Anomalous Polarization of the Light Scattered from the Atmosphere Observed in 1955-1957

By T. Sekigawa and T. Sato

(Department of Physics, Tokyo College of Science)

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Abstract

Recently, the fact has already been published that anomalous polarization of the light scattered from the above has often been observed since 1954 and in lower atmosphere.

This report is to investigate several cases of anomalous polarization observed since 1955 in Tokyo, Hakone, and the top of Mt. Fuji, etc.

1. Introduction

It is already known that air molecules or other particles existing in the atmosphere scatter the sun-light, and the scattered ray has a possibility to be polarized. According to Rayleigh’s Scattering Theory, the polarizability $P$ of the light due to the primary scattering which reaches the observer 0 is given as follows (See Fig. 1) by

$$P = \frac{D_1^2 - D_2^2}{D_1^2 + D_2^2} = \frac{\sin^2 \varphi}{2 - \sin^2 \varphi}$$  \hspace{1cm} (1)

where $D_1$ represents the amplitude due to the vibration component of the polarized light within the plane including both the direction of sun-light and the line of vision (the plane expressed as plane $(xz)$ and be called the plane of vision), and $D_2$ the amplitude due to the vibration component vertical to the above plane, while $\varphi$, called the angle of vision, is the angle made by the direction of the sun and the line of vision. According to formula (1), if $\varphi$ is zero, $P$ becomes zero, and if $\varphi$ 90°, it becomes 1. This means that the light coming at right angles with the direct rays of the sun ought to be prefectly polarized. In actual observations, however, the value of $P$ at the maximum polarization point is 0.7 ~0.8 even when the weather is perfectly fine. This is because Rayleigh’s theory deals only with the primary scattering caused by the molecules of pure and dry atmosphere, but the real atmosphere contains vapors and various kinds of dust, therefore we must take the scattering influenced by some of these substances into consideration as well as the secondary scattering.

The following is made with a correction term attached to (1) in consideration of the above scattering,

$$P = \frac{a \sin^2 \varphi}{2 - a \sin^2 \varphi}$$  \hspace{1cm} (2)

$a$ is a constant determined by atmospheric conditions at the time of observation, and if it is properly chosen, a curve similar to the actual observation is to be gained at 30° $< \varphi < 150°$ (1). The case in which a curve such as obtained from formula (2) is observable is named the normal polarization, but the fact has already been published that a quite different curve from the above has often been observed since 1954 (1) and in the lower atmosphere (2).

This report is to investigate several cases
Fig. 2. Tokyo, Aug. 23, 1955.
- - - - Observed
- - - - Normal
($a=0.66$)

Fig. 3. Hakone, Nov. 3, 1955
- - - - Observed
- - - - Normal
($a=0.78$)

Fig. 4. Toyama, Jan. 1, 1957
- - - - Observed
- - - - Normal
($a=0.60$)

Fig. 5. Top of Mt. Fuji, Aug. 13, 1956.
- - - - Observed
- - - - Normal
($a=0.80$)
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Fig. 6. Top of Mt. Fuji, Oct. 13, 1957, 2:30 p.m.
- × - Observed
- ○ - Calculated
\[ a = 0.62 \quad \frac{1}{k} = \frac{1}{5} \]
\[ a = 8 \quad m = \infty \]

Fig. 7. Gotemba, Oct. 13, 1957 2:30 p.m.
- × - Observed
- ○ - Calculated
\[ a = 0.64 \quad \alpha = 7.85 \]
\[ \frac{1}{k} = \frac{1}{20} \quad \alpha' = 12.56 \]
\[ \frac{1}{k'} = \frac{1}{20} \quad m = \infty \]

Fig. 8. Top of Mt. Fuji, Oct. 14, 1957, 2:50 p.m.
- × - Observed
- ○ - Calculated
\[ a = 0.88 \quad \alpha = 2.5 \]
\[ \frac{1}{k} = \frac{1}{6} \quad m = \infty \]

Fig. 9. Gotemba, Oct. 14, 1957, 2:50 p.m.
- × - Observed
- ○ - Calculated
\[ a = 0.66 \quad \alpha = 1.5 \]
\[ \frac{1}{k} = 2/5 \quad m = \infty \]
of anomalous polarization observed since 1955.

Measurement was carried out by a method by Geophysical Magazine Vol. 27, No. 3, p. 455.

2. General Results

Observations were carried out for three consecutive years from 1955 to 1957, on days deemed to be perfectly fine. During the two years of 1955-1956, we had only one observation apparatus, no more than a single observation being made for each case. The number of observation was 35 in Tokyo, 25 at Hakone, 7 at Toyama and 19 on the top of Mt. Fuji, the total being 87. Some of these data at each place are shown in Figs. 2-5. These data were all obtained by the use of Wratten filter K 46. In the figures, full lines show the observed results, dotted lines the curves estimated by calculation. We shall discuss further on these lines in section 3.

In the figures, the maximum around 90° is deciphered to be normal polarization, and moreover around 20°, 50° and 100°, the maxima are often to be found. This is made out to be due to the anomalous polarization caused by the extra scattering by atmospheric particles.

Thus it is nearly ascertained by the above observations that recently in Japan there have been existing in the sky minute particles which cause anomalous polarization through extra scattering.

In order to measure how high these particles are situated, two polarimeters have been used since 1957 for simultaneous observations. At the first step, the observation was carried out simultaneously on the top of Mt. Fuji (3776 m above the sea-level) and at Gotemba (473 m above the sea-level). These results are shown in Figs. 6-9.

Figs. 6 and 7 show the records at both of the above points at 2.30 p.m., Oct. 13 and Figs. 8 and 9 at 2.50 p.m., Oct. 14. When compared with each other, the curves have approximately the same type. It is inferred, therefore, that the cause of anomalous polarization should sometimes be attributed to the atmosphere layer above the mountain top, which is higher than 4000 m above the sea-level.

