ON THE OBSERVED POLARIZATION OF COMET IKEYA-SEKI (1965 VIII)

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(Received 7 April, 1978)

Abstract. It is shown that the grain material should be of the silicate type in order to produce the observed polarization reversal in the comet Ikeya-Seki. The polarization reversal is shown to arise as a result of the segregation of different sizes of grains in the tail of the comet due to the effect of radiation pressure.

1. Introduction

An analysis of the observed polarization in comets gives information about the nature of the particulate matter. In fact, it is found that the amount and nature of polarization is quite sensitive to the nature of the material of the dust. Large number of polarization observations and their analysis have been carried out on different comets in the past (Bappu and Sinvhal, 1960; Liller, 1960; Remy-Battiau, 1964, 1966; Donn *et al.*, 1967; Clarke, 1971). The polarization observations of interest here are those of comet Ikeya-Seki (1965 VIII) made by Weinberg and Beeson (1975, 1976). They have made extensive polarization measurements of this comet at different wavelengths and for different scattering angles. However, in the above-mentioned paper they have given the detailed results for only $\lambda = 5300$ Å. The most interesting result of their observation is the change in the polarization from positive to negative values as the scattering angle (θ) changes from 116° to 135°. They have made an analysis of these observations in terms of the Mie scattering theory for different constant values of the refractive index and for different values of α in the size distribution function, $N(a) \propto a^{\alpha}$.

Here, we would like to analyse these polarization measurements based on the particle models. We will try to show that there is a separation of particles of different sizes along the tail of the comet which is expected from physical reasoning and this can explain in a natural way the observed polarization.

2. Analysis of Grain Models

Let us first examine the polarization arising out of single grains. In Figures 1 to 6 we have shown the results based on exact Mie theory (van de Hulst, 1957) for the scattering angles covering the region of observations of Weinberg and Beeson and for different grain materials, although there is some indication that the grains in comets may

