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TEST OF

THE POLARIZATION OF LIGHT AT SEA

Tests conducted from July through September 1933.

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sextant telescope. It introduces no changes in the use of the sextant, making no changes in the sextant altitude corrections for height of eye, refraction, etc., calculated from the usual formulas or tables.

Polarizing Binoculars - The polarizing binoculars consisted of a pair of standard binoculars with Nicol prisms mounted behind each eye piece. The prisms reduced the field of view from 8° to 5° and caused a loss of light of 50%.

The effect of the Nicol prisms in the binoculars was to increase the contrast, and hence the visibility, of light-colored objects against the sea background, especially in sunny and bright weather conditions. They reduced the glare of the sunpath on the water and increased the ease in seeing objects in directions toward the sun. In overcast or dark weather the polarization binoculars were no better than ordinary binoculars.

3. RECOMMENDATIONS

With respect to the polarizing sextant, Captain Greenlee has suggested that, say, three sextants be provided with Nicol prisms and sent out for tests by Naval navigators.

With respect to the polarizing binoculars, no definite suggestion is made here. A definite decision can be reached after consultation with various officers. The polarization binoculars which I have used are, of course, on hand available for tests, but it might be better to equip with a Nicol prism some standard Navy glass which is used for some more or less special purpose such as reading flag signals, or looking at shell splashes, etc.

Nicol prisms about 8 mm. square and 18 mm. in length are suitable. These are easily available in this country at the present time and cost about $20 each. The work of mounting them in a sextant telescope or in binoculars or most types of telescopes is very simple.

4. THE POLARIZING SEXTANT

In the case of the sextant the altitude of the sun above the horizon is measured by bringing the image of the edge of the sun as seen in the instrument into contact with the horizon. The sea-sky scene in which the sextant observer is interested is the sea and sky at the horizon directly underneath the sun. And from this region stretching out over the sea toward the observer is the sunpath on the water. The brightness of the sunpath depends, of course, on the altitude of the sun, the roughness of the sea, the clouds in the sky, etc.

Consider the case of the sea ruffled by a breeze stronger than, say, 3 knots; it makes no difference in the following discussion whether the breeze be 3 knots or 30 knots, or more. It was found that a Nicol prism set always to eliminate the horizontal electric vector of the light darkened the sea relative to the sky under the sun and reduced the intensity of the sunpath on the sea. It thus in general made the horizon sharper and more distinct, and therefore improved the ease of making an accurate sextant observation.

Photographs of the sea-sky scene underneath the sun with and without a Nicol prism over the camera lens are shown in Plates 2, 3 and 4. The conditions under which the pictures were taken are given in the data under each figure. The pictures A taken without the Nicol are ordinary photographs. The pictures B taken with the Nicol are polarized light photographs, the region a b c d of these pictures being the polarized portion. The region a e b of pictures B is unpolarized and should be disregarded, this region being outside of the diagonal median plane of the Nicol. It happened that I did not get the Nicol oriented in the best position on the camera (I had to toggle up the apparatus after I got to sea) so that the polarized field of view was unnecessarily cut off to some extent. However, upon comparing regions a b c d of pictures B with pictures A the reader will get a fairly truthful impression of the action of the Nicol prism. The pictures show the reduction in the intensity of the sunpath, the darkening of the sea relative to the sky and the hardening of the horizon.

The Nicol prism was mounted in the sextant telescope as shown in (a) Plate 5, P being the Nicol and E the eyepiece lens. Being inside of the telescope the Nicol was out of harm's way. The prism could, of course, be put on the end of the eyepiece as shown in (b) Plate 5. This might be a desirable arrangement in case the observer wished to be able to remove or attach the Nicol quickly without otherwise disturbing the sextant. The Nicol was also placed in the sighting tube T of the sextant as shown in (c) Plate 5. In a third experiment the Nicol was used in the large telescope of the sextant, being mounted as in (a) Plate 5.

The Nicol was found to work equally well in either the large or small sextant telescopes or in the sighting tube. It did not limit the field of view, because of its own field of view is about 5° and that of the sextant is usually a little less than 5°. The Nicol reduces the intensity of unpolarized light by about 50% which was of no consequence in the case of sun sights with the sextant.

