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WHY INSECTS FLY TO LIGHT BY NIGHT

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It is well known that insects are attracted to lighted lamps at night. Lamps were used long ago for the study of the insect fauna at times when harmful insect were on the wing and, in later times, for the destruction of certain insect pests. Special luminous traps are constructed for catching insects by night, the newest models of which are equipped with mercury lamps — powerful sources of short-wave light rays (Mazokhin-Porshnyakov [1956a, 1956b, 1958] ; Frost [1957] Pfrimmer [1957]).

Why do insects fly to light, generally choosing lamps rich in ultraviolet radiation ? As we shall see there is no straight answer to this simple question.

From observations carried out over many years on insects flying to lamps, a number of facts have been accumulated which cannot altogether be explained by any of the hypotheses involving the mechanics of the attractive action of light. We enumerate the principal facts below.

Apparently, not all night-flying species of insects and species flying throughout the day (males of the family of moths Liparidae, hornets, Phytometra gamma and others), fly to light to an equal degree ; One does so in great numbers, another in lesser numbers. Diurnal insects rarely fly to light and probably only in those instances when they are disturbed during their nocturnal quietude. Similarly, insects fly both immediately to a source of light and to an illuminated screen, for example, an illuminated white wall. Sometimes they fly to lamps by the shortest route— direct, but they generally take a complex and irregular path. The reaction of insects to the spectrum is selective ; the shorter the length of the light wave, the greater its attraction. For the majority of species, the most attractive rays are the ultraviolet, violet and blue, and the least attractive are the red rays. The number of insects flying to light drops sharply on moonlight nights. In northern latitutes, attraction to light is far poorer than in more southerly latitudes, particularly in steppes and deserts. Having flown to a source of light, the majority of insects become inactive and settle down within the limits of the zone of illumination. Often they do not fly as far as the source of light but drop down some distance away and remain quiet so long as the light does not go out. Other conditions remaining equal, the intensity of the flight to light depends upon a number of meteorological factors (temperature and humidity of the air, wind speed) but with these we shall not be concerned.

Popular among biologists is the theory of V. Buddenbrock [1917], whereby insects are attracted to light mechanically and not of their own will, describing around it a path which consists of a logarithmic spiral. Having entered the zone of illumination of the lamp, the insects from the furthest point of motion keep a steady angle φ between the direction of the incident light beam and the axis of the body (menotaxis). With certain angles of entry into the zone of light the preservation of the angle φ inevitably leads, within the radial divergence of the light rays, to the insect's taking a path in the form of a logarithmic spiral and approaching the lamp. Later on, Buddenbrock [1937] quoted the experimental results of V. Ludwig [1933] on caterpillars as experimental proof of his theory. In laboratory experiments the caterpillars actively preserved the angle φ and moved to the point source of the light along a logarithmic spiral path, but Ludwig himself [1933, 1934] did not in the least attempt to explain the light-compass reaction of other insects in the same way.

However, the elegant theory of Buddenbrock is not supported by observations in nature. Insects fly not only to a source of radially divergent rays of light (a lamp) but also to the diffuse light of a screen or to a narrow pencil of light. Their path to the lamp is not constant : now straight forward, now in a zigzag manner, and again, it would seem, chaotically. Only directly near the lamp do the insects sometimes describe circles or spirals.

Other information on the causes of the flight of insects to light has been published . According to the opinion of F. Mell [1954] a bright artificial light has a highly irritating action on night-flying insects (moths), stimulating them into activity in consequence of which they appear to fly to the light.

V. Matten [1956] compared the nature of the behavior of insects flying to light with the behavior during the day, when nocturnal insects, after being rather excitable, settle down in a darkened box. Under these conditions they fly out of the box (to the light) and do not retire to the back of the box which is dark. In other words, one says that the excited insect makes for the light. The same takes place at night when one lights a lamp. Falling into the zone of light, the insect, according to the opinion of Marten, becomes excited and in order to get away from the strange situation directs itself to the light where it seeks a darkened place for its diurnal rest.

