Problems of Menotactic Orientation According to the Polarized Light of the Sky

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It is shown that the knowledge of the E-vector direction of the linearly polarized light at any point of the sky alone is insufficient for the determination of the position of the sun. If the E-vector direction of a second point is not known the knowledge of at least one other parameter is necessary. This parameter might be the height of the sun over the horizon. With the knowledge of the height the infinite number of solutions for the sun's position becomes reduced to two, or in special cases to one. These cases are derived.

One of the highest developed orientation behaviour of lower animals is the menotactic orientation to the linearly polarized light of the sky. As was discovered by v. Frisch [1] bees are able to indicate the direction to a food source to their hivemates by means of their waggle-dance. In the normal situation, in the vertical comb the angle between sun and goal is transposed into the gravitational angle. Bees are also able to dance, however, on a horizontally arranged comb: In this case, the wagging run points directly towards the goal, whereby the bee keeps menotactically at the same angle to the sun as in the previous flight. Even if the sun itself is not visible directly but is covered for instance by clouds, the dances are still orientated. It is sufficient in this situation if the bee is able to see a small area of the blue sky of an angular diameter of 10 to 15 degrees. The animals behave then as if they were able to determine the azimuth of the sun from the direction of the E-vector of the linearly-polarized skylight. The degree of the polarization of the light is not important, since introduction between animal and sky of a polarization-filter, which increases the degree of ploarization, does not change the orientation as long as the E-vector direction remains unaltered.

Sometimes the dances observed by v. Frisch [1] have not been unidirectional (see Gruppe 4, p. 396 in v. Frisch's book). He has shown that the ambivalent dances occur if a given E-vetor orientation is realized not only at one but at several different points of the sky. That means that the E-vector direction of a given point of the sky in this situation has not been sufficient in order to determine the azimuth of the sun. Since v. Frisch did not work out the conditions for the general cases in which the E-vector direction of a point of the sky is insufficient for the determination of the sun's azimuth the cases which allow unique or only ambivalent determination of the positions of the sun will be deduced as follows.

The considerations will be based on the assumption that the E-vector of the linearly polarized light is perpendicularly arranged to the plane which is given by the observer, the observed point at the sky and the sun. This condition is realized for most areas of the sky (see v. Frisch's book).

Fig. 1 shows a diagram of the sky: The sun is at the position S, the observer in the center O of the celestial sphere, the observed point on the sky is P. The great circle ("Grosskreis") through S and P is within the plane S O P, that is, the E-vector of light, observed in P, is perpendicular to this great circle as indicated by the double arrow.

If an animal is looking at the point P, and if it is able to determine the E-vector direction in P, it has in fact determined the great circle through S and P. Therefore it is able in principle to derive that the sun must be located somewhere on this

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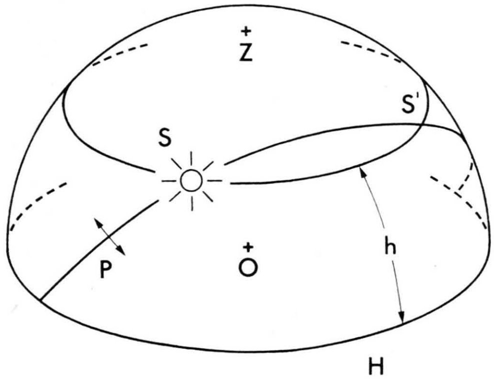

Fig. 1. An animal in the center O of the celestial sphere observing a point P at the sky is able to determine from the E-vector direction in P the great circle ("Grosskreis") through P that is perpendicular to the E-vector. The position of the sun is on this great circle. To specific the position of the sun furthermore, the height h of the sun above the horizon H can be used: The intersection of the height circle with the great circle defines the two points S and S′ which are possible positions of the sun. A unique determination of the sun's position is only possible in special cases or with the knowledge of other parameters.

great circle: However, the exact position and therefore the azimuth of the sun cannot be derived from the E-vector direction in P alone. Knowledge of the height of P over the horizon gives no additional information useful for the determination of S. This means that an animal always needs more information than the E-vector direction at a given point of the sky in order to determine the position (or the azimuth) of the sun.

In natural conditions it is sufficient in principle if the animal determines the E-vector direction at a secont point P′ of the sky: the intersection above the horizon of the two great circles, defined by the E-vector directions at the points P and P′ give the position of the sun.

As has been shown by v. Frisch, it is sufficient for the bee, however, to see only one small area of the sky (defining one E-vector direction) in order to dance with the correct orientation. So we have to ask for another, second parameter that may be used by the bee in order to reduce the infinite number of possible positions of the sun. This parameter might be the height h of the sun over the horizon H (Fig. 1). If this height at different hours of the day is known to the bee, the number of posible positions of the sun can be reduced to two, or in special situations even to one. Fig. 1 shows the two possible positions S and S′, which are determined by the intersections of the great circle through S and P, and the height-circle with height h over the horizon, respectively.

Unique solutions occur in the two following special cases:

1. If the observed point P is located on the great circle that passes through S and is tangent in S to the height circle, the two solutions S and S′ are coincident, and the solution therefore becomes unique (Fig. 2). If the animal is looking at any point of the sky that is located on this great circle, it is able in principle from the knowledge of h and the E-vector orientation at P to determine the exact position of the sun.

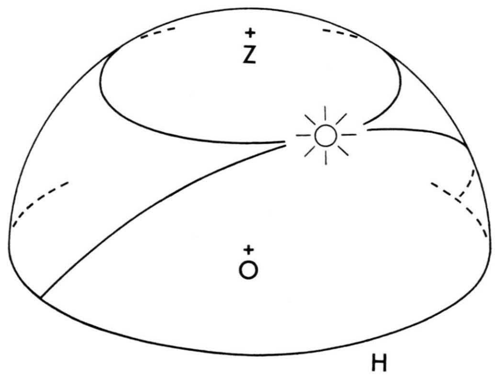

Fig. 2. If the observed point P is on that great circle through S, which is tangent to the height circle, the position of the sun can be determined uniquely from the E-vector direction in P.

2. If the observed point P has the same height h over the horizon as the sun, the solution is unique, too, since P is coincident with S′, S′ therefore can be discarded directly, leaving S as the position of the sun.

A third situation of interest is the situation in which P is located on the great circle defined by the position S of the sun and the zenith Z: The E-vector direction then is parallel to the horizon and the azimuth angles of the solution S and S′ are always 180° apart from each other, whereas in the general case the difference between the azimuths of S and S′ might have all values between 0° and 180°.

The considerations as shown above have the following result: The knowledge of the E-vector direction of any point of the sky alone is insufficient for the determination of the sun's position and therefore its azimuth. If the height of the sun over the horizon is known, too, the infinite number of solutions of the sun's position becomes reduced to two, or in special cases, to one. Only in these special cases is the E-vector orientation at a point of the sky alone sufficient for an appropriate menopolarotactic orientation. In the general case, more information is needed, as for instance the E-vector orientation of at least one other point, the degree of polarization, the mean light intensity, or the colour of the sky light. Experiments are in progress which allow to test the concept developed above.

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[1] K. v. Frisch, Tanzsprache und Orientierung der Bienen, Springer-Verlag, Berlin, Heidelberg, New York 1965.