INTENSITY CHANGES IN SUNSPOTS AND STARSPOTS

The observations of sunspots have surprises to offer even to this day. A very elusive fact about sunspots is their relative brightness with respect to the undisturbed photosphere. Until recently, there have been conflicting reports regarding the presence of significant differences in the relative brightness of individual spots. The confusion existed because most of the observations were in the visual, where the scattered light caused a lot of uncertainties. However, the work of Ekmann and Maltby (*Sol. Phys.*, **35**, 317, 1974) in the near infrared clearly showed that there were significant differences in the darkness of individual spots. What turned out to be more interesting was that Albregtsen and Maltby (*Nature*, **274**, 41, 1978) were able to correlate the umbral intensity at 1.67 µm with epoch in the solar cycle. However, since the latitude of occurrence of sunspots changes with the epoch, they have tried a correlation with latitude as well. They did succeed but with a somewhat smaller correlation.

Two factors that could change the sunspot intensity are (i) a change in the Wilson depression and/or (ii) a change in the efficiency of non-radiative energy transport. As can be seen from sunspot models, the deficiency in gas pressure, with respect to the undisturbed photosphere, at a depth of unit optical thickness in a sunspot, is an extremely sensitive function of the Wilson depression (Maltby, *Sol. Phys.*, **55**, 335, 1977). Thus, very small changes in the Wilson depression are sufficient to account for the observed change in the relative intensities. On the other hand, any change in the efficiency of non-radiative transport, possibly caused by changes in the magnetic properties of the sunspot, could result in changes in the radiative output. Both these possible causes for the change in the relative intensity are closely linked with the theory of the formation and structure of sunspots.

A similar effect could be thought of as existing for starspots too. The stars that are suspected to be spotted, show changes in their light output which are attributed to the passage of regions of differing intensity across the line of sight. The secular changes in the mean depth of the light curve have been monitored and are attributed to possible variations in the latitudinal and longitudinal extent of the spot phenomenon (Bopp and Evans, *Mon. Not*, R. *astr. Soc.*, **164**, 343, 1973). However, no significant changes in the B-V colour were detected at that time. Hence the spot was assumed to be completely black in their model. More recent BVRI observations of BY Diaconis (Davidson and Neff, *Astrophys. J.*, **214** 140, 1977) did show up changes in the R-I colour. These observations fit a starspot model, which, spart from requiring a change in longitudinal extent from 200° to 220° in about an year, needs a change in average spot temperature from 3780 K to 3670 K. It remains to be seen whether further photometric observations would show a definite trend in the variation of starspot temperature and intensity. Spectroscopy of this and similar stars at various phases of the light variation will almost certainly yield a better insight into the spot phenomenon in general.

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FROM DUST TO DUST AND IN BETWEEN

The intersteller grains have fascinated astronomers for the past five decades. We know that something in the form of tiny submicroscopic sized solid particles exists out there. However, their true nature is still an enigma. Michael J. Barlow [*Mon. Not. R. Astr. Soc.*, **183**, 367-395 (Paper I), 397-415 (Paper II), 417-434 (Paper III), 1978] has investigated the destruction and growth of dust grains in various astrophysical situations. We summarize some of his results.

In Paper I, the physical sputtering, by which lattice particles in a solid grain material are knocked out by bombarding atoms or ions, has been discussed. From the existing experimental data for low energy sputtering it has been concluded that $E_T = 4H_S$ where, E_T = the threshold energy below which no sputtering occurs and H_S = the mean energy required to remove one lattice molecule from a grain surface. It appears that the threshold energy E_T and the sputtering yield (Y) at low energies of the incident particles are independent of both the angle of incidence and the energy transfer factor. E_T and Y depend only on H_S. This suggests that the sputtering ejection mechanism must be a process of resonance energy transfer rather than a billard ball-type collision sequences often used in the existing theories of low energy sputtering. A table is given for the sputtering yield factor (S) for various grain materials and incident particles like hydrogen, Helium and CNO group. The atoms and ions of the same element are considered to give the same value of S.

Assuming a hot gas in equipartition the thermal sputtering rate in H II regions is important for H and He only. Both these atoms give identical contributions with the assumed abundance of $n_{He}/n_H = 0\ 1$. Only ice grains at the outer edge of a dense H II region surrounding early type stars would suffer significant destruction due to sputtering. The lifetime of grains in this case is $\sim 10^4$ years which is of the same order as the dynamical lifetime of a dense H II region. The sputtering in an inter-cloud medium seems to be unimportant.

