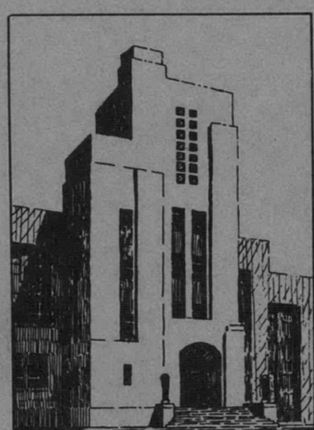
THE DAVID W. TAYLOR MODEL BASIN

UNITED STATES NAVY

LUMINOUS LIVING ORGANISMS

BY C. PUISSÉGUR



MAY 1947

TRANSLATION 221

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NAVY DEPARTMENT
DAVID TAYLOR MODEL BASIN
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LUMINOUS LIVING ORGANISMS

(LES ÊTRES VIVANTS LUMINEUX)

by

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(Science et Vie, Volume LXX, Number 348, September 1946, Paris, France)

Translated by R. Widmer

Foreword by Captain H.E. Saunders, USN

Navy Department
David Taylor Model Basin
Washington, D.C.

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FOREWORD

The reader may well wonder what concern an organization like the David Taylor Model Basin could have with luminous living organisms. It is, of course, not interested in them directly as organisms but indirectly it considers them of great possible importance as indicators of various hydromechanical phenomena taking place in the sea.

It has been noted that, in tropical waters where phosphorescence occurs, the organisms of this group become luminous in areas and regions where the water is disturbed, such as in the boundary layer and the wake of ships, in the tip vortices of propellers, in the tops of breaking waves, and in other places too numerous to mention.

If the exact type of disturbance which causes a luminous organism to emit light can be determined, the organism may eventually serve a most useful scientific purpose as a visual indicator of this type of disturbance in any particular hydromechanical setup.

The causes of this unusual action, as given in Figures 2, 6, 8, and 9, on pages 3, 11, 13, and 14 of this translation, are still rather general, in the nature of "any disturbance." Nevertheless, the information gained here, when combined with information gleaned from other sources, may in time build itself up into a framework from which general conclusions may begin to be drawn.

LUMINOUS LIVING ORGANISMS

ABSTRACT

Living organisms appear to us as remarkable converters of energy: Green plants absorb light radiations and convert them into chemical energy, used in turn for the synthesis of their living material. Animals in turn, beginning with chemical energy supplied by nutritive materials, produce mechanical work, heat, electricity, and light. The production of light is encountered in the most diverse representatives and over the most extensive range of the animal kingdom, as well as in the vegetable kingdom. The production of light is a startling phenomenon, long shrouded in mystery. It has astonished a goodly number of men, caused others to indulge in poetic revery, and has given rise to the development of legends. Sometimes it is a useless luxury; in other cases it is an excellent auxiliary for the organism which produces it. But despite this richly diverse character, it participates naturally in the cycle of transformations and conversion of energy. Although a study of it has not attracted any large number of scientists and research men, and although many of its aspects are still largely unexplained, the fundamental part played by oxidizing diastases in the production of this type of light is known today. Thus, just as the beautiful flower exploits the banal and even ugly soil for its existence, vegetable and animal luminescence creates its radiant splendor from the action of humble oxydases.

INTRODUCTION

In European countries, on beautiful summer evenings, the female of the species firefly or glowworm illuminates the night with its opalescent light, produced under its shell and wings. The light can be seen along the hedges, slopes, and stone walls in the country. This insect represents a classical example of a luminous living organism. However, it is far from being the only one having this extraordinary characteristic. In fact, all over the world, on the earth and particularly in the sea, species of animal and vegetable life exist, endowed with the ability to produce visible light. This is the function called by biologists photogenesis or actinogenesis.

Luminescent organisms are encountered in the most rudimentary or primitive living structures, i.e., the luminescent bacteria (*Photobacteria*) and the Protozoa (*Noctiluca*, etc.). Among the multicellular plants some types of thallophytes such as mushrooms and toadstools, are known to have luminescent characteristics; see Figure 1. Actinogenic characteristics have even been found in certain flowers, such as the *Tropaeolum, Euphorbia,* and *Verbena*. But it is among the Metazoa that the largest number of luminous

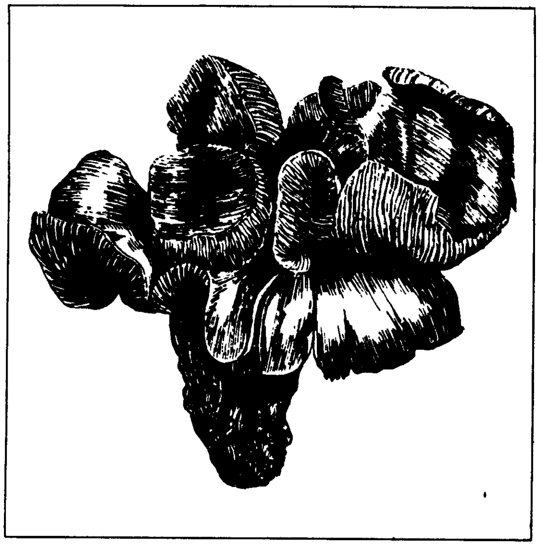

Figure 1 - "Agaric de l'Olivier"
(Olive-Tree Lichen)