Nevertheless, the principal idea of Marten [1956] and Mell [1954], the desire for light when in an excited state, brought forward to elucidate the cause of insects flying to light, does not agree with the facts. It is contradicted, for instance, by observations on cockroaches and earwigs. If these are suddenly illuminated they retreat into dark places and do not crawl to the light. In addition to that both insects fly to lamps at night.

Another fruitful idea of Marten [1956] agrees very closely with the brief and undeveloped opinion of N. C. Dekthyarev[1925]. These authors speak of the desire of insects for light as an outlet from some retreat beyond the limits of which it perceives a path to unhindered flight.

Having studied the ideas of these two recent authors, we shall try to elucidate the mechanism of the flight of insects to light as we see it. The consideration of an example well known to all will assist us in this attempt. If a nocturnal moth is released in a room during the day it immediately flies to a dark corner and never to a window— the most illuminated part of a room. Under similar conditions diurnal moths will behave in an opposite manner; they turn to the light immediately and begin to crawl on the glass of the window frame trying to get free. The reason for the different behavior of these moths leaves us in no doubt. Nocturnal moths are active only at night; during the day they pass their time in concealment, avoiding light (negative phototropism). Diurnal moths are active only during the day, when they turn to light (positive phototropism). Light draws the moth to the window because it appears to be an open space. However, with the approach of evening the behavior of the moths changes; the diurnal ones cease to fly, the nocturnal ones turn to the window — above all to the illuminated parts the room. It means that, in the presence of a general diffuse light both moths (one during the day, the other in the evening) strive to reach the most illuminated place. The same behavior is noticed when a lamp is lighted in a room at night; both moths begin to gyrate round the lamp turning towards the source of light, which is brighter than the evening sky. Consequently, in the evening both moths exhibit a positive phototropism; for nocturnal moths this positive phototropism is perfectly normal but for diurnal moths it is abnormal —produced by a sudden violation of its nocturnal quietude.

Nocturnal moths behave similarly when, under natural conditions, they suddenly come upon a zone of artificial illumination. They turn towards the source of light since the brighter illumination—the sign of open space— is a path to freedom. This was once clearly seen in the behavior of a hornet which surprised us; while on the wing the hornet beat itself against a sheet (at night) lighted by a mercury lamp in the same way as a diurnal moth at a glass window.

Consequently, light attracts nocturnal and diurnal insects not by itself and not just as a source of light, but as an indication of open space or as an absence of obstruction. Open space is always better lighted than a closed one - it attracts insects so that they can more easily orientate themselves for the exercise of one or another vital function.

During their life insects constantly make use of bright illumination as indicative of space. Thus, light penetrating through holes acts as a signal showing the position of exits from hollows or other refuges. Flying out of dense vegetation, insects orient themselves in the direction of aperture among the branches through which the light of the sky penetrates. Many such examples can be quoted.

Now it is necessary to explain why short-wave light rays act on insects more strongly than rays of longer wave length. One would think that the maximum spectral sensitivity of their eyes is just in the short wave part of the spectrum, that is, the ultraviolet, violet and blue rays are brighter to insects than the yellow and orange-red. A similar conclusion is drawn by some authors who have estimated the spectral sensitivity of insects' eyes according to the attractiveness of the various light rays of the spectrum. According to experiments on the behavior of insects one cannot rigidly prove that their reactions are proportional to the stimulation of the photoreceptors and that it does not depend upon the action of one or another reflex action. For example, it is well known that the female cabbage butterfly, up to the oviposition period, is far more attracted to red and purple light (the color of flowers frequented by it) but after the ripening of the sexual products the greatest attraction comes from yellow light (the color of the leaves on which it lays its eggs; Ilse [1937]). More reliable electro-physiological experiments in which the reactions of the photoreceptors were measured directly show that the eyes of insects are maximally sensitive to the yellow (490-550 mμ rays. For confirmation of the existence of a second maximum sensitivity in the ultraviolet, which was observed by I. Walther [1957] on the fly Calliphora and the American cockroach, more careful measurements are required.