Shock waves produced by cloud-cloud collisions or by expanding supernova remnants can also cause sputtering of grains. Here, unlike the situation for hot gas in equipartition (H II region), the CNO group makes a significant contribution to the total sputtering rate in a shock, whereas H atoms make only a maximum of 16% to the total sputtering rate. This difference in behaviours between light and heavy particles is explained as follows. The sputtering rate is proportional to the product of velocity (v) and energy ($\frac{1}{2} . mv^2$) of the incident particle. For a gas in equipartition, the energy is the same for all particles, so that v and thus the sputtering rate will be smaller for the heavy particles. In the case of shock waves, a grain moving with a macroscopic velocity with respect to the shocked gas, all particles have essentially the same velocity relative to the grain, so that the energy and thus sputtering will be predominant for the more massive particles. The supernova remnants are shown to provide most important situation in which sputtering lifetimes are 2×10^8 years for ice grains and $(5 \text{ to } 20) \times 10^8$ years for refractory grains. These lifetimes are almost independent of grain radius and only weakly depend on sublimation energy H_S.

For cosmic rays of MeV and GeV order, it has been shown that the collision cascade sputtering dominates evaporative sputtering produced by thermal spikes. Even if all the electron excitation energy loss by fast particles in a grain material could be transferred to the lattice particles, the observed cosmic ray flux spectrum could not cause significant destruction of the ice grains. Cosmic X-rays can interact with the grains primarily via the photo-electric effect but their role in grain sputtering is insignificant.

In Paper II, Barlow has considered the chemical reactions on the surfaces of ice grains. The chemical sputtering on grain via modified gas kinetic reaction, $H_2O + H \rightarrow OH + H_2$, even in shock waves yield lifetime of ice grains equal to 4.1×10^5 yrs which is longer than that for physical sputtering, the grain slowing time and gas cooling time. Therefore chemical sputtering of ice grains will be of no importance in the interstellar medium. However, if an impinging H atom gets trapped on the surface of graphite grain by chemisorption potential, it can react directly with the lattice carbon atoms. If the grain temperature exceeds the critical temperature above which reaction of an atom of given species can occur faster than the time for recombination, graphite grain of radius $a = 1.5 \times 10^{-6}$ cm will be destroyed in times of order $6 \times 10^5 / n_H$ yrs in a warm molecular cloud and $6 \times 10^6 / n_H$ yrs in H II region, where n_H = number density of gas phase H atoms. It has been suggested that such a destruction mechanism could provide an explanation for the weak 2175Å extinction feature towards certain stars immersed in H II regions, e.g., θ Ori system in the Orion complex and 30 Doradus nebula in LMC. It is for this reason that the E_{B-V} towards η Car derived on the basis of the magnitude of extinction hump should be considered a gross underestimate. No such suface reaction will take place in diffuse interstellar clouds or in intercloud medium because the graphite grain temperature would be too low ($\lesssim 33$ K). Thus the overall abundance of graphite grains in the interstellar medium would not be affected significantly by the localized destruction of graphite grains in young H II regions and in the cores of warm molecular clouds due to the rarity of the O stars.

The question of destruction of grains by grain-grain collisions during cloud collisions along magnetic field lines has been examined from the viewpoint of dynamical anlysis in shocked region after the clouds come in contact. The destruction lifetime for adiabatic or isothermal shocks turns out to be 1.4×10^{10} yrs which is of the order of the age of the Galaxy. It can therefore be concluded that the classical Oort-Van de Hulst grain-grain collision mechanism is unimportant as a destruction mechanism for ice grains during cloud collisions. Another destruction mechanism involves the collision in a shock-front of grains from the same cloud due to their spiraling around transverse magnetic lines of force. The lifetimes against destruction in this case is $\simeq 10^9$ years for ice, silicate and iron grains and are much longer than those found for sputtering by supernova remnants. Thus grain-grain collisions are not a significant overall destruction mechanism for interstellar dust and in shock-fronts, destruction by sputtering will always be more important.

The grain destruction by photodesorption, defined as a process whereby an adsorbed particle is desorbed (ejected) from a surface by a photon via a quantum process, has also been discussed on the basis of somewhat sparsely available experimental data. A photodesorption cross section $\sigma_{pd} = 5 \times 10^{-18}$ cm^2 for molecules on ice mantle and corresponding yield $Y_{pd} = 5 \times 10^{-3}$ for each incident photon with $912 \text{ Å} < \lambda < 1900 \text{ Å}$ has been adopted. Photodesorption by infrared photons is unlikely to be important since vibrational oscillator strengths are typically $\simeq 10^{-5}$ times those of electronic transitions, whereas the diffuse infrared photon flux in the wavelength region of interest is only $\simeq 10^2$ time that of ultraviolet photons capable of photodesorption in unobscured regions of intersteller space. Even in shielded clouds ultraviolet photodesorption will always be the controlling factor in mantle growth. Once the ice grains are exposed to ultraviolet photons, the mantle will be destroyed by photodesorption before they can be converted into refractory types of less volatile grains. It is found that for an ice grain with $a = 10^{-5}$ cm, the lifetime against destruction by photodesorption is $\sim 5 \times 10^4$ years.

