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Optical phenomena and optical illusions near lighthouses

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With 3 Figures

Quite a few optical phenomena and optical illusions can be observed in connection with lighthouses. The light source or beacon of the lighthouse can be said to play the role that the sun or the moon plays in meteorological optics. This is why scattering phenomena, the rainbow, the corona and the heiligenschein have been observed in lighthouse beams or near lighthouses and why haloes probably occur in lighthouse beams in appropriate weather conditions. In addition to these optical phenomena an observer looking at a lighthouse beam is likely to perceive many optical illusions. The beam seems to be curved or it even seems to rotate around a point far from the lighthouse. Furthermore the beam seems to have a certain length, which changes when the direction of the beam changes.

The phenomena and the illusions mentioned above will be described in this article in relation to lighthouses; they have been observed by the author near the lighthouses on the Dutch North Sea Islands. A general treatment of related phenomena reported to occur in the atmosphere is to be found in Minnaert (1954).

Part 1: Optical Phenomena

Scattering

A lighthouse beam is visible because air molecules, dust particles and cloud droplets in the beam scatter the incident light in all directions. All sorts of phenomena observed near lighthouses can be attributed to scattering. For an observer standing at the foot of the lighthouse, for instance, the brightness of the light beam depends on the purity of the air: the more particles there are in the beam, the brighter it is. Furthermore, the forward-scattering is greater than the back-scattering. This effect can easily be seen by an observer standing at some distance from the lighthouse. He finds that a light beam pointing towards him is brighter than a beam pointing away from him. This is what the author observed as he stood at some distance from the Texel lighthouse.

Blue light scatters more strongly than red light. This effect is not observed very often in connection with lighthouses because most lighthouses nowadays use mercury-vapour lights, which can be considered as 'nearly monochromatic' (*Kangieser*, 1950). It is only when the lighthouse has an incandescent bulb as its light source that the light source sometimes looks more reddish with increasing distance. For this effect to occur there must be sufficient particles in the atmosphere to cause considerable scattering. The reddish appearance of the light source has its counterpart in the red-coloured disc of the sun that is low on the horizon.

The author observed the phenomenon of a reddish light source at Midsland, 6 km from the Terschelling lighthouse. During drizzle the light source looked dim and reddish. As the author approached the lighthouse (weather unchanged) the light became brighter and whiter. On another occasion the author could see both the (mercury-vapour) lighthouse of Vlieland and the (incandescent-bulb) lighthouse of Terschelling at the same time. When sailing from Terschelling to Harlingen as darkness was falling, the distances between him and the lighthouses of Vlieland and Terschelling increased. The colour of the Vlieland light remained constant, whereas the light from the Terschelling lighthouse became more reddish. The difference in colour increased with increasing distance from the lighthouses.

The difference in colour is also linked to the weather conditions. As was mentioned above, the brightness of a lighthouse beam is a measure of the purity of the air for an observer standing at the foot of a lighthouse. Similarly, the difference in the colour of light emitted by two lighthouses, one having an incandescent bulb as light source and the other a mercury-vapour lamp, is a measure of the purity of the air for an observer standing at a position from which he can see both lighthouses.

Light that is scattered at an angle of 90° is strongly polarized perpendicular to the plane of incidence (i.e. the plane through the observer and the light beam). One can see this effect easily when studying the polarization of the blue sky by looking through polariod sunglasses: the polarization is found to be at its maximum at an azimuthal distance of 90° from the sun. The polarization of the light received by an observer from the beam of a lighthouse can also be studied by looking through polariod sunglasses. To an observer wearing these sunglasses the light beam is perfectly visible when viewed from the side. If the observer rotates his sunglasses over an angle of 90° so that they are perpendicular to their normal position, then the light beam is only poorly visible when viewed from the side. The autor abserved the polarization of light very clearly in the lighthouse beam of Texel.