According to our opinion a stronger reaction of insects to ultraviolet rays depends not so much upon the light sensitivity of their eyes as upon thepeculiarities of their life. If we compare the role that light plays in indicating open space with the spectral composition of day and night light we see that the short-wave light, particularly the ultraviolet, is above all a characteristic feature of exposed areas; light coming from exposed areas is richer in ultraviolet rays than that from closed areas. The point is that terrestrial surfaces (soil, vegetation) strongly absorb short-wave light and reflect mainly the long waves. Therefore, ordinary objects, except chalk outcrops, trunks of birch and some kinds of flowers cannot be sources of reflection for short-wave radiation. In nature the only sources of this reflection seem to be the sun and sky— orientators which certainly lead to open space. If insects oriented themselves to yellow or orange-red light rays the light would lead them on a wrong path : Instead of leading into open space it would lead to a surface reflecting those rays.

During the day the sources of ultraviolet, violet and blue light rays appear to be the sun and sky : the atmosphere scatters light, principally short-wave light (beginning with λ 300—310 mμ) . During the night the sources of short-wave radiation appear to be predominantly in the sky, the natural light of which contains a considerable amount of ultraviolet radiation. The luminescence of the night sky is the principal source of ultraviolet and general short-wave radiation during the hours of darkness (Khvostikov, [1937]). Moonlight, as reflected from a reddish surface, contains a few blue and other short-wave rays and the direct light of stars and planets plays only a small part in night illumination (~25 % with a new moon).

Consequently, when the sun is not directly visible only the light from the sky can safely orient insects to escape into space. That is why a lighted lamp attracts nocturnal insects; the more short-wave rays (ultraviolet among them) it contains, the stronger is the attraction. Such illumination is similar to natural night but is brighter.

This fact was proved directly in experiments in which nocturnal or diurnal insects were kept in a dark container with a window fitted with various colored light filters. Almost all the insects rushed to the uviol glass, which is black to us, and passes only ultraviolet light, and not to the green or yellow filters which are bright to us, even though, in terms of energy, the latter transmitted more light than the former.

Our hypothesis also elucidated other aspects of the behavior of insects toward light. For instance, insects do not fly away from a lamp because even a temporary exposure to an illuminated zone brings about an adaptation of the eyes to light. Ultraviolet rays, in the same way as other longer light rays, actively transfer the protective pigment of the ommatidia from the nocturnal position to the day position : Piament travels upwards to the dioptic apparatus of the ommatidia and seems to restric the inlet apertures (Merker [1929]). The sensitivity of light-adapted eyes drops a hundred times and they are not capable of discerning objects under a lower illumination. Because of the mechanism of adaptation a burning lamp "does not permit" insects to side-track into the obscurity of night. In addition to this, nocturnal species of insects become sluggish and lose their activity, a conditions which corresponds to the natural state when the protective eye pigment is in the diurnal position.

A lamp does not attract all nocturnal insects to an equal degree. Above all, light-loving insects living in open, strongly illuminated biotopes (steppe species, inhabitants of water and coastal areas) fly intensively . For example, aquatic insects (Dytiscidae, Corixidae) during flight often plunge in one swoop upon the shining roofs of houses or on to asphalt roads or hot-bed frames, assuming them to be water surfaces or a mirror reflecting the night sky. Other nocturnal species frequenting darker places (earwigs, cockroaches, Tenebrionidae, Tineidae) rarely fly to light.

On steppes and deserts, in contrast to wooded areas, light radiates to great distances on account of the flatness of the relief and dryness of the air. That is why the radius of the attractive action of radiation on steppes and arid areas is so high and insects fly so readily to lamps from over large areas : Hundreds of thousands of individuals are caught in traps at night (Bogush [1951]). In districts with a very humid climate, for example in Abkhaz, the advantage of mercury-vapor lamps over the usual (half-watt) lamps is less noticeable because the water vapor in the air strongly absorbs ultraviolet rays, limiting their distribution (Milyanovskii [1957]).