Astrophysics and Space Science **57** (1978) 491–497. *All Rights Reserved*

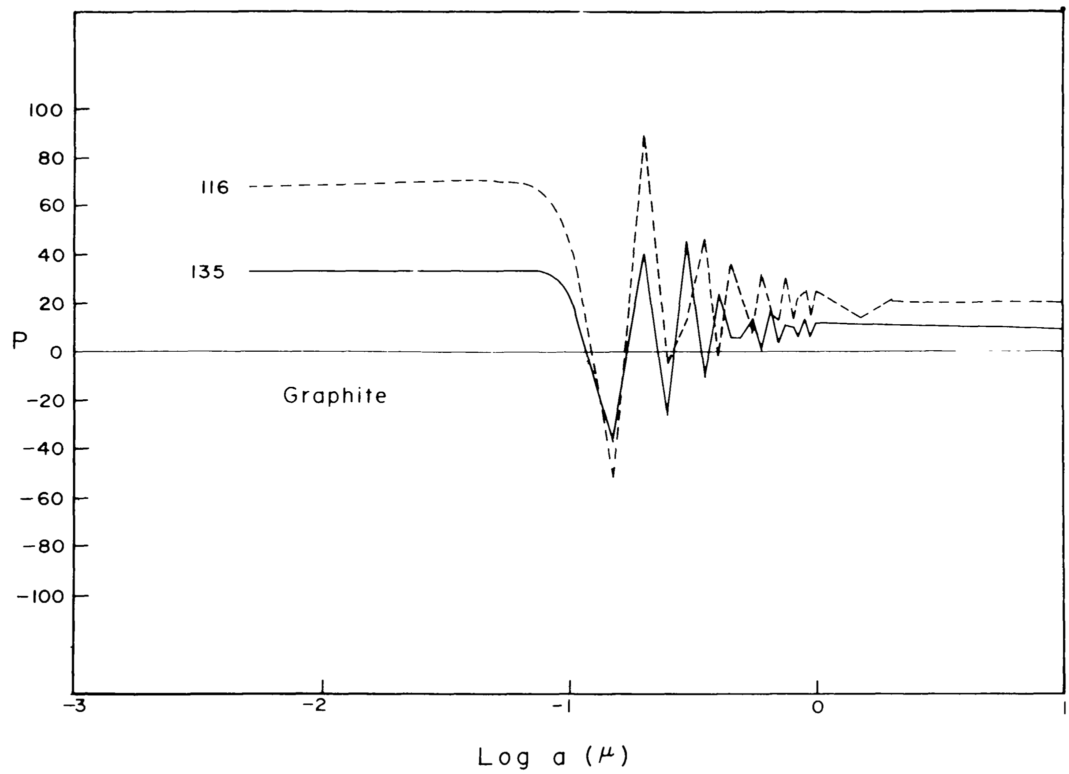

Fig. 1. Curve of polarization versus particle size for $\lambda = 0.53\,\mu$ and for scattering angles of 116° and 135°.

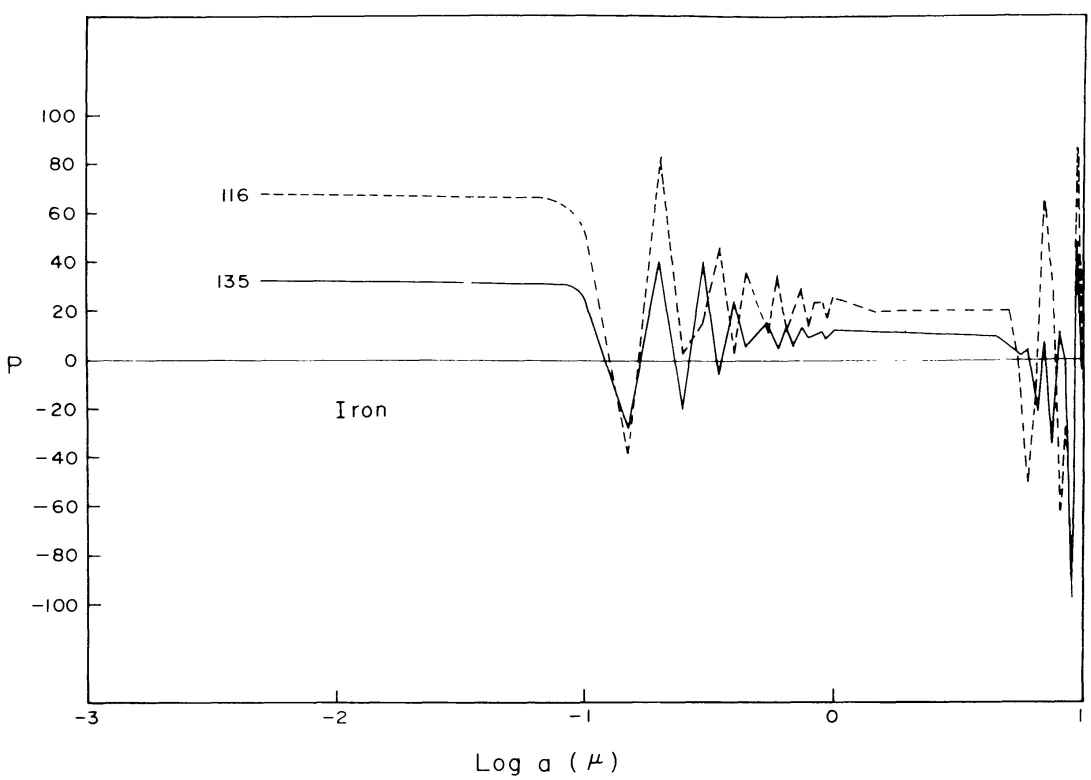

Fig. 2. As Figure 1.

