) towards the cloud core. This would cause the observed variation of $\lambda_{\max}$ (decreasing with increasing r) and also decrease the dust to gas mass ratio in the outer regions of the cloud. The increased dust concentration in the core is consistent with the observed lower limits on the extinction values for this region (Cernicharo & Bachiller 1984).

5 Conclusions

Polarization measurements for stars in the region of the dark cloud B5 have been used to determine $\lambda_{\max}$, the wavelength at which linear polarization attains its maximum value. Since $\lambda_{\max}$ is proportional to the average grain size along the line-of-sight, the results indicate that:

(i) The average dust grain size in B5 is much larger than the mean interstellar value.

(ii) The average grain size along the line-of-sight shows a variation with the angular distance from the cloud centre. The mean grain size increases with decreasing distance from the cloud core where *IRAS* detected a newly born star IRS 1.

(iii) Large dust grains almost twice the size of the mean interstellar grains are present in the inner regions of B5.

The large values of $\lambda_{\max}$, its radial variation, the observed extinction and the dust to gas mass ratio in B5 could be understood if the dust grains in B5 grew by accretion of condensable heavy elements from the gas on a time-scale of $\sim 10^6$ yr and then the larger grains segregated gravitationally towards the cloud core on a time-scale of $\sim 3\times 10^7$ yr.

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