This parasitic thallophyte is common in autumn in the region of the Mediterranean Sea. It is found at the foot of olive trees and is luminous principally on the under lamellate surface of its crown.

species can be found. They occur in varied groups irregularly arranged from the Beroidae and certain medusas to the deep-sea fish, ranging from worms, mollusks, and crustaceans to the insects, the Echinodermata, and the Tunicata; see Figures 2, 3, 4, and 5. It is interesting to note that among vertebrates the fishes, the most primitive class of all, are the only class endowed with the photogenic function.

Enthusiastic terms have often been used to describe these luminescent phenomena. In fact, even though certain rare species of small size do not make much of an impression on our senses, or on our imagination, others such as the *Noctiluca* (nightlighter) are so abundant in the ocean that they make it luminous. The luminous globes of the pelagic species and the enormous suspensions of *Cyanea* are known to sailors or sea travelers. Those fortunate enough to investigate the sea bottom have been priviledged to observe the beautifully illuminated fields of the Isidae and the Gorgonacea species which are cousins of the Corals. Luminous polyps brought to the surface by the nets of fishermen perform a magnificent luminous dancing spectacle before they die and their light is extinguished. Phosphorescent octopi, moreover, cast myriads of sparkling multicolored and changing lights in all directions.

FROM THE UNICELLULAR PHOSPHORESCENT ORGANISM TO THE COMPLEX MULTICELLULAR BEING PROVIDED WITH LENS AND REFLECTOR

The variety of groups to which luminous living organisms belong explains the diversity of structure of their light-producing organs.

In the simplest case there is no specialized mechanism. Very simple cells produce the light, either isolated as in bacteria or *Noctiluca*, or side by side without precisely defined locations such as the filiform cells of "Agaric de l'Olivier" (olive-tree lichen) and the epithelium of certain types of jellyfish such as pelagic medusa.

Luminescent bacteria are encountered either in suspension in water or on the recesses and hollows of the bottom. They can be cultivated as cultures easily on media consisting of stale, putrefying bouillons. As they are capable of living on cadavers, they impart a luminescence to the flesh of the fish, crustaceans, and even to the meat of a butcher's shop which has reached the stage of putrefaction. Meat inoculated with these bacteria becomes luminescent and emits white and greenish lights in darkness. Moreover, these same microbes can make living animals luminous. The waterflea, a small leaping crustacean which is very common under all the rocks and shingles of beaches, having become luminous after absorption of these bacteria, transmits this characteristic through several successive generations.

Occasionally, luminous epithelial cells collect in localized tissues at certain definite points of the body. This is the case of the type of jellyfish known as Beroidae, which have eight luminous tendons or cords, and of the Polynemidae, in which only the lower surface of their scales glows. For the former, see Figure 2, and for the latter, Figure 3e.

A more complex stage is attained when the luminous cells are closely united with cells of a differing nature, such as nerve cells and muscular cells. The combination then becomes a luminous organ or photophore (Light-bearer) in the true sense of the term. Numerous luminous animals reveal this

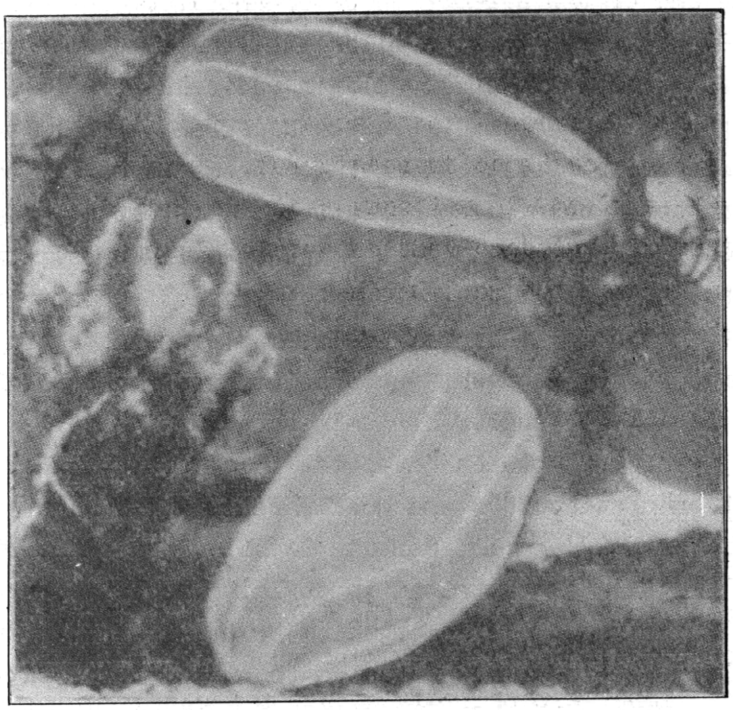

Figure 2 - Beroidae

A type of organism similar to the jellyfish. They are common in the Mediterranean and resemble small transparent balloons a few centimeters long. They are free-floating and are provided with eight longitudinal bands which on contact, or when excited by any stimulus whatever, are traversed by a luminous flow, i.e., they glow or light up.

structure; it may be very simple as in the ***Phyllirrhoë*** and pholads, of average or medium complexity as in the case of the luciole, or it may attain an extreme complexity as in the case of Crustacea, Cephalopoda, and fish.