In Paper III, surface molecular recombination on grain surfaces, heavy element depletion in interstellar space and growth of mantles on grains have been investigated. Based on quantum mechanical calculations and experimental data on adsorption energies and the activitation energy for migration on the surface of graphite or iron grains, it has been shown that H_2, CH_4, NH_3, H_2O and HF among other molecules can be desorbed from graphite surface. Note that the desorption always occurs in the form of a saturated hydride because of the removal of the bond from the surface and hence reducing the binding energy. None of the heavier atoms will be desorbed as a monohydride from the graphite grain. Si, Ge and probably Sn should desorb as tetrahydrides but Pb may be trapped. Boron should be desorbed as BH_3. All other metal atoms will be trapped except the alkali atoms like Na, K, Rb, Cs and also Zn. Ca and Ti, because of their large physical adsorption binding energy on silicate grain surface and large atomic polarization will be trapped on silicate grains and Fe might also be trapped. All other elements have their hydride recombination energy in excess of adsorption energy and so they are expected to be desorbed as monohydrides.

The depletion of certain heavy elements can be considered in two categories (1) a constant underlying depletion of certain elements (*e.g.* Fe and Si) due to grain membership (2) The variability of the depletion factors along different lines of sight can arise due to adsorption and trapping of metal elements on to grain surfaces competing against sputtering. The high velocity shocks can destroy even the refractory grains and can thus account for the undepleted abundances of Fe and Si in high velocity cloud components. In the diffuse interstellar medium, non-metallic elements should not be depleted by trappings on grain surfaces except in shielded dense clouds. Carbon is depleted by a factor of 6 of the formerly adopted cosmic abundance of carbon. This can account for known features of 2200 Å extinction hump, CO molecules, observed temperatures of the diffuse clouds etc.

The depletion of Na, K and Zn exhibit a trend quite different from other metals because the reaction, $MH + H \rightarrow M + H_2$, M = Na, K or Zn, prevents these atoms from being trapped on to the grain surfaces in diffuse clouds. However, in dense clouds the formation of H_2 takes precedence. H_2 cannot react with adsorbed metals since the dissociation energy of H_2 is larger than the recombination energy of metal hydride molecules. Therefore, at high cloud densities with low H atom abundances, Na, K and Zn will begin to be depleted. The observatons indicate that Na is only lightly depleted towards stars with $E(B-V) \leqslant 0.10$. For diffuse interstellar clouds with $E(B-V) \lesssim 0.3$ the depletion factors for Na and K are between 3 and 10. Considering specific example of dense cloud towards ζ Oph, it is known that H_2 density $\gtrsim 10^3$ cm^{-3}. At this density $n_H / n_{H_2} \sim 3 \times 10^{-2}$. The elements Na, K and Zn appear to be depleted by a factor of 2 due to adsorption and trapping on the surface of grains. This is in addition to the depletion factor of 3 for Na and K and nil for Zn, the latter due to lower condensation temperature for Zn.

The rest of the common metallic elements should undergo differential depletion at all cloud densities, due to surface adsorption and trapping unless they are returned to the gas phase by sputtering mechanism such as interaction with shock wave. Among the noble gases, He and Ne because of their low adsorption energies and Ar because of its low critical sputtering velocity will be prevented from accreting on to grain surfaces by ordinary thermal desorption. In circumstellar H II region and intercloud medium, there is no significant depletion of atoms other than that accounted for by grain membership.

Finally the star question of growth of ice mantle must be examined. The predicted ice band at 3.1 μm has always been observed only in the direction of dense molecular clouds. The optical depth $\tau_{ice} \leqslant 0.02$ for the highly reddened star VI Cyg No. 12 ($A_V = 10$). Whereas $\tau_{ice} = 1.4$ towards Becklin-Neugebauer object. Looked from other angle, one has for BN and VI Cyg No. 12, $\tau_{ice} / \tau_{silicate}$ in the ratio of $\geqslant 15$. This suggests a great difference in the mass of ice coating on grains towards these two objects. This is understood in Barlow's model as being due to the BN object being situated in a dense shielded molecular cloud which favours the growth and retention of ice mantle. The direction towards VI Cyg No. 12 lacks any molecular cloud and the intervening material seems to be spread over a long path implying low density. Alternatively, the gas may be accumulated in an intracluster shell exposed to the intense ultraviolet radiation field of the entire OB association. These options would not permit mantle growth. Similarlity towards the Galactic center, $\tau_{ice} < 0.25$, $A_V / \tau_{ice} \geqslant 110$, one samples a 10 kpc path through mostly "normal" interstellar material. The recombination and ejection processes alone will inhibit growth of mantles in regions of low shielding. In order for ice mantles to grow against the hostile processes of dissociation by the interstellar ultraviolet radiation field, molecular recombination, photodesorption etc. the grains have to have a shelter in the regions of sufficiently high shielding such as the dense dust clouds. Otherwise only the refractory grain species would remain.

In epilogue, a Shakespearean may eulogise with a lovely tune : "And yet, to me, what is this quintessence of dust ? man delights not me; no, nor woman neither, though, by your smiling, you seem to say so."

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