Moreover, Fig. 10 show the record at Hakone (980 m above the sea-level) at Nov. 1, 1956, in which phenomenon of anomalous polarization is observed at the vicinity of 1000 m above the sea-level.

3. Discussion

Assuming that the anomalous polarization might be due to the scattering caused by extremely fine, even-grained particles, we will estimate the size and nature of these particles.

According to Mie’s theory on the scattered light, the intensity of diffused scattered light is obtained from the following:

\[
I_T = \frac{\lambda^2}{4\pi^2 r^2} \int \left( \sum_{\nu=1}^{\infty} \left( \frac{a\nu}{v(v+1)} \pi_{\nu} + \frac{b\nu}{v(v+1)} \right)^2 \right) \left( v\pi_{\nu} - (1 - v^2)\pi_{\nu} \right) \, d\nu
\]

\[
I_{II} = \frac{\lambda^2}{4\pi^2 r^2} \int \left( \sum_{\nu=1}^{\infty} \left( \frac{a\nu}{v(v+1)} \pi_{\nu} + \frac{b\nu}{v(v+1)} \right)^2 \right) \left( v\pi_{\nu} - (1 - v^2)\pi_{\nu} \right) \, d\nu
\]

where \( I_T \) means radiation intensity vertical to the plane of vision, \( I_{II} \) radiation intensity in the direction of the plane of vision.

Again

\[
I_T = \frac{\lambda^2}{4\pi^2 r^2} i_1, \quad I_{II} = \frac{\lambda^2}{4\pi^2 r^2} i_2
\]

and \( i_1 + i_2 \) is the total radiation in the \( \phi \) direction, and \( i_1 - i_2 \) the excess of the polarized
light over the unpolarized light in that direction, therefore,

\[ P = i_1 - i_2/i_1 + i_2 \]

and

\[ \pi_v = \partial P_v(v)/\partial v \]

is Legendre's polynomial of \( v \)th degree, and \( \pi_v' = \partial \pi_v/\partial v \)

\[ \alpha = \frac{2\pi \rho}{\lambda} \]

\[ \beta = m \alpha \]

\[ 2\rho \] diameter of the sphere

\[ \lambda \] wave-length of light

\[ m \] index of refraction, general complex

\[ \alpha \] is adapted to the curve gradient, \( k = (i_1 + i_2)/(I_1 + I_2) \)

We use the following:

\[ a_v = \frac{av}{v(v + 1)} \]

\[ b_v = \frac{bv}{v(v + 1)} \]

\[ A_v = \sqrt{\frac{\pi \rho}{2} J_{v}(1/2\alpha)} \]

\[ B_v = \sqrt{\frac{\pi \rho}{2} J_{v+1/2}(\beta)} \]

\[ C_v = \sqrt{\frac{\pi \rho}{2} H^{(2)}_{v+1/2}(\alpha)} \]

Obtaining \( a \) from the polarizability at 90° in the observed curves, taking the number of curve-peaks and the gradients into consideration, and substituting the following values into the above expression, we make up the curve shown as dotted lines in each figures.

<table>
<thead>
<tr>
<th>( a )</th>
<th>( \alpha )</th>
<th>( 1/k )</th>
<th>( m )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fig. 6</td>
<td>0.62</td>
<td>8.0</td>
<td>1/5</td>
</tr>
<tr>
<td>Fig. 7</td>
<td>0.64</td>
<td>7.85</td>
<td>1/20</td>
</tr>
<tr>
<td>Fig. 8</td>
<td>0.88</td>
<td>2.5</td>
<td>1/8</td>
</tr>
<tr>
<td>Fig. 9</td>
<td>0.66</td>
<td>1.5</td>
<td>2/5</td>
</tr>
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Assuming that \( \alpha \) has been estimated as shown above, we calculate the diameter of the particles.

\[ 2\rho = \frac{\alpha \lambda}{\pi} \]

where

\[ \lambda = 4.6 \times 10^{-8} \text{ cm} \]

therefore, in case

\[ \alpha = 3 \quad 2\rho = 0.44 \times 10^{-4} \text{ cm} \]

and, in case

\[ \alpha = 8 \quad 2\rho = 1.33 \times 10^{-4} \text{ cm} \]

\[ \alpha = 10 \quad 2\rho = 1.47 \times 10^{-4} \text{ cm} \]

4. Conclusion

The following conclusion may be obtained from the above results.

1. In the atmosphere there float minute particles, to some extent even in grains, which seem to cause anomalous polarization.

2. The size of these particles can be estimated to be about 1 μ.

3. Some of them exist even more than 4,000 m high.

4. In case \( m = \infty \), the observed curves conform a great deal to the theory. Therefore the anomalies can be explained as caused by the presence of the particles imprecise to light.

5. We observed, in general, the greater curve-gradients in 1957 than in 1956. This means that there was a sharp decline in the intensity of polarizability, in other words, it shows that in 1957 those particles were much more homogenized and grew smaller in diameter.

Concerning the altitudes of particles in question, a further investigation is in progress.

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References

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1955 年から 1957 年の大気異常偏光の観測

関川 俊男, 佐藤 隆寿

最近, 大気中に異常な偏光現象が起っている事は既に観測されている。著者は 1955 年から 1957 年までの大気 4000 m までの各層に於て異常偏光現象を観測することが出来た。観測結果、地表より高度 4000 m までの各層に於て異常偏光現象を観測することが出来た。即、異常偏光を起させる原因となる粒子は地表附近から 4000 m 以上の高度にわたって存在する事が確実となった。しかもその粒子は大気 1 μ 程度の不透明なものと見積ることが出来る。