In the luminous apparatus of insects a reflector exists which projects the light-radiation toward the exterior of the light-producing organ. Thus waste and dissipation of the light is avoided or eliminated as it traverses the body of the animal; see Figure 7 B.

In the case of certain species of Crustacea, Cephalopoda, and fish, the light-producing apparatus is accompanied by a highly developed optical mechanism. Although these species are only distantly related, similarities, resemblances, and curious parallels which are very detailed are noted in the structure of their luminous organs. Comparison of the luminous organ of the Cephalopoda ***Histioteuthis ruppelli*** with that of a luminous fish is most suggestive in this respect; see Figure 8, C and F. This resemblance of luminescent structures is accompanied by another just as interesting, which is concerned with the eyes of the Cephalopoda and of the fish. It is well to note particularly the remarkable parallelism in the evolution of the light-producing organs and of the eyes of these organisms.

Now, even if very sharp similarities exist between the luminescent organs of species which occasionally differ radically, there is still a great diversity of such organs, not only between different groups but between members of the same group as well. Among the fishes, for example, one species is luminous owing to a mucus which spreads over its entire body or forms in sinuous bands consisting of agglomerated scales or in button or shieldlike plates and protuberances. The latter may or may not project from the surface of the organism. A single luminous species may possess several types of light-bearing or photogenic organs, such as is noted in Crustacea and fish.

The location and number of luminescent organs varies greatly according to the organic structures involved. They are spread very rarely over the greater portion of the body, and most rarely over the entire body; such examples include the *Phyllirrhoë*, certain Cephalopoda, and certain fish. Most generally, they are concentrated in definite zones or regions. They appear to be sown on the body of the organism by mere fancy and phantasy; according to species they are encountered on the most varied parts of the body. These include the thorax and abdomen of insects, the periphery and vicinity of the eye in case of Cephalopoda and fish, opercular bones, jaws, flanks, tip of the tail, tentacles (in fish), ocular penduncles of the Crustacea and the lower part of the gills of fish. Though the number of the luminescent organs is very limited in some organisms, it may run to several hundreds in others. In some instances, they delineate the outline of the organism faithfully.

Several light-producing organs may combine to produce compound organs, as is true for fishes and Crustacea.

Among organisms which undergo metamorphoses, the light-producing organs suffer the fate of the other organs. For example, in the case of the ***Pyrophorus***, as shown in Figures 4c and 7 A, they undergo a change in shape as well as in location. The very young larva has an unsymmetrical organ straddling its head and thorax. Later the shape of this organ changes and it completes its development by adding a series of points arranged in regular files along its abdomen. In the adult, finally, a different arrangement develops: Two separate thoracic organs appear which are either oval or rounded, and a ventral organ is produced at the center of the first abdominal segment.

Finally, it is of interest to mention the luminescence of the egg of certain light-producing organisms, such as the Beroidae, ***Pyrophorus***, and firefly. The eggs of the glowworm are luminescent even in the maternal ovaries. Hence, this insect is photogenic at every stage of its life cycle.

THE PRODUCTION OF LIGHT

In 1667, R. Boyle succeeded in restoring luminescence to dried morsels of fireflies by moistening them. Thus he showed that photogenesis is not a function of life.

Two hundred and twenty years later, Raphael Dubois, whose name is closely linked with the study of luminescent organisms, showed that the activity of photogenic organs is not a function of the life of the cells, but is a product of the chemical substances they contain. Filtration of solutions made of macerated photogenic organ removed from dead organisms yielded a luminous liquid. A ***Pyrophorus*** killed at minus 100° C (minus 148° F) remained luminous when removed from the test tube. Moreover, the same organism retained its luminosity for several hours when electrocuted.