Rainbow

When standing at the foot of a lighthouse one generally does not detect sharp distinctions between the brightness of different parts of the beam. During rain, however, the author observed distinct dark and bright sections in the beams of the lighthouses of Terschelling and Schiermonnikoog, as shown schematically in Fig. 1. When an observer stands directly under the beam with his back to the lighthouse, the bright section, marked d in Fig. 1 is at an angle of ca. 42° to the horizontal. This section is contiguous to a relatively dark section on the side nearest the light source. The other end of the dark section is at an angle of ca. 51° to the horizontal. Sometimes another small bright section can be seen at the boundary of the dark section on the side nearest the light source, although this section is always fainter than the bright section at 42°.

We shall now concentrate on describing the brightest section. The light from this section is strongly polarized perpendicular to the plane of incidence. The polarization can easily be detected through polaroid sunglasses. The

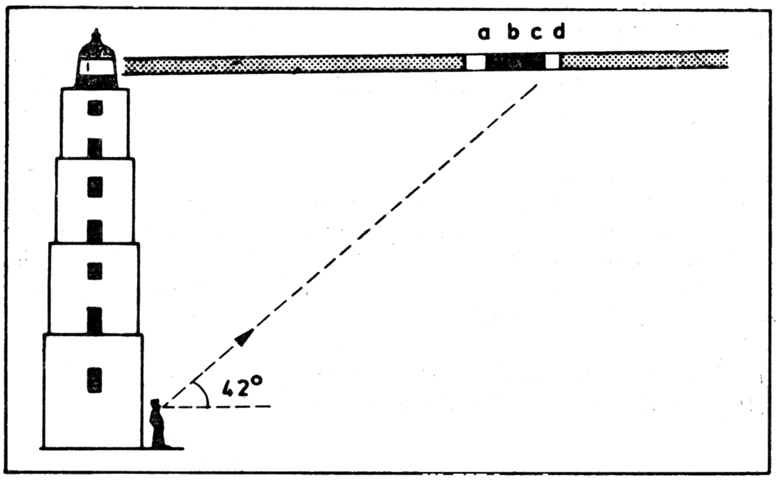

Fig. 1. Rainbow in the light beam of a lighthouse, as seen by an observer standing at the foot of the lighthouse. The bright section in the beam, marked *d*, corresponds to the primary bow. If the light source is an incandescent bulb this bright section has a red border (c) on the side nearest the light source. The dark area, marked *b*, corresponds to Alexander's dark band. Sometimes another bright section, corresponding to the secondary bow, is seen. This section is generally fainter than the one at *d*.

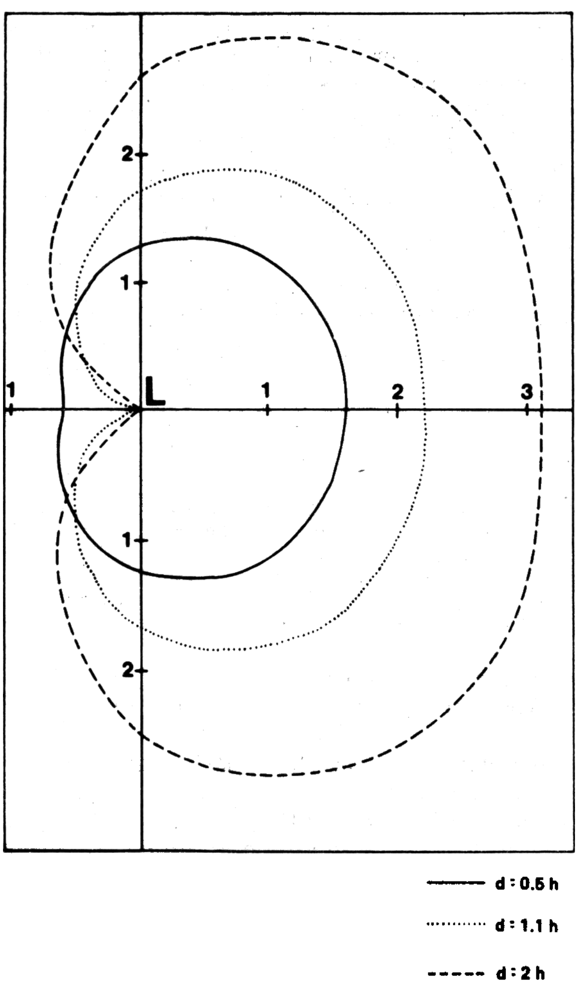

Fig. 2. Horizontal plane through the light source *L* at height *h* above an observer. The figures indicate the values of d/h at the points marked on the axes. The curves consist of the points in the plane where the observer sees the primary bow during rain. The observer is directly below the horizontal axis in the figure at distances *d* of 0.5 *h* (solid curve), 1.1 *h* (dotted curve) and 2.0 *h* (dashed curve) from L, respectively, and is standing with his back to the lighthouse.

bright section shows the greatest light intensity when one holds one's sunglasses in a position perpendicular to the normal position. If the sunglasses are returned to their normal position the bright section disappears.