The improvement in the horizon given by the Nicol was usually very marked, the sun path being reduced in intensity, the sea darkened, and the horizon rendered more sharp. In the best cases the horizon, seen through the Nicol, underneath the sun appeared as a sharp deep blue edge of the sea, just as it appears in directions at right angles to or away from the sun in clear breezy weather. The usual color filters were, of course, put over the sun to reduce its intensity, but when the Nicol was used no color filters were found necessary to be used over the horizon.

The reduction in the brightness of the sun path occasioned by the Nicol increased with the altitude of the sun. This is shown in Plate 6 in which the abscissas are the altitudes of the sun above the horizon and the ordinates are x the amount by which the sparkles in the sun path were diminished by the Nicol. For example, $x = 8$ means that the sun path was rendered 8 times less intense by the Nicol, or was 1/8 of its normal intensity. In Plate 6 the dots are measurements made with the polarization photometer, shown in Plate 1, of the sun path near the horizon for breezy days at sea in sunny weather. The curve of Plate 6 is a theoretical curve calculated from Fresnel's equations. In view of the fact that the measurements were difficult to make the observed points agree as well as can be expected with the theoretical curve. In this case the theory is so simple and direct that we may without question accept the theoretical curve as being correct. And we may merely conclude that the measurements gave results entirely to be expected, although, to be sure, the measurements were made before the theory was worked out and therefore before we knew what to expect.

The theoretical curve rises to infinity at a solar altitude of about 72°. This merely means that the Nicol reduces the intensity of the sun path sparkles to zero at this altitude of the sun. It is seen from Plate 6 that the reduction in the brightness of the sun path is not great for solar altitudes below 25° but increases rapidly as the solar altitude increases from 30° to 90°. Plates 2, 3, and 4 show the polarization effects down the sun path for solar altitudes 48°, 39° and 26° respectively.

It is important to note that the Nicol prism introduces no changes in the corrections to the altitude of the sun for height of eye, refraction, diameter of the solar disk, etc., as calculated from the usual formulas or tables. Theoretically the Nicol prism should introduce no complication in these respects and several series of careful observations with and without the Nicol showed that no complications existed.

In a mirror calm sea, which rarely exists, there is practically no sun path and the horizon is sometimes difficult to distinguish. The Nicol usually darkens the sea to some extent even in this case and renders the horizon somewhat more distinct. This is true in fairly calm hazy weather, but the Nicol cannot be said to enable one to see the horizon when the true horizon is, without the Nicol, completely obscured by haze.

5. POLARIZING BINOCULARS AND THE POLARIZED LIGHT EFFECTS AT SEA.

General Polarization Effects. If one gazes at the sea through a Nicol prism and rotates the prism slowly about its axis, it is found that at two positions of the Nicol 180° apart the sea is darkened. At the two positions at 90° to these the sea is approximately unchanged by the interposition of the Nicol. This shows that the light of the sea is partially polarized. The direction of the electric vector of the polarized component of the light from the sea is approximately in the horizontal plane independently of the altitude of the sun or the direction in which the observer is looking.

On the other hand, the light scattered from objects such as ships, buoys, white caps, sea gulls, etc., is practically unpolarized. So that upon looking at them with the Nicol no change in their intensity is observed when the Nicol is rotated about its axis.

Therefore, in general, in looking at an object against the sea as a background in the region from a few hundred yards from the observer out to the horizon, the sea is darkened by the Nicol, properly oriented, whereas the object is not. If the object is lighter than the sea background the Nicol thus causes an increase in the contrast of the object against the background and thereby enhances the visibility of the object. If the object were darker than the background the Nicol will degrade the contrast and lower the visibility of the object.

Likewise the light of the sky is usually partially polarized and the Nicol will increase or decrease the visibility of an object against the sky depending on whether the object is brighter or darker than the sky background.