In the filtrate of the mucus of the pholads, Dubois separated two mutually reacting substances which produce luminous radiations when combined. These are:

1. Luciferine, a quaternary compound very closely resembling albumin and oxidizable.

2. Luciferase, a diastase of the peroxidase group.

In air, a simple solution of luciferine oxidizes but the reaction takes place too slowly to produce light. However, the addition of only a small quantity of luciferine to the solution suffices to produce luminescence. It is certainly a diastasis phenomenon, for boiling the solution extinguishes the light, exactly as boiling arrests artificial digestion. On the other

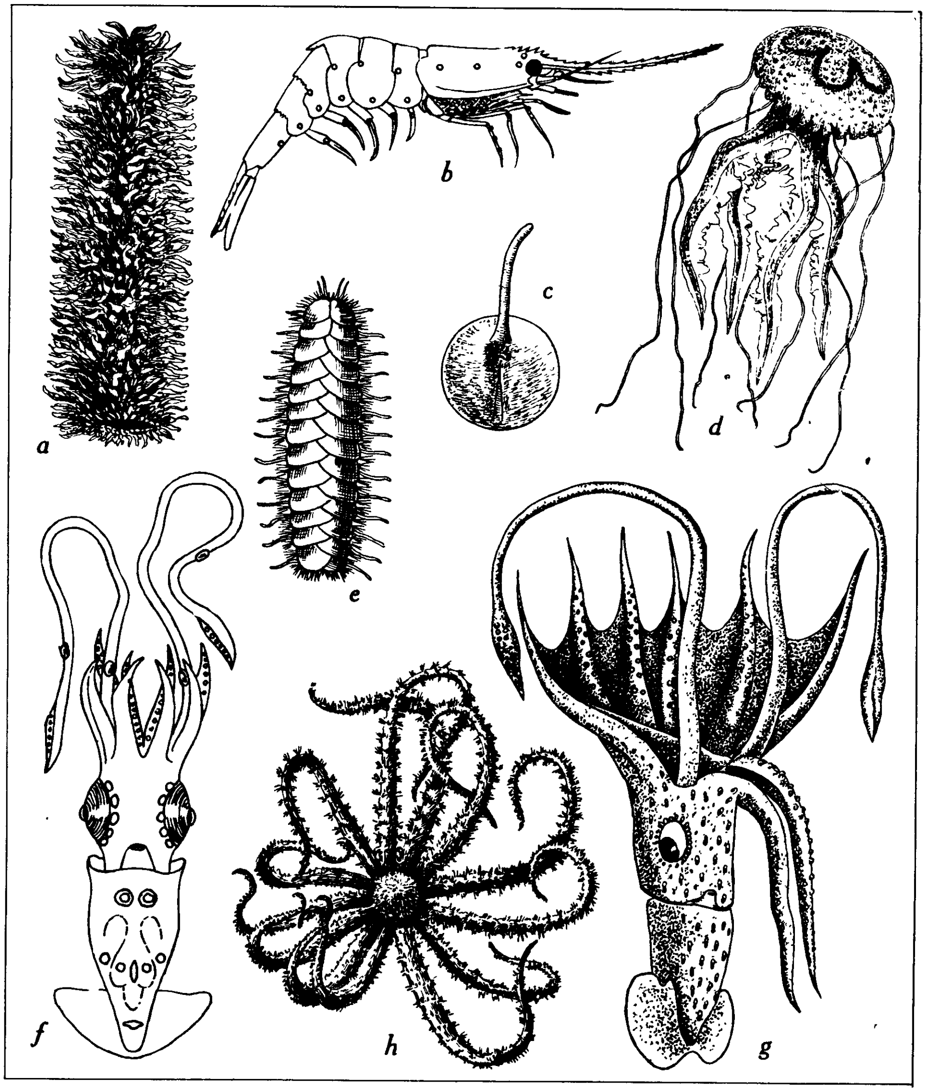

Figure 3 - Luminous Marine Organisms

a. Colony of *Pyrosoma*: These colonies, which attain a length of 10 cm (3.93 inches) along the coasts of France, are composed of a large number of individuals 5 mm (0.196 inch) long. They are closely huddled together into a horizontal floating transparent muff. Rhythmical contractions of the individual organisms, which aid its locomotion, produce the luminescence of the colony. In warm seas such colonies attain a length of 2 m (6.56 feet).

b. *Systellaspis debile* : A shrimp several centimeters long bearing photophores on its legs and body.

c. *Noctiluca* (nightlighter): A curious protozoid, either spherical or ovoid, about 0.5 mm (0.019185 inch) mean diameter; it is striking chiefly because of its groove but more so for its flagellum, whose movements are too slow to produce locomotion. It enjoys a very extensive geographical distribution. Its luminosity does not occur throughout the entire cell, but is produced by a large number of tiny luminous dots.

d. Pelagic *noctilux* : A very common species of Mediterranean medusa; four oval prongs elegantly fringed, eight tentacles. Size of the umbrella or dome, 6 cm (2.36 inches).

e. *Polynoe*: A curious worm about 3 cm (1.181 inch) long, living on the bottom or in the crevices between the rocks, where it seeks refuge with agility. Its body is covered with imbricated scales improperly termed exterior wings. It is the lower part of this wing which is photogenic or luminescent.

f. *Thaumatolampas*: Deep-sea squid; photogenic organs scattered, but abundant about its eyes.

g. *Histiothentis* : Another species of squid about 20 cm (7.87 inches) long, having numerous scattered photophores, also very abundant about the eye.

h. *Brisinga* : A starfish having long and flexible arms; its luminescence is emitted by both the central disk and the tentacles. Its over-all diameter ranges from 15 to 20 cm (5.90 to 7.87 inches). It is named for the sparkling jewel of Freya, who is the goddess of beauty, love and wisdom, in the mythology of the Scandinavian countries.

hand, it is surely a phenomenon of oxidation, because a very intensive oxidizing agent can be substituted for the luciferine, such as potassium permanganate, with identical results.