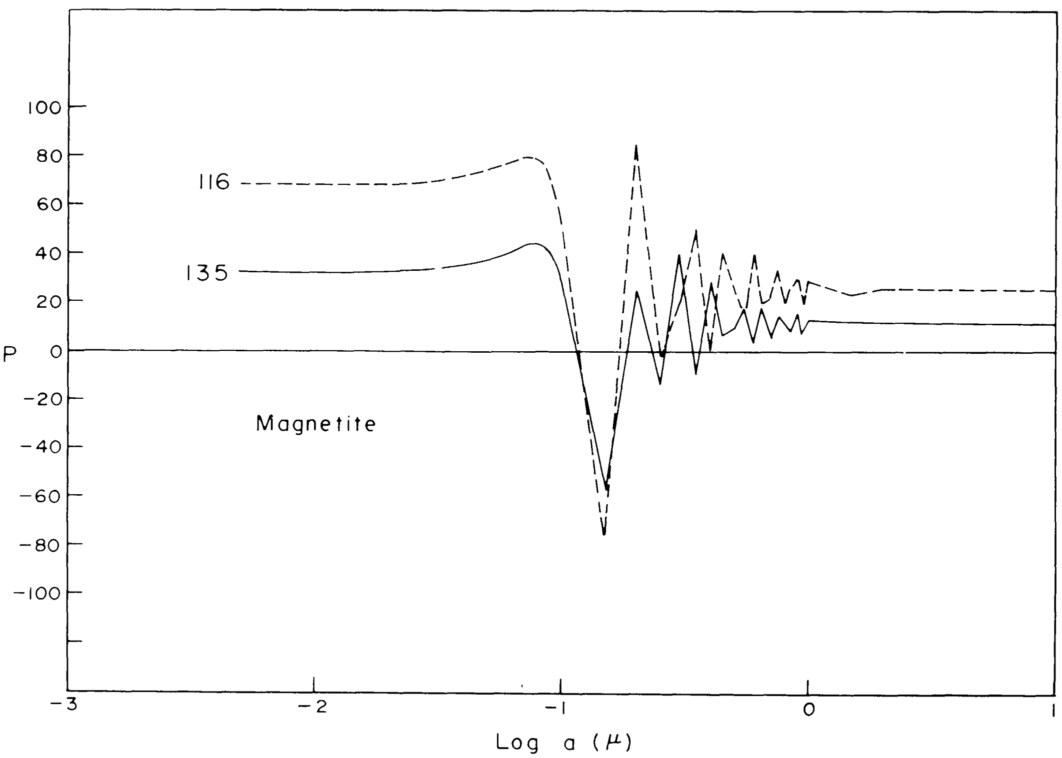

Fig. 3. As Figure 1.