The polarization binoculars are shown in Plate 7. They were made to our order by the Bausch and Lomb Optical Company, and consisted of a standard pair of 6 power, 30 mm. objective, binoculars with small Nicol prisms, of the Glan Thompson type, 8 mm. square and 18 mm. long fitted in tubes which screwed to the eye pieces. Plate 7 b shows the polarization binoculars complete and in Plate 7 a the Nicol prisms in their tubes have been unscrewed and placed alongside of the binoculars. The Nicol prisms may be rotated about their axes for best adjustment. There is a loss of light of 50% due to the Nicols and the field of view of the binoculars, which without the Nicols is about 8°, is restricted to about 5° by the Nicols.

<u>Use of the Polarization Binoculars</u>. It was found that the polarization binoculars were often better than the ordinary binoculars. Since the light of the sea was usually polarized with electric vector mainly in the horizontal plane the Nicol prisms of the polarization binoculars were turned so as to refuse transmission to the horizontal electric vector of the light and were left permanently in this adjustment. Thereafter the polarization binoculars needed no further adjustment except for focus, and were exactly the same to use as the ordinary binoculars. In fact, except for their constricted field of view, one would not realize that there was anything peculiar about the polarization binoculars.

The polarization binoculars gave the best improvement on bright days: (1) because on bright days the polarization of the sea and sky was greater than on dull or overcast days; (2) because on bright days the 50% loss of light due to the Nicols was less harmful than on dull days; and (3) because on bright days objects were more often brighter than the background than on dull days.

Effects on Bright Days. White lighthouses at a distance barely distinguishable with ordinary binoculars were easily seen with the polarization binoculars. White sails of ships hull down could be readily seen with the polarization binoculars when often they could be picked up with only the greatest difficulty with ordinary binoculars. The improvement in the case of the upper structure of a destroyer hull down was marked. White markings, such as hatches of a motor boat 3 miles away, were clearly made out with the polarization binoculars, but could not be seen at all with the ordinary binoculars; similarly with white sea gulls a miles or so away. A red bell buoy about 1-1/2 miles away could clearly be made out as red with the polarization binoculars whereas with ordinary binoculars its color was doubtful. Several times the color of a ship or boat at a distance could not be determined, white or black, with ordinary binoculars; with the polarization binoculars its correct color was revealed immediately.

Reduction of Glare of Sunpath on the Water. With the polarization binoculars the brightness of the sun path on the water was reduced without at the same time reducing the brightness of objects in the glare of the sun path. As explained in the case of the polarizing sextant, Section 4, for altitudes of the sun less than 20° the reduction of the sunpath glare was not very marked. For altitudes of the sun above 25° the reduction of the sunpath glare was considerable and resulted in an improvement in looking toward the bearing of the sun. One could search the horizon, pick up buoys, etc., towards the sun with little fatigue or eyestrain.

Wake of Periscope, Shell Splashes, Whitecaps, etc. On a sunny day in Long Island Sound the foamy wake of the periscope of a submerged submarine was easily followed with the polarization binoculars, with ordinary binoculars it was lost almost immediately and could not be picked up again. The submarine was 1 or 2 miles away. The polarization binoculars simply made the sea considerably darker leaving the white foam of the wake unchanged, so that the white foam stood out in greater contrast against the dark background.

In the same way the polarization binoculars increase the visibility of whitecaps, tide rips and breakers.

The polarization binoculars should make shell splashes more visible, for this is exactly the case of a bright or white object against a sky or water background. I had no opportunity to observe shell splashes.

Sea Oily Calm and Ruffled by a Breeze. The polarization effects are less when the sea is oily calm than when it is ruffled by a breeze. There is practically no difference in the polarization effects of the sea with a 5 knot breeze or with a breeze of 25 knots or more.

Dark or Overcast Weather. The amount of polarization of the light of the sea in cloudy weather is nearly the same as, perhaps slightly less than, the polarization in sunny weather. However, for overcast conditions and moderately dull weather the polarization binoculars were rarely any better than the ordinary binoculars; they were almost never worse than the ordinary binoculars. In overcast weather objects are not well lighted, so that darkening the sea did not increase the visibility of the objects to any important extent. For very dark overcast conditions and at night the loss of light of the polarization binoculars is harmful and ordinary binoculars are usually preferable.