These preliminary studies were continued and extended by Dubois himself and by other biologists, principally by Newton Harvey, to other living organisms. In particular, numerous experiments were made on phosphorescent insects. Thus the nonspecific character of a luciferase was demonstrated which can react on various luciferines belonging to related species. Diastase determines the color of the light emitted. The following experiment on American glowworms of two related genera, the *Photinus* and *Photuris* , shows this very well:

a. *Photinus* luciferine plus *Photinus* luciferase gives red light,

b. *Photuris* luciferine plus *Photinus* luciferase gives red light,

c. *Photinus* luciferine plus *Photuris* luciferase gives yellow light, and

d. *Photuris* luciferine plus *Photuris* luciferase gives yellow light.

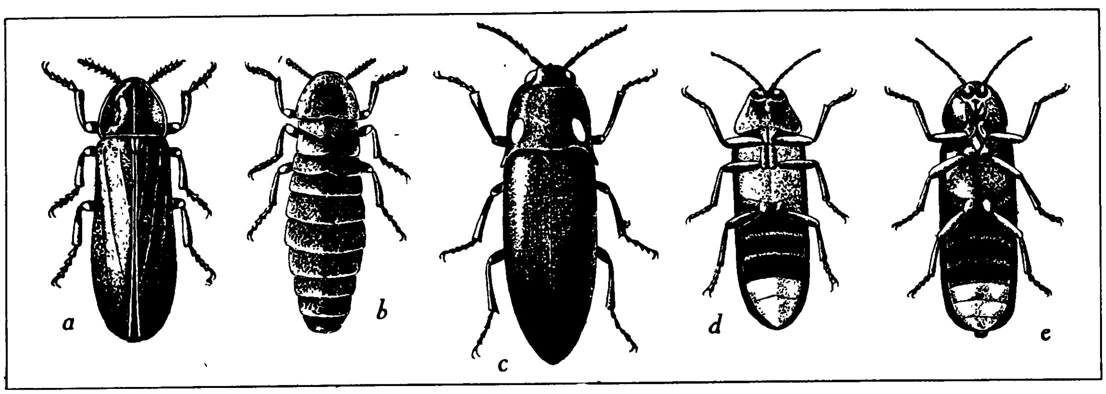

Figure 4 - Luminescent Insects

a. Winged male firefly. Feebly luminescent along its two posterior abdominal segments only; length of body 11 to 13 mm (0.433 to 0.511 inch).

b. Female firefly, wingless larval; very luminescent along its three posterior abdominal segments.

c. *Pyrophorus noctilux* ; a species of South American Coleoptera, of crepuscular and nocturnal habits, enclosed in a brown shell; length, about 4 cm (1.57 inch); three photophores, two on the thorax and a ventral one on the first abdominal segment, not visible in the figure. The abdominal organ emits a more intense light than both thoracic organs combined.

d. Male lightning bug, ventral view: The light is produced at the level of the two posterior abdominal segments.

e. Female lightning bug; although winged, it mates with the male on the ground or on the leaves. The light is emitted by the two penultimate abdominal segments. These lightning bugs, which attain a length of 1 cm (0.39 inch), are exclusively native to southern climates; they are found in the extreme south of France.

Thus, by an "oxy-luminescence," cells are able to produce light. In the case of many organisms, cells produce a luminous mucus, which, in the most primitive cases, spreads to the exterior of the organ through a discharge duct; see Figure 8, A and E. In contrast, in the most highly developed cases, i.e., where evolution has progressed to the greatest extent, the organ is a ductless gland not having a canalization to the exterior of the organism; see Figure 8, B, C, D, and F. The light emitted by the cells diffuses in all directions, traversing the tissues themselves to a greater or lesser depth. However, in the most highly developed organs, the light is projected toward the exterior of the body by the opaque layer of pigmentation which prevents or impedes the rays from dissipating inside the body of the organism, and by the reflector which casts the rays toward the bi-convex lens which collects them and projects them toward the exterior. The external reflector acts on a concave mirror such as used on a gasoline lamp. The skin, which is transparent as that of the cornea of the eye and the conjunctive membrane, permits passage of the light. A complex photogenic organ thus functions as an eye in reverse. The similarity between an eye and a photophore is of very special interest in certain Crustacea, such as ***Mysis***. Here the eye, which is bivalent, functions both as a photogenic organ and as a visual one; i.e., as a transmitter and as a receiver.

