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THE BEHAVIOUR OF THE POLARIZATION OF POLYDISPERSE INTERPLANETARY CLOUD

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A preliminary study of the behaviour of polarization on polydisperse clouds based on computed models is presented. The possibility of the application of the results on very typical optically thin cosmic clouds, such as dust atmospheres of comets, is discussed.

Information concerning the physical properties of the dust particles in some astronomical objects such as zodiacal light, comets or reflexion nebulae is still very scarce. The present methods of determination (or estimation) of the sizes and refractive indices are based usually on the assumption of scattering properties of polydisperse media likely to be found in interplanetary or interstellar space, by restriction to the case of spherical particles and by using a simplified assumption to size distribution function and fitting of the computed models on the observations of real objects.

Even if the efficiency of this somewhat awkward method is not sufficient enough to describe very complicated structure of cosmical dust, the computed models ranked out at least the most probable type of the real cosmic dust particles.

The computation of the models is made for a defined scattering element. The scattering element considered here, situated at a given point, may be a single spherical homogeneous particle endowed with the idealized optical properties, or a small-volume element of space occupied by a number of such particles, of various sizes and optical properties, whose positions are not fixed but must be in a random motion within the time interval in which an observation is to be made. (Otherwise the scattering process would be defined better as the interaction between the complex amplitudes than as the intensities.) It means that the volume of space must be so large that a perfect sample of all the particles of the studied medium it represents is included and optically thin.

A very typical astronomical object which nearly fulfils these conditions is the dust atmosphere of a comet which represents such a space scattering element quite perfectly. Except the very close vicinity of the cometary nucleus, where the optical thickness of the dust atmosphere may be somewhat larger, the cometary head and tail can be supposed to be optically thin media where the effects of second and higher-order scattering are negligible. Moreover, the phase angle is defined by the position of the object in its orbit. Therefore, the comets seem to be favourable objects for the application of the classical theory of the light scattering.

The colour or spectral gradients of the cometary continuous radiation have been studied by several authors (F. Walker 1959, M.H. Johnson 1960, W. Liller 1960, V. Vanýsek 1960, K. Pflug 1968, D. Challonge and M. Bloch 1966). They all found faint reddening of solar radiation scattered on the dust atmosphere of comets. Recently, W.L. Gebel (1970) found for Ikeya-Seki (1967n) and Honda (1967b) no significant difference in spectral distribution of the Sun and comet's continuum which conflicts with the results of previous studies. However, this discrepancy might be explained by the reflection on the nucleus and relatively very large particles in the inner part of the cometary head.

The reddening of the cometary continuum, for instance, implies significant differences between dust particles in comets and in reflection nebulae, where some tendency of "bluening" on interstellar grains (relatively to the colour of the illuminating star) is observed. Nevertheless, the application for spectral relative gradient Sun-comet (or colour difference) is de-emphasized by the fact that the size-distribution factor for the particles is virtually unknown. Although the integration of the phase function over large size interval swept out some resonance peaks, the numerical process involving the phase function (particularly the number of integration steps) modified slightly the phase function and the small differences of intensities in two or more wavelengths of scattering light are uncertain. Therefore, the interpretation of direct comparison of computed and observed spectral distribution must be considered as tentative only.

On the other hand, the polarization pattern of scattering polydisperse medium seems to be more efficient for the inspection of actual physical properties of the dust particles, especially for a sample of larger particles.

The polarization for a given spherical scatterer is determined by size parameter $x = ka$ ($k = 2\pi/\lambda$ is wave number, a radius of the particle), complex refractive index $m = n - in'$, and phase angle ϑ, where for the forward direction of the incident radiation $\vartheta = 0^o$.

The degree of polarization p_o of a single particle is given by relation

$$p_o = \frac{i_1(\vartheta) - i_2(\vartheta)}{i_1(\vartheta) + i_2(\vartheta)} \qquad (1)$$

where dimensionless intensity parameters

$$i_j(\vartheta) = i_j(x,m,\vartheta) \ , \quad (i_j = 1,2)$$

are identical with those of van de Hulst (1957) and are related to differential cross-section for a given ϑ

$$\sigma_j(\vartheta) = k^{-2} i_j(\vartheta)$$

For the polydisperse medium in unit volume the polarization $p(\vartheta)$ is determined by expression

$$p(\vartheta) = \frac{P_1(\vartheta) - P_2(\vartheta)}{P_1(\vartheta) + P_2(\vartheta)} \ . \qquad (2)$$

$P_j(\vartheta)$; $(j = 1,2)$ are normalized phase functions.

$$P_j(\vartheta) = 4\int_0^\infty n(x)\, i_j(\vartheta)\, dx \bigg/ \int_0^\infty x^2\, n(x)\, Q_{sc}(x)\, dx \; ; \qquad (3)$$

where $Q_{sc}(x)$ is the scattering cross-section and $n(x)$ number of particles for $x + dx$ size interval. For practical purposes the $n(x)$ can be replaced by size distribution function valid in limits of numerical integration x_1k^{-1} to x_2k^{-1}. Where only the polarization is computed, the integration of scattering cross-section can be omitted from the numerical procedure.