Polarization Effects of Objects on Shore. In general the light from most objects is polarized to some extent. A sandy beach seen from a mile or more off shore is usually made brighter by the Nicol prism and the polarization binoculars, its true yellow color (or whatever color it may be) being brought out slightly more clearly. The green color of trees or fields ashore is heightened and made slightly greener. In general the light from an object is of two kinds: (1) some of the light is scattered from the object after partial penetration; this light gives the true body color of an object such as the red color of a brick, or the green of a green leaf; (2) some of the light is genuinely reflected from the surface of the object, giving the object a sheen or a sparkle. The first sort of light is unpolarized, the second sort is partially or completely polarized; the first sort passes through a Nicol prism undisturbed, the second is partially or totally eliminated by the Nicol. Thus the Nicol serves to remove the sheen, or the glint or the sparkle from objects and therefore to reveal their true body colors. The aspect of wet rocks, wet sea-weed, a wet road, glare from paper, a granite boulder in the sun, high lights on a shiny surface as a painted automobile, (not, however, reflections from metals), are often completely changed when viewed through a Nicol prism.

However, although the polarization of trees, beaches, etc., was often quite marked, I did not find that the polarization binoculars enabled me to make out any details of objects on a distant shore much better than ordinary binoculars.

Haze cutting is small. It has often been said that the light scattered by haze should be polarized for the same reason that the light of the sky is polarized, and that therefore one could by means of a Nicol prism remove the veiling glare due to haze and thereby improve seeing through haze. This is partially true, but indeed so little true that the improvement in seeing through haze was found to be practically negligible.

In the case of hazes so thick that visibility was reduced below 4 or 5 miles the polarization of the haze was practically zero. In the case of thin hazes which made objects, say, 8 miles away slightly bluish, the Nicol prism or the polarization binoculars removed the blue veil to some extent, and thereby improved the seeing. But the objects could be seen pretty well anyway with ordinary binoculars, and the improvement due to the polarizing devices was practically inconsequential as far as cutting the haze was concerned.

<u>No Dispersion of the Polarization Phenomena</u>. Continual tests with color filters added to the polarizing binoculars showed that the polarization effects were constant throughout the visible spectrum. This is in agreement with theory, for no marked dispersion of the polarization effects would be expected from theoretical considerations.

<u>Polarization of the Sky</u>. The polarization of the sky has been extensively investigated by others[1,2] and there are probably no facts about it which are not known.

The main facts of the sky polarization are as follows: The direction of the electric vector of maximum polarization is in circles around the sun, the polarization is greatest at right angles to the sun becoming less as one nears the sun and the anti-solar point. The polarization is less for a hazy sky than for a clear sky; the polarization of clouds is zero. As a result a Nicol properly oriented darkens the sky and often brings out clouds more clearly. The polarization of the sky near the horizon is usually slight or zero because there is usually haze near the horizon.

Since an airplane is usually seen as a dark spot against a brighter sky background one would not expect that a polarizing device would improve the visibility of airplanes as seen by an observer on the ground. As a result of many tests in looking at airplanes and lighter-than-air craft with polarizing binoculars, I concluded that no important improvement was offered by the Nicol prism in this case.

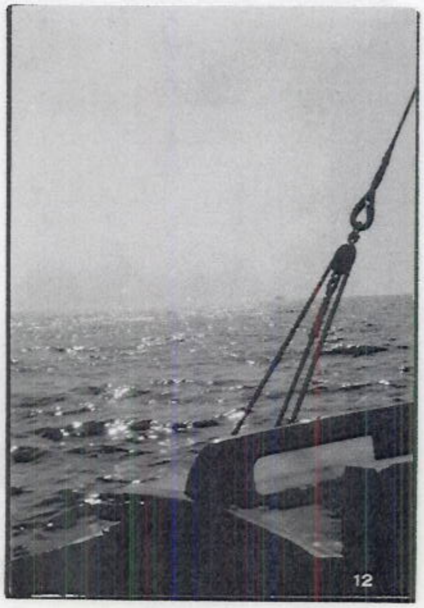
Since the haze in the sky causes a reduction in the polarization I had the idea that perhaps a measurement of the sky polarization might enable a person on the ground to measure the haze overhead and hence to predict the visibility conditions which an airplane might encounter. Observations, however, thus far indicate that the idea is not practical because the haze may be stratified in layers and the polarization observations may be complex and perplexing.