While the lighthouse beam rotates the bright section moves backwards and forwards along the beam. If an observer is looking at the beam through polaroid sunglasses, he has to keep changing the position of these sunglasses if he wants to keep the bright section at maximum light intensity.

The phenomenon just described is formed in the same way as a rainbow. The bright section at 42° corresponds to the primary bow; the dark section corresponds to Alexander's dark band and the fainter section at 51°, which sometimes occurs, corresponds to the secondary bow. The fact that the distance between the bright section and the light source depends on the direction of the light beam causes the bright section to move backwards and forwards along the beam. The direction of the plane of incidence also depends on the direction of the light beam. Consequently, one has to adjust the position of one's polaroid sunglasses as the beam rotates in order to keep the bright section at maximum light intensity.

The path of the bright section in the horizontal plane through the light source can be computed for given ratios of d/h, where d is the distance between the observer and the foot of the lighthouse and h is the height of the plane in which the beams rotate above the observer. Fig. 2 gives three resulting curves for different ratios of d/h (*Floor*, 1980). The bright section takes the shape of part of such a curve when the lighthouse has divergent beams. The author observed this phenomenon near the lighthouse of Vlieland. This lighthouse emits its light in two divergent beams, each of which illuminates a quarter of the horizontal plane through the light source on either side of the lighthouse.

The most striking difference between a rainbow in the beam of a lighthouse and the normal rainbow is the wealth of colour in the latter and the lack of colour in the former. The absence of colour in most cases can be ascribed to the fact that most lighthouses use 'nearly monochromatic' mercury-vapour lamps. But even in the case of Terschelling, which has an incandescent bulb as its light source, only a reddish edge could be seen at the position marked c in Fig. 1. The main reason that other colours were absent is that the eye is less sensitive to colour at low light intensities. For the same reason no colours, apart from a reddish edge, can be seen in lunar rainbows (*Minnaert*, 1954; cf *Sager*, 1980).

Analogous rainbow phenomena in light beams have been observed by *Botley* (1980) and Harsch and Walker (1975) (in searchlight beams) and by *Kangieser* (1950) and *Jorgensen* (1953) (in beams of ceilometers).

Haloes, corona and heiligenschein

Just as rainbows originate from a 138° deviation of sunlight caused by raindrops, the common 22° halo originates from a 22° deviation of sunlight caused by ice crystals. It is probable that in appropriate weather conditions (light snow or floating ice crystals) haloes will also be visible as a bright section in the beams of lighthouses. To see these the observer would have to be facing the lighthouse and standing at a distance that is at least 2.5 times the height of the plane of the light beams above him. In order to observe a halo in a light beam properly one would first have to screen the light source, since it is so much brighter than the halo.

The paths of bright sections of the beam which correspond to the 22° halo and the 46° halo can be computed with the same formulae as were used for the rainbow (*Floor*, 1980). Fig. 3 gives an example of the paths that might be followed by bright sections in the beam which correspond to the 22° halo and the 46° halo, respectively. Just as in the case of the bright section of the beam corresponding to the rainbow, the bright sections of the haloes will probably also move backwards and forwards along the beam; the haloes however are likely to be visible only during a smaller part of a rotation.