The mass flight of insects to light on steppes and deserts is also assisted by the fact that in more southern latitudes the night is darker than in the north. On light nights the contrast between artificial and natural illumination is visible from far smaller distances,over which the radius of the attractive action of light diminishes. Moonlight by itself does not stimulate the activity of insects (except mayflies) and, moreover, it does not depress it as some authors suppose (Williams, Singh and Ziady [1956]).

Nevertheless, our hypothesis does not pretend to explain all the reactions of insects to light. Thus, we do not touch upon the unusual features of certain groups of insects in their behavior to light,which, it appears, is due, to other causes (linked up with the various physiological states of the population, etc.). For example, winged aphids, Aleyrodidae and other insects, during the periods they are searching for food plants for their progeny, are strongly attracted to yellow light rays, and "white" light with ultraviolet has a repellent action (Moericke [1955]).* Moericke supposes that at the time of migration, aphids and other insects which have completed a long flight turn upwards to the light of the sky. When the time for oviposition approaches the reaction changes :The aphids begin to fly downwards to the ground in search of food plants, reacting especially strongly to yellow and green light rays. The orientation downwards towards the earth at this period appears to be the result of a negative reaction to the light of the sun and sky.

It was observed that the ovipositing moth *Heliothis zea* (Boddie) does not react identically to one and the same light rays at various hours of the day: As darkness approaches the attractive reaction of green light rays decreases but that of the blue increases (Callahan, [1957]). According to the data of Dufay [1957] some moths react strongly to yellow rays in the presence of equal but high-energy illumination, but with low (equal) energy illumination the blue rays above all are attractive. In the two latter instances the stimulation to activity of moths by short-wave (blue) light rays in the evening may similarly be connected with the predominance of such rays in crepuscular and nocturnal illumination.

Thus, basically the mechanism of the flight of nocturnal insects to light rests, evidentally, on the same behaviour as is constantly effected under natural conditions. It is impossible to fit everything into our hypothesis since its basic propositions have never received experimental proof. We suppose that the more strongly light attracts insects the nearer its spectral composition approaches that of the diffuse light of the sky. The verification of this supposition might result from a comparison of the attractive action of radiation exactly matching the spectral composition of the light of the sky (for definite periods of the day) with light of some known composition. Technically it could be obtained by matching with a corresponding luminophore. If luminophores are put onto a screen and exposed to strong ultraviolet light the screen will radiate like the night sky. In other words, it is possible to construct a luminescent lamp for insects on the same principle as modern daylight lamps are constructed.

There is a simpler technical solution : to illuminate the white cover of a lantern with such filters as transmit various light rays proportional to the distribution of energy in the spectrum of the sky. Besides this, one must realize that the distribution of energy in the spectrum of the sky is not constant : It changes considerably at various times during the day. Are such screeens extremely attractive to insects ? Further experiments will elucidate this point.

SUMMARY

Hitherto the cause of the flight of insects to light at night has not been elucidated. Buddenbrock's (1917, 1937) popular hypothesis threw no light on the question, as insects fly not only to a radial source of light rays, for instance, a lamp, but also to diffuse light reflected from a screen.

It is very probable that light attracts insects only because it is a sign of open space, or an absence of restraints. In nature open spaces are much better illuminated than closed ones and they attract insects because there are no obstacles to avoid. Thus they can orient themselves more easily in the carrying out of one or another of their vital functions. During their life insects constantly make use of brighter illumination as an indicator of open space (exit from cavities, from dense vegetation, etc.).

Open space is characterized, above all, by an abundance of short-wave, generally ultraviolet rays. The source of these rays during the night appears to be the sky—. an orienting source which leads to open space. The greater the quantity of short-wave rays (including ultraviolet rays) an artificial light contains, the more readily it attracts nocturnal insects. Such illumination is similar to, but brighter than, natural light at night.

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* On this is based the principle of action of automatic traps for aphids, the chief element of which appears to be a yellow adhesive surface or yellow surface covered by water.