6. DEDUCTIONS FROM MEASUREMENTS AND THEORY.

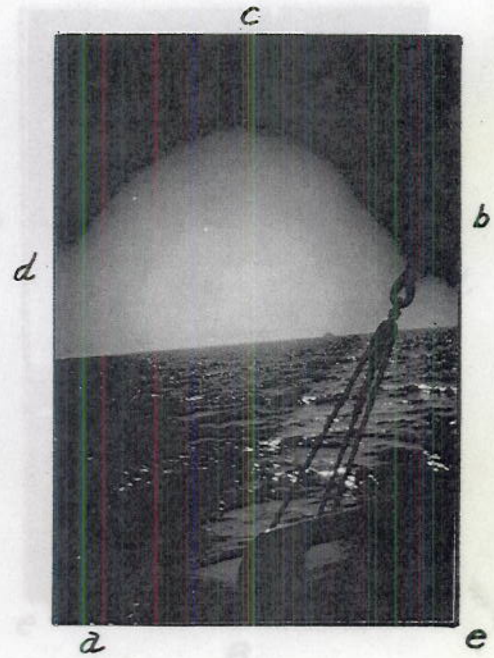
A fairly complete series of measurements of the polarization of the light of the sea were made and have been discussed from the standpoint of theory. We shall not give in this report the measurements or the theoretical treatment; they will be published in some scientific journal. However, it is of interest to summarize here the results very briefly.

Polarizing Photometer

Plate 1



A
WITHOUT NICOL



B
WITH NICOL

ATLANTIC OCEAN.

11:12 A.M.
ALTITUDE OF SUN 48°
VISIBILITY 15 MILES
CLEAR SKY, BRIGHT BLUE SCENE
WIND 12 KNOTS
SEA SMOOTH

SHOWS MARKED ELIMINATION OF SUN PATH, DARKENING OF THE SEA AND MORE DISTINCT HORIZON CAUSED BY NICOL.

PLATE 2

A
WITHOUT NICOL

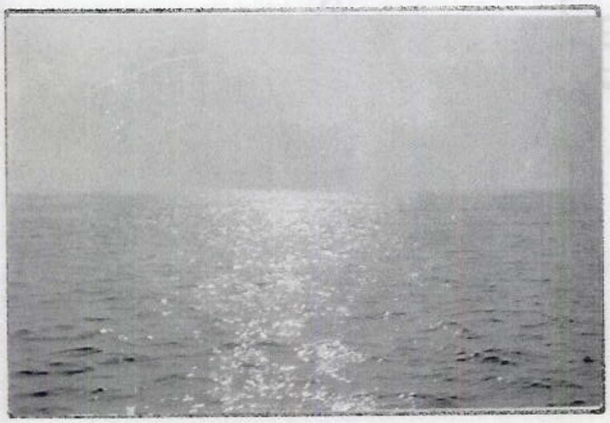
B
WITH NICOL

CHESAPEAKE BAY

9:50 A. M.
ALTITUDE OF SUN 39°
VISIBILITY 12 MILES
CLEAR SKY, BRIGHT BLUE SCENE
WIND 18 KNOTS
BAY CHOPPY

SHOWS MARKED ELIMINATION OF SUN PATH, DARKENING OF THE SEA AND IMPROVEMENT IN THE HORIZON CAUSED BY THE NICOL. KENT ISLAND IS IN THE BACKGROUND.

PLATE 3



A
WITHOUT NICOL

B
WITH NICOL

LONG ISLAND SOUND.

3:40 P.M
ALTITUDE OF SUN 26°
VISIBILITY 4 MILES
HAZY, BLUE GRAY SCENE
WIND 7 KNOTS
SOUND VERY SMOOTH

SHOWS SOME ELIMINATION OF SUN PATH, DARKENING OF THE SEA AND HARDENING OF THE HORIZON.