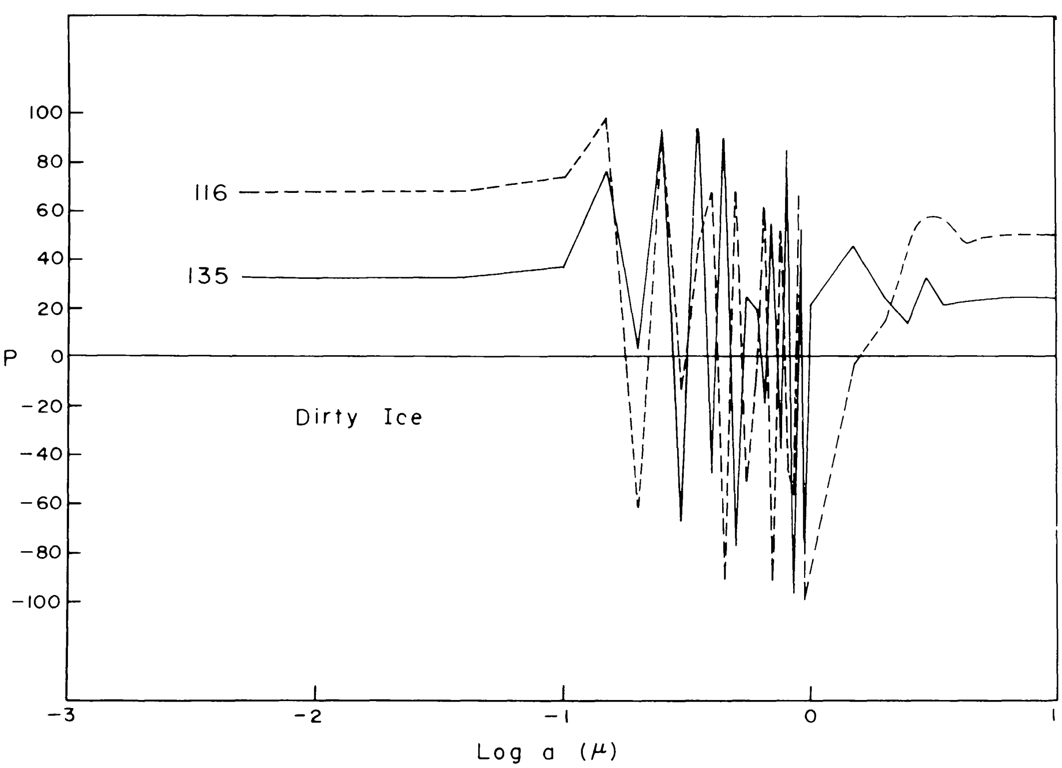

Fig. 4. As Figure 1. For Dirty ice we have used $m = 1.33 - 0.05i$.

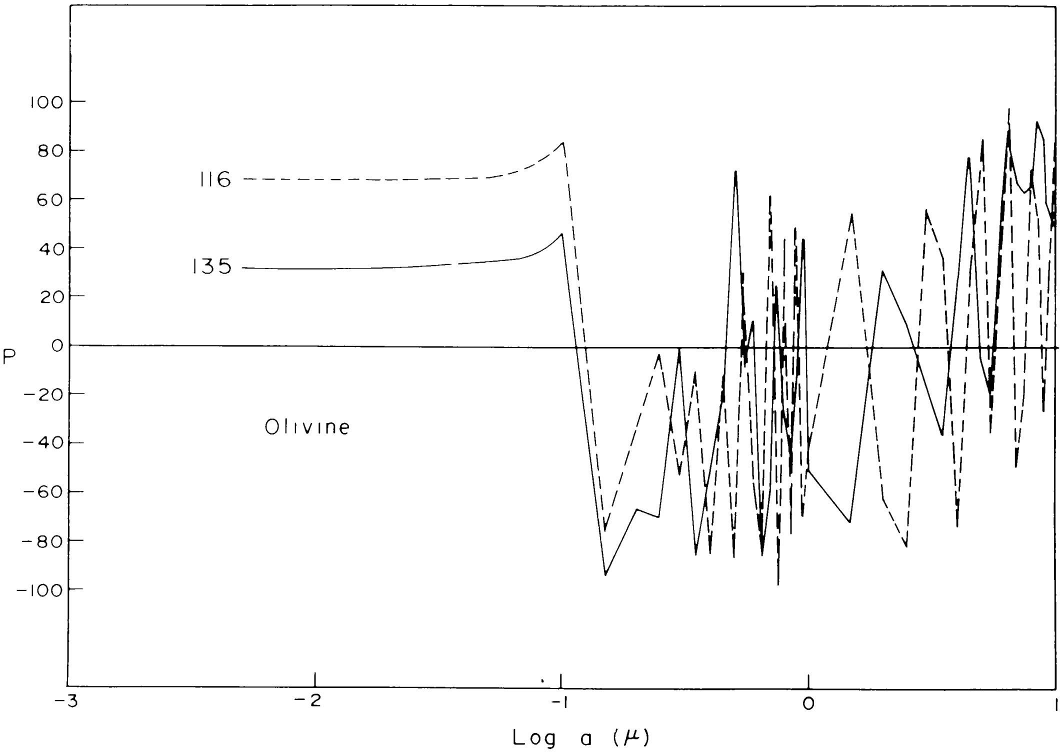

Fig. 5. As Figure 1.