The calculations of Mie scattering on optically thin polydisperse media carried out by the author on CDC 3600 computer at University of Massachusetts' Research Computing Centre, permitted the study of scattering behaviour of more than 200 optically thin cloud models for wavelengths $\lambda = 0.36\mu$; 0.44μ ; 0.55μ; and 0.61μ. The limits of the size parameter are $x_1 = 0.8$; $x_2 = 15$ for $\lambda = 0.55\mu$. Other parameters are listed in Table 1. The results of several selected samples are presented in Figs. 1, 2, and 3.

There exists some typical behaviour of the scattering pattern for dielectric and conductor's polydisperse optically thin media, in used limits of x.

Generally the integration process over particle sizes leads to the depolarization effect.

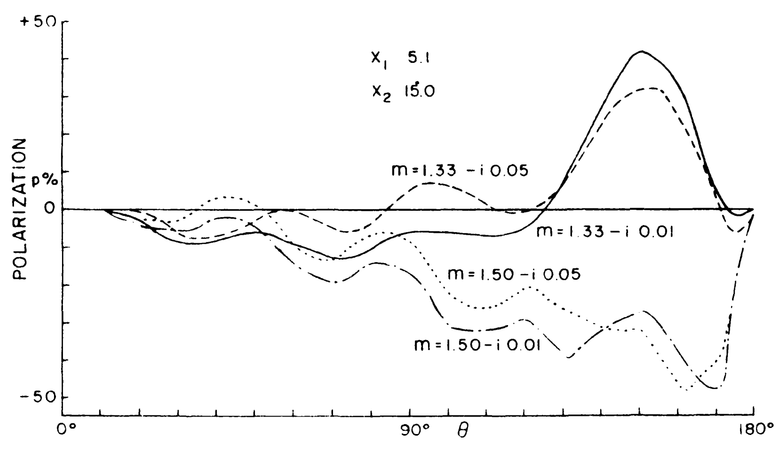

Figure 1

This is due to the fact that the angular scattering pattern of polydisperse medium with a continuous size spectrum should be a smoothed function of x , without several maxima and minima characteristics of single particles or monodispersed cloud.

The probability that the polarization $p(\vartheta)$ of the scattered light in the polydisperse cloud will be at a given phase angle the