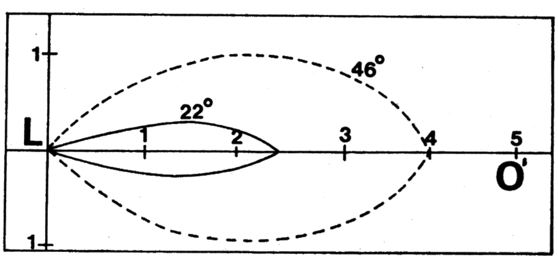

Fig. 3. Horizontal plane through the light source L at height h above an observer, seen from above. The figures indicate the values of d/h at the points marked on the axes. The curves consist of the points in the plane where an observer is likely to see the 22° halo (solid curve) and the 46° halo. The observer is directly below $0'$ facing the lighthouse at a distance $d = 5h$. Weather conditions: light snow or floating ice crystals.

If an observer looks at the light source of a lighthouse from some distance during mist or drizzle he will see it surrounded by a bright aureole. This phenomenon is the counterpart of the corona that is often seen around the sun and the moon.

The phenomenon known as heiligenschein can also be seen near a lighthouse. The best place to stand is on a grassy dune, which is touched by the lighthouse beam. If the observer takes up a position in which the light beam casts his shadow on the grass of the dune, more light is sent back by the area just around the shadow of the observer's head than by other areas of the dune. A heiligenschein can occur even if there are no raindrops or dew on the grass to intensify the brightness. The author has observed the heiligenschein on dry grass at Terschelling and even on the gravel surface of a car park on Texel.

Part 2: Optical illusions

Lighthouse beams and perspective

Lighthouses usually emit their light in beams that rotate in a horizontal plane. However, to the observer the plane in which the light beams rotate does not look horizontal at all. When the observer faces the lighthouse a light beam on the far side of the lighthouse seems to touch the earth's surface at only a short distance behind the lighthouse. Light beams pointing to the left or the right also seem to bend downwards, the highest point of the beam being the light-source of the lighthouse. If the observer looks in a direction perpendicular to the line between himself and the lighthouse, then the light beams again seem curved. But if he holds a straight stick horizontally in front of his eyes he can verify that the beam is straight; the horizontal surface of the sea and the horizontal beam seem to approach each other owing to perspective distortion. The same effect can be seen for instance in connection with a long horizontal contrail in the sky; i.e. it seems to bend towards the ground.

If there are dunes near the lighthouse which are about the same height as the lighthouse itself (as is the case near the lighthouse of Texel), the dunes seem to influence the shape of the beam above them. When the author faced the lighthouse of Texel it seemed to him that the 'highest point' of the beam was no longer the light source but was a point above the highest visible part of the dunes.

The most impressive optical illusion associated with lighthouses is seen when one stands with one's back to the lighthouse and some distance away from it and one watches successive beams. Just as anti-solar rays of the low sun seem to converge in the anti-solar point (*Corliss*, 1977), the successive light beams that pass over the observer's head seem to converge in the anti-light source point; this point is in the direction to which the straight line from the light source to the observer's eye can be extended. The lighthouse beams even seem to be emitted by a light source at the anti-light source point and seem to rotate around that point. Such an optical illusion, which the author observed on Texel, is seen more easily when a solid object screens the light source of the lighthouse.

Changing length of the light beam

If one watches a light beam pointing in some direction, one is struck by the fact that the beam suddenly comes to an end. The direction in which the observer sees the end of the beam is parallel to the direction of the beam itself. The intensity of the light which the observer receives from the remote parts of the beam is strong enough to give him the impression that the beam stops abruptly. The fact that the observer perceives the remote part of the beam to be bright is due to the small angle between his direction of vision and the direction of the beam. At small angles the extent of the area in which scattering particles contribute to the intensity of the light received by the observer is at its maximum.

To an observer watching a rotating beam the length of the beam appears to change continuously. The beam seems to reach its maximum length when passing over the observer's head. The length then seems to decrease and reach a minimum when the beam is at the far side of the lighthouse. Involuntarily one chooses as a measure of the length of the beam the angle α between the end of the light beam and an imaginary straight line passing through the observer and the light source; there is nothing else for him to go by in order to estimate the length of the beam. However, if, instead, he were to look at the front of a building obliquely from one side and then directly from the front, the front wall would not look longer, for there are sufficient points of reference, such as windows, doors etc. for the observer to make a reliable judgement of the size of the wall. Since there are no points of reference to help the observer estimate the length of the beam of a lighthouse, he interprets an increasing angle α as a lengthening of the beam.

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