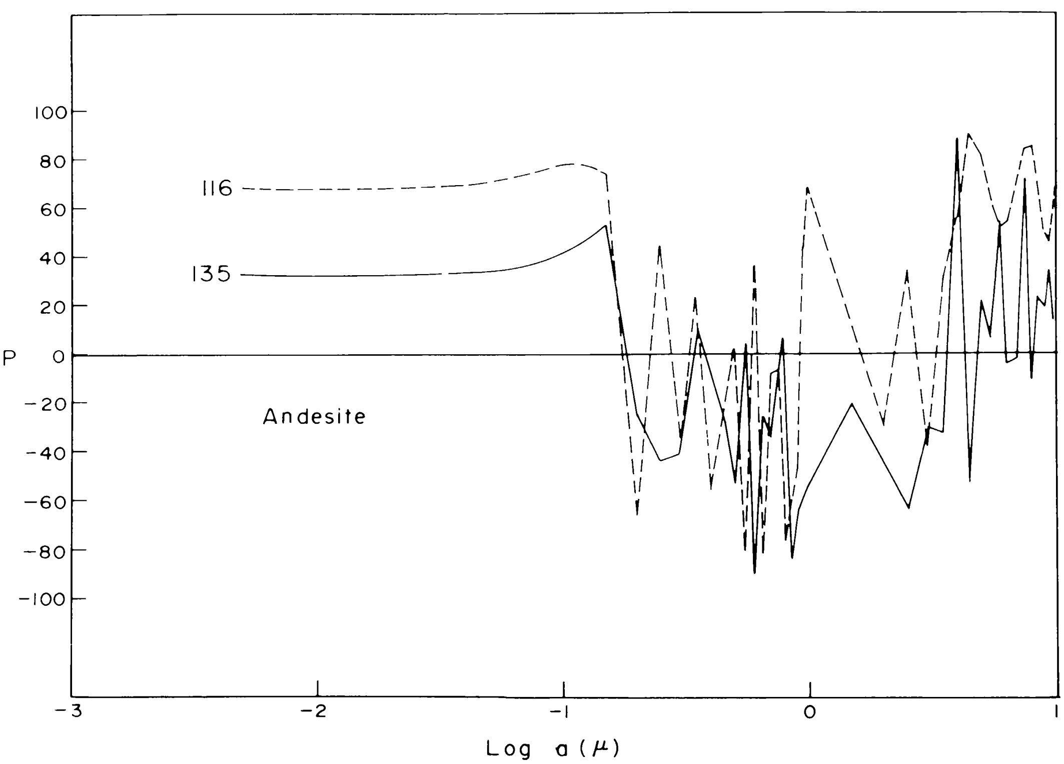

Fig. 6. As Figure 1.

be of silicate in nature (Maas *et al.*, 1970; Ney, 1974; Rieke and Lee, 1974; Woolf and Ney, 1969). We have shown the curves only for $\theta = 116°$ and $135°$ as others lie in between these two limits. The results are shown for the size range of $0.005\ \mu$ to $10\ \mu$ for $\lambda = 0.53\ \mu$. The refractive index for the model grains are taken from various papers (Pollack *et al.*, 1973; Huffmann and Stapp, 1973; Taft and Philipp, 1965; Schalén, 1965).

The calculations were also performed for $\lambda = 0.43\ \mu$ and $\lambda = 0.575\ \mu$ (Weinberg and Beeson, 1976) and the results are similar to that of $\lambda = 0.53\ \mu$. We have used the size intervals of 0.005, 0.05 and $0.5\ \mu$ for the size ranges between 0.005 to 0.1, 0.1 to 1.0 and 1.0 to $10.0\ \mu$, respectively. Figures 1 to 6 are used to show the general trend of the results expected, as we have not used very fine grid points for the sizes. One may note the following interesting results from these curves. For all the grain models studied, the polarization is positive for sizes $a \lesssim 0.1\ \mu$. For $a \gtrsim 0.1\ \mu$ there are oscillations in the polarization curves which will be smoothed out with the use of a size distribution function. For the materials andesite and olivine, the smoothing will finally result in a negative polarization and for other materials it will give a positive polarization. Therefore, if positive and negative polarizations are required at the same time, the material of the grain should be of the silicate type. It is also interesting to note that the positive polarization for small size particles is around 30 to 70%, which could be brought down by summing over a size distribution function. Similarly, the mean negative polarization over the size range of 0.1 to $1\ \mu$ should be of the order of 30 to 40%. These value are roughly in the observed range of positive and negative polarizations in comet Ikeya-Seki. However, it may be noted that the curves for the scattering angles between 116° and 135° are similar in nature. Therefore, in order to get positive polarization for $\theta \sim 116°$ to $\theta \sim 125°$ and negative polarization for $\theta \sim 125°$ to $\theta \sim 135°$ we require mostly smaller size particles to exist in the former case and only larger size particles to exist in the latter case. Let us now try to see whether this is reasonable to expect in a comet.