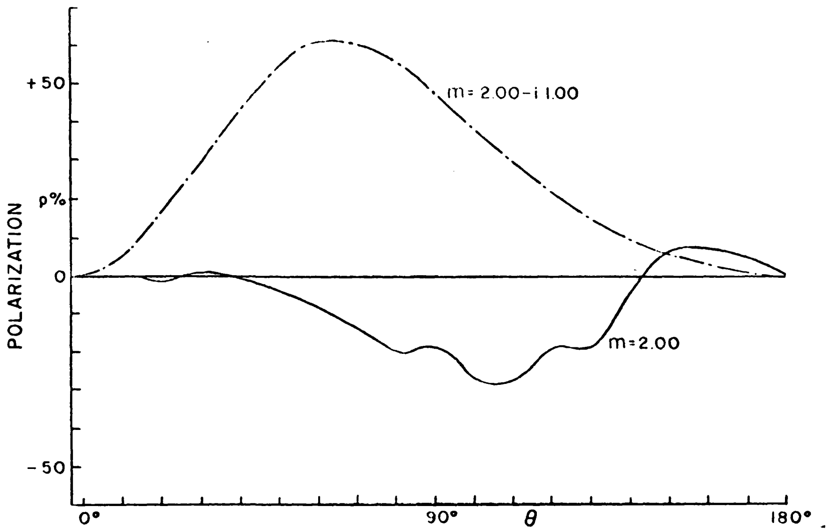

Figure 2

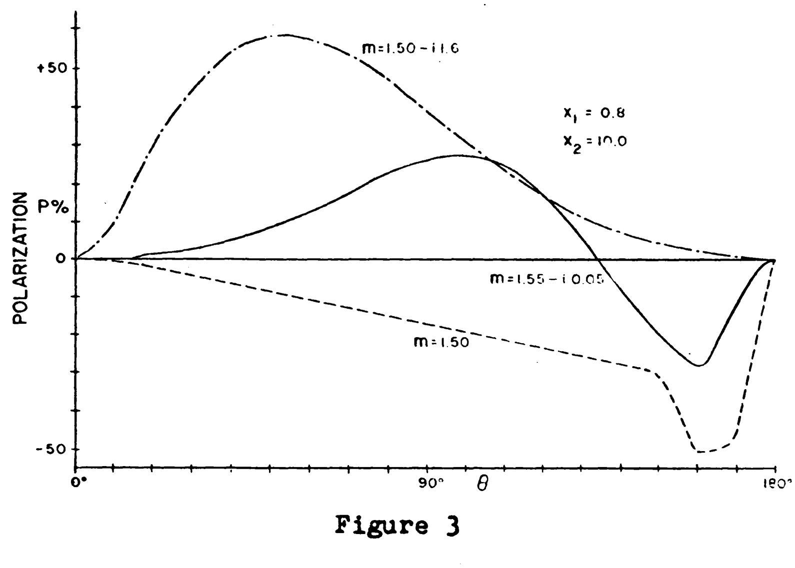

Figure 3

T a b l e   1

Characteristics of the illustrated samples of polydisperse clouds
(Figs. 1, 2, 3)
Reference wavelength $\lambda = 0.55\,\mu$

Range of x x_1	x_2	Distribution function $\phi(x)$	Refractive index $m = n - in'$ n	n'	Type of particles
5.1	15.0	x^{-4}	1.33	0.01	ice particles
			1.33	0.05	
			1.50	0.01	silicate-like
			1.55	0.05	
0.8	10	x^{-4}	1.50		
			1.55	0.05	
			1.50	1.6	
			2.00		limonite-like
			2.00	1.00	

same as the polarization $p_0(\vartheta)$ for dominant particles with dominant size x_0 is very low as far as the x range of interest is large enough. The probability that the polarization $p(\vartheta) < p_0(\vartheta)$ is very high and generally the depolarization effect must be expected at any ϑ. Then the absolute value of depolarization factor

$$D(\vartheta) = \frac{p_0(\vartheta) - p(\vartheta)}{p_0(\vartheta)} \leq 1 \qquad (4)$$

will be different from zero at any ϑ (except at 0° and 180°).

The difference in polarization on clouds of absorbing particles and clouds containing dielectrics is very significant:

a) The "positive" polarization is to be found for absorbing clouds (even with moderate absorbers) with maximum between $\vartheta = 60^\circ$ to 90°.

This very remarkable and most important property is connected with the conductivity of the scatterers. The shift of the polarization maximum to lower phase angles with increasing imaginary part of refractive index seems to be very typical.

b) The "negative" polarization (i.e. the negative $p(\vartheta)$ from relation (2)) near phase angles $150^\circ - 170^\circ$ is very typical of all studied clouds models with dielectric particles.

Even if the monodisperse cloud containing large absorbing particles can exhibit also negative polarization, for the dielectric polydisperse scattering medium such behaviour is most typical.

This is not valid for clouds with very small particles ($x \leq 1$) where the scattering pattern is almost the same as for the Rayleigh scattering and $p(\vartheta)$ is always positive with maximum at $\vartheta = \pi/2$.

The polarization of cometary continuum has been studied by several authors. The polarization of cometary light is usually over 10% and increases up to 25% or more as follows from the measurements made in extended wavelength intervals (M. Blaha et al.1958, A.A. Hoag 1958, H.M. Johnson 1960, D.E. Blackwell and R.V. Willstrop 1957) or in monochromatic light (M.K.V. Bappu and S.D. Sinvhal 1960, M.K.V. Bappu et al. 1967). Rémy-Battiau [1)] (1964,1966) shows that the polarization indicated the presence of dielectric particles rather than metalic micrometeorites. Similar conclusion follows from the study by Donn, Powell and Rémy-Battiau (1967). This is in agreement with the Whipple icy conglomerate model for the cometary nuclei.

The present available polarization measuring of comets does not permit interpretation with sufficient accuracy because the observation period covers only a small range of phase angles. From the present discussion, however, it is evident that the change of polarization with the phase angle is more important for the estimation of the physical properties of the scattering medium than the absolute value of polarization degree.

For instance, the fast change of polarization with phase angle in the backward direction (if detected on real objects) might be a very significant support for the present hypothesis of dielectric character of the dust grains in the cometary atmospheres. There-

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1) Rémy-Battiau (1966) used for computation of the polarization (as well as the phase function) average values of $i_1(\vartheta)$ and $i_2(\vartheta)$, as some simplification of the numerical procedure, which might not be quite helpful in determining the scattering properties of aggregates of particles.

fore, the polarization measurements of faint distant comets are very desirable.

A most detailed study based on more than 200 models of polydisperse clouds is in progress and it will be published later.

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