For certain biologists, the phenomenon of the production of visible light by certain living organisms constitutes only a special case of the emission of invisible light radiations by the majority of living beings. The use of very sensitive photoelectric counters has led to the discovery of numerous chemical reactions emitting ultraviolet radiations, invisible to the human eye. This discovery stimulated Gurwitsch to believe that the majority of tissues emit ultraviolet rays. Certain scientists see in an expansion of this phenomenon the possible cause of the emission of light radiation perceptible to the human eye. Although sharply criticized, this hypothesis is supported by several cases observed of ultraviolet radiations produced by organic agents. In any case, it has been impossible to show any infrared or ultraviolet emissions in the case of glowworms.

DO LUMINOUS ORGANS OWE THEIR LIGHT TO SYMBIOTIC PHOTOGENIC BACTERIA?

Symbiosis, an enduring and mutually beneficial association between two living organisms, is encountered to varying degrees among both the flora and the fauna. It will suffice, for present purposes, to recall the symbiotic relationships which exist in the case of ***Hydra*** and of certain freshwater worms with microscopic blue-green algae, the ***Zoochlorella***, or again

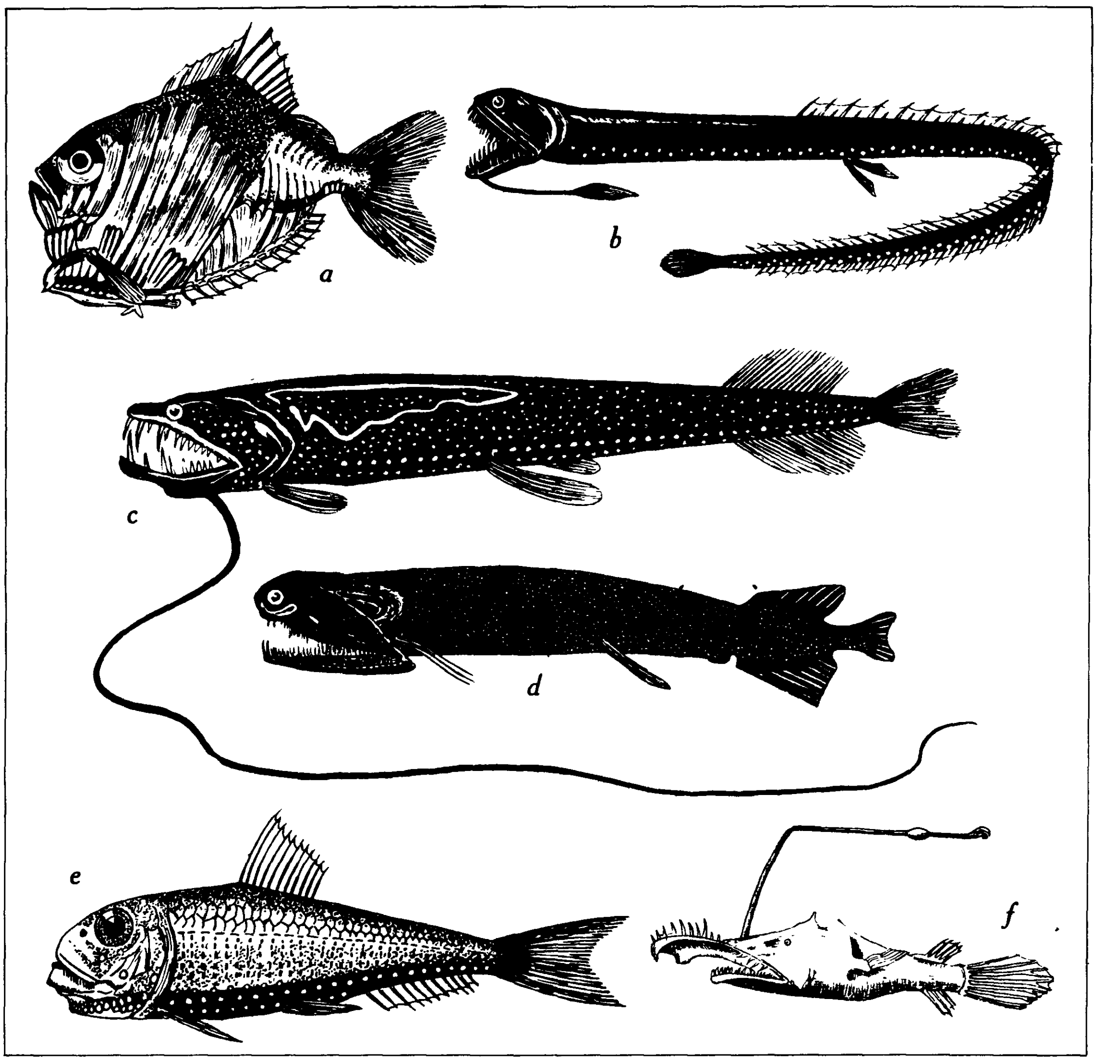

Figure 5 - Luminous Deep-Sea Fish

These fish show very differing shapes, standard and irregular. Very elongated shapes predominate, with occasional extraordinary development of sensitive appendages which serve as lures for fishing. In all, the head is huge, powerful, almost always provided with retractable and terrifying jaws, armed with numerous pointed teeth. In most cases, these fishes are of small stature or size, ranging to a few centimeters, rarely to a few decimeters.