From a knowledge of the known angles and the distance involved, one can estimate the distance along the tail from the head of the comet for the scattering angles of 116° and 135°. It turns out that the distances are of the order of 0.8 and 1.6 AU, respectively, for the two angles. This shows that the polarization observations referring to $\theta = 116°$ and $135°$ corresponds to distances on the tail of the comet which are quite separate from each other. The theory of the motion of dust particles in the tail has been worked out in detail by Finson and Probstein (1968a). This theory has been applied to many comets with satisfactory results (Finson and Probstein, 1968b; Sekanina and Miller, 1973; Jambor, 1973; Sekanina, 1976). In this theory, the particles are essentially driven out by the radiation pressure, which is usually denoted by the parameter $(1 - \mu)$, where

$$(1 - \mu) = \frac{0.585 \times 10^{-4}\, Q_{rp}}{a\varrho}\,. \qquad (1)$$

TABLE I

Ratio of Q_{rp}/a for different size grains for $\lambda = 0.53\ \mu$

a (μ)	Q_{rp}/a	
	Andesite	Olivine
0.001	3.2 (−2)	1.7 (−2)
0.01	3.8 (−2)	2.5 (−2)
0.05	5.2 (−1)	9.4 (−1)
0.1	2.4	4.7
0.2	3.6	6.7
0.5	2.1	2.8
1.0	5.7 (−1)	7.7 (−1)

The factor $(1 - \mu)$ essentially refers to the ratio of solar radiation pressure to gravity; Q_{rp} is the efficiency factor for radiation pressure; a and ϱ are the radius and the density of the grain, respectively. Equation (1) shows that $(1 - \mu) \propto Q_{rp}/a$ for a given material of the grain. We have given, in Table I, the ratio of Q_{rp}/a for different sizes and for materials andesite and olivine. The table shows that for $a \lesssim 0.1\ \mu$, the value of $(1 - \mu)$ is very small, while for $a \gtrsim 0.1\ \mu$ the value of $(1 - \mu)$ is larger than unity. Therefore, we expect the larger size particles ($a \gtrsim 0.1\ \mu$) to be driven out farther along the tail as compared to smaller size particles ($a \lesssim 0.1\ \mu$). This conclusion is also supported by more detailed work on many comets based on Finson and Probstein theory (see Sekanina, 1976). Therefore, we expect smaller size grains to dominate in the region corresponding to $\theta \sim 116°$ as compared to that of $\theta \sim 135°$. This should result in the positive polarizations for $\theta \sim 116°$ and negative polarizations for $\theta \sim 135°$. In actual practice, there will be a transition region between the two domains which should make the polarization change from positive values to negative values.

Conclusions

We have shown that along the tail of the comet there is a segregation of different sizes of grains due to the effect of radiation pressure. The resulting size variation along the tail should explain in a natural way the observed polarization reversal in the comet Ikeya-Seki (1965 VIII).

It might also be mentioned that we have carried out an analysis of the scattered continuum observations of Stokes (1972) on comet Bennett 1969*i* and it also indicates that the particles should be such that $n \sim 1.6$ and $k \sim 0.05$.

Acknowledgement

I would like to thank Dr G. A. Shah for some helpful discussions.

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