PLATE 4

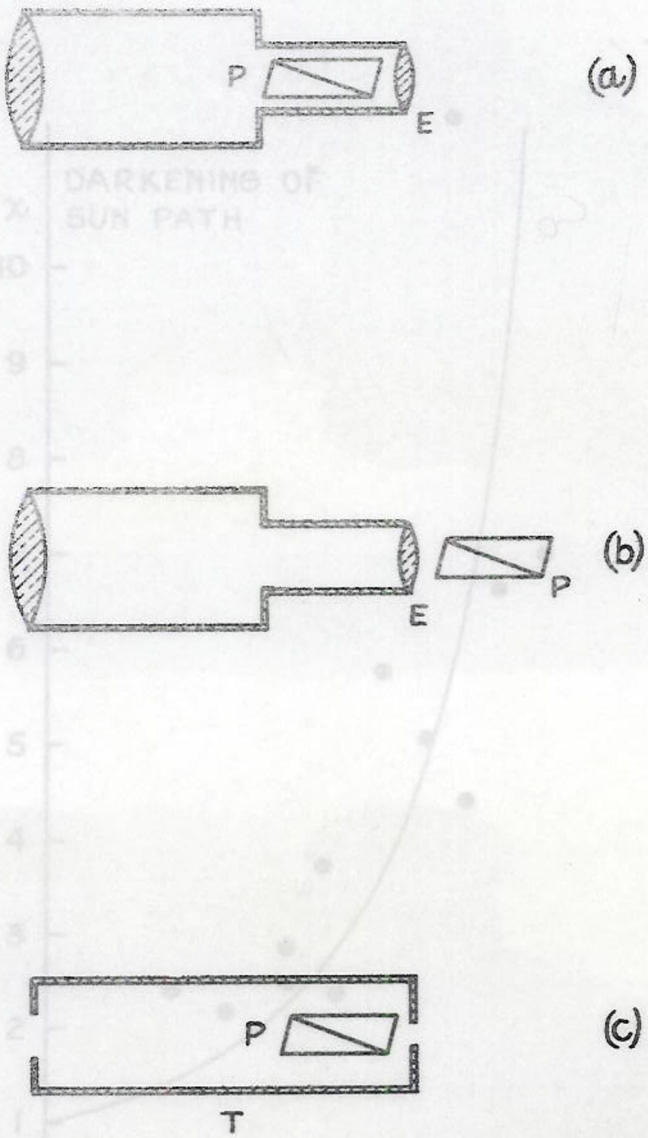


PLATE 5

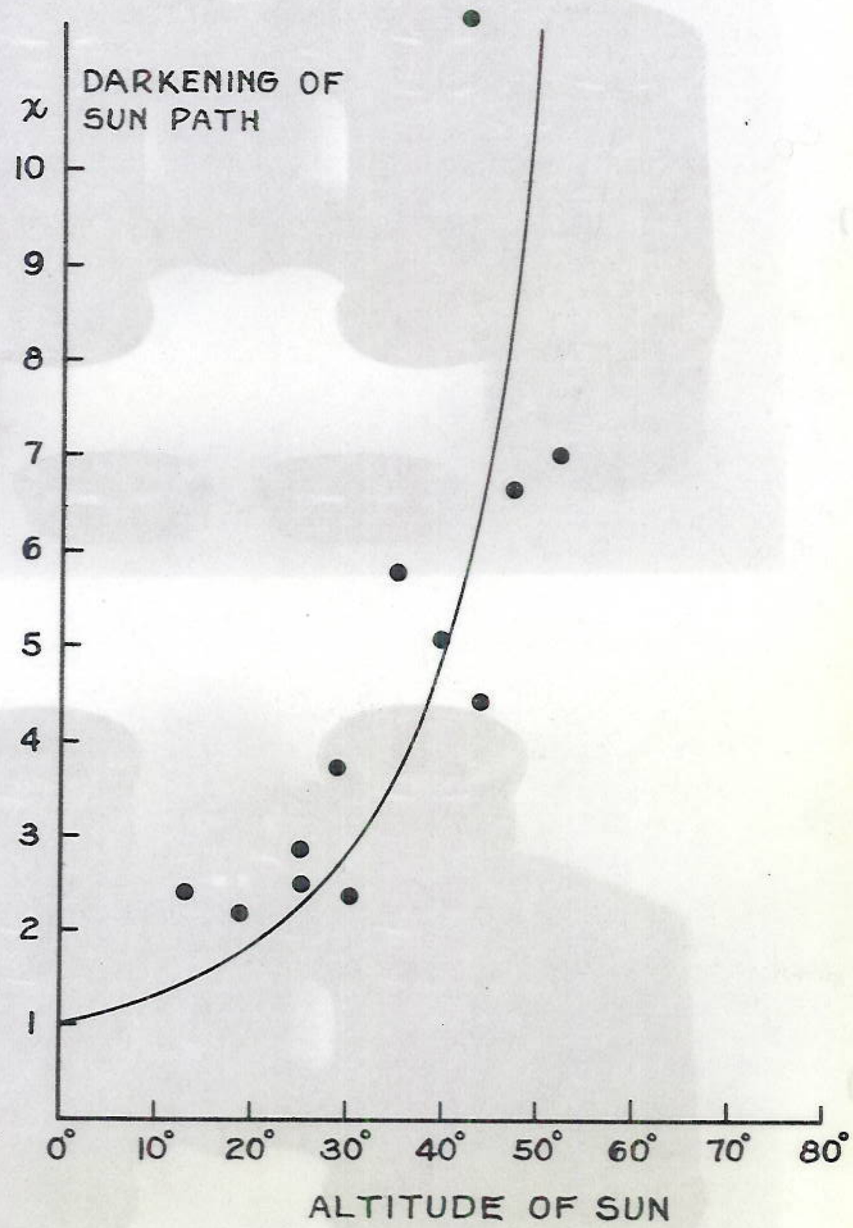