a. *Sternoptyx diaphana*; widened body, sown with small rows of photophores beneath the eye and the mandible on the flanks, and at the base of the tail.

b. *Idiacanthus fasciola* ; cell-shaped body, two lateral rows of photophores.

c. *Lamprotoxus flabellibarba* ; photophores in rectilinear rows on its flanks, scattered over the entire surface of the body and forming a curious, sinuous band behind the gills.

d. *Malacosteus niger* ; captured near the Azores at a depth of 2200 m (7218 feet). The articulation of the jaw is very far toward the rear of the body, recalling those of serpents. It permits opening a disproportionately large mouth; numerous photophores spot its entire body, two large photophores of different color near the eye.

e. *Ichthyococcus ovatus* ; one of the least nonstandard among deep-sea fish, photophores in lateral rows, below the eyes and in the vicinity of the gill-slits.

f. *Lasiognathus saccostoma* ; enormous gullet with pointed teeth, a long tentacle terminating in a crochet hook and provided with a strange luminous bulge or swelling.

the symbiotic condition of the bacteria found in the root nodes of the Leguminosae, and finally the far more familiar example of lichens, consisting of the symbiotic association of an alga and a mushroom or toadstool.

Piérantoni, discovering that a small worm found in phosphorescent earth, the *Microscolex phosphoreus*, is infected with photogenic bacteria, and finding analogous bacteria also in the luminescent mucus of Cephalopoda, micro-organisms also susceptible to cultivation, believes in the existence of a symbiotic relationship between these bacteria and the cells of the luminescent organ. Bacteria have likewise been proved to exist in the luminescent organs of pyrosomes and fish; see Figure 9. In the photogenic cells of glow-worms, granulations have been detected; however, it has not been proved that they are bacterial in nature. Additional research appears definitely necessary to solve the problem raised by Piérantoni.

OPERATING CONDITIONS OF THE LUMINOUS MECHANISM

Even though it appears evident that the luminescent mechanism seems to function by enzymic (diastatic) oxidation of luciferine in all cases, its operating conditions vary greatly over a wide range of living organisms.

In the first place, luminescence can only be produced in darkness. The Beroidae and the *Noctiluca* only illuminate after remaining in darkness from a quarter to half an hour. In the case of the foregoing organisms, their luminescence is extinguished by light. In insects, luminescence is excited by the intermediary of nervous reactions, i.e., it is stimulated by the nervous system. Merely exposing the head of the lightning bug to light radiations instantly arrests photogenic activity. In the majority of cases, luminescence occurs equally during daylight and during the night. Furthermore, by day, a species can be excited to luminescence which ordinarily does not so respond, merely by the application of proper stimulants. The *Pyrophorus*, when excited by electricity or heat, becomes luminescent in daylight.

Oxygen is indispensable to the phenomenon. An olive-tree fungus or lichen immersed into boiled water does not become luminous. In ordinary water from which the air has not been driven out by boiling, this fungus becomes luminescent. The photogenic action of a pholad is terminated by putting the organism into a flask of CO_2 gas. The luminescence can be restored completely simply by transferring it to an atmosphere of oxygen. In any case it seems that the requisite oxygen pressure is very low; it is only 3 mm (0.1181 inch) of mercury for the Coleoptera.

Temperature exerts its effect on actinogenesis; heat, for example, activates light emission in the pholads, the *Pyrosoma*, and the *Phyllirrhoë*.

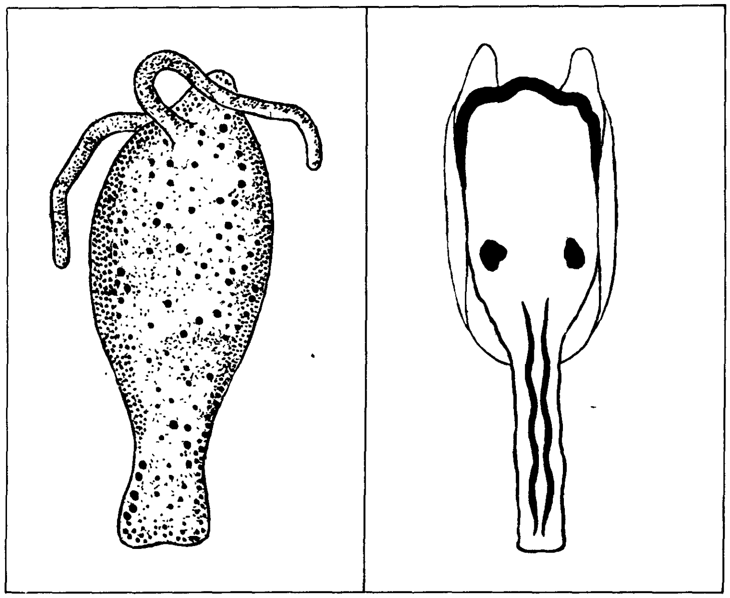

Figure 6 - Photogenic Activity among Mollusks

Left: ***Phyllirrhoë***, a naked mollusk, not provided with a shell, native of the Mediterranean, Atlantic, and Pacific. Its light emission was stimulated by ammonia. The photophores, or rudimentary development, dot or speckle the body with small globules of light.