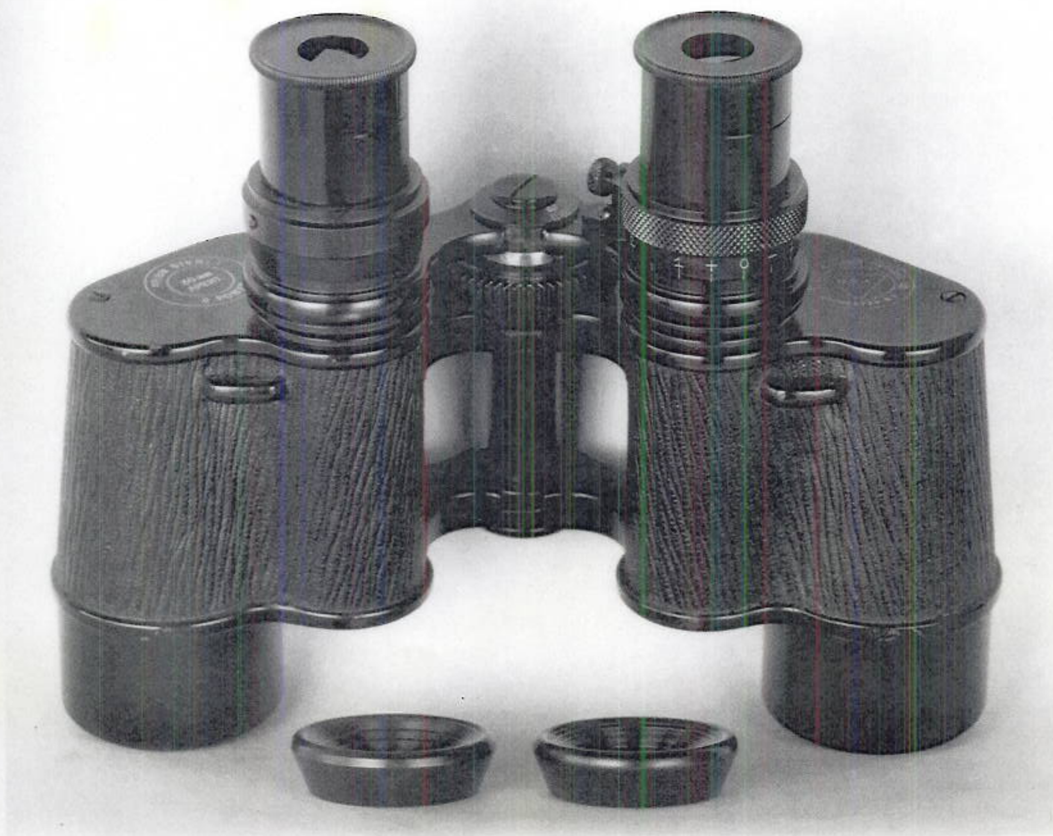
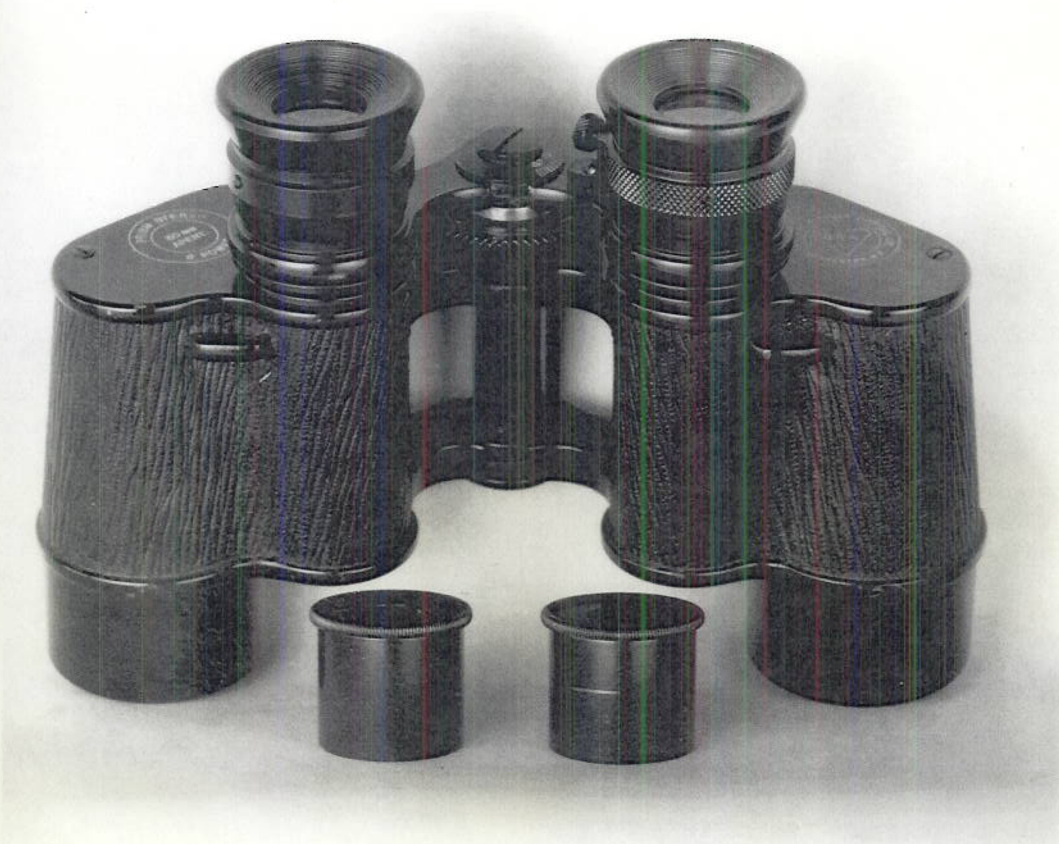

DARKENING OF SUN PATH
χ
10
9
8
7
6
5
4
3
2
1
0°
10°
20°
30°
40°
50°
60°
70°
80°
ALTITUDE OF SUN

PLATE 6



(b)



(a)

Polarizing Binoculars
Plate 7