Right: ***Pholad dactylus***, a bivalvular mollusk, common to the coasts of France where it digs small holes in the sand, in wood, and especially in the rocks. Its luminous mechanism consists of 3 stripes and 2 spots, yellowish in color. The photogenic cells are corniform (horn-shaped) or ciliated (hairy), and are connected to nerve and muscle fibers. They produce a luminous mucus, even when removed from the organism.

However, inordinately high temperatures arrest the phenomenon. A ***Pyrosoma*** extinguishes its light at 60° C (140° F) while a ***Phyllirrhoë*** ceases to emit light at 61° C (141.8° F). Optimal temperatures exist over the range from 6° to 10° C (42.8° to 50° F) for the ***Bacillus phosphoreus*** and range from 20° to 25° C (68° to 77° F) for the ***Pyrophorus***. Finally, low temperatures seem to have a smaller effect on the phenomenon, for photogenic (actinogenic) microbes impart luminescence to ice; a ***Pyrophorus*** retains its brilliance even at minus 100° C (minus 148° F).

Mechanical and chemical agents or factors are also influential [in producing luminescence]. Such types include contact, shock or impact, and disturbance of the environment; they either excite the organism to phosphorescence or increase the intensity of radiation, if already luminous. The ***Noctiluca*** become luminescent merely as a result of the agitation and oscillation to which they are subjected by the waves of the sea. Sea water containing them resembles molten silver when its surf breaks on the sands. The area of the beach from which the waves have receded is populated by myriads

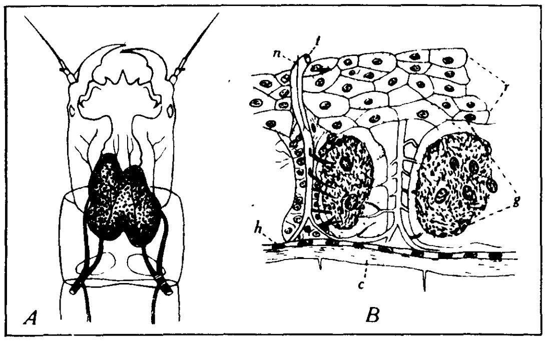

Figure 7 - Luminous Organs of Insects

A. Photogenic organ of the larva of the *Pyrophorus noctilux*, at hatching (incubation). The connections between the single actinogenic organ and the trachean network are visible.

B. Photogenic organ of the lucioles: g, actinogenic gland, containing cells replete with granulations; r, reflector consisting of several layers of cells, casting the light toward the exterior of the organism (bottom of figure); t, very ramified (greatly branched) trachea supplying or conducting air; n, nerve; h, hypodermics.

of these organisms, previously non-luminous; they glisten and sparkle beneath the tread of the pedestrian, leaving a track of luminous footprints. Electricity functions similarly in the case of the pholads and the *Pyrophorus*. In the case of the latter an interesting similarity even exists between the reaction of a photophore and the reactions of a muscle, excited by direct current. In both cases a response is recorded when the circuit is opened and another when it is closed.

Fresh water and ammonia stimulate the phenomenon in marine organisms. Alcohol produces initially a superficial excitation, characterized by a recrudescence of the luminosity, followed by extinction of the light radiation, for alcohol upon penetration coagulates both luciferine and luciferase.

PROPERTIES OF THE LIGHT EMITTED

The color of luminescence is extremely variable. It is white in the case of the olive-tree fungus and lombrics, clear blue in the *Pyrosoma*, light blue or of azure tint in the *Phyllirrhoë*, greenish in the *Cyanea*, the Lampyridae, and the *Bacillus phosphoreus*. It ranges from red to violet, embracing or covering the entire visible spectrum, in the Lampyridae and Elateridae.

Moreover, it not only changes from species to species, but ocassionally in the same species with various individual specimens. The light of the Gorgonacea fluctuates rapidly from red to purple and blue. Brisk shaking changes the clear or bright blue light of the *Noctiluca* to white; this occurs instantly upon such excitation. The larva of the *Pyrophorus* emits a blue light, while that of the fully developed insect is green. A single species may be provided with photophores of differing colors. In the case of the Coleoptera, *Phengodes*, the anterior portion of the body lights up red, the sides green. The fish Malacostraca has a large photophore of red hue near its eye and, further back, a small one which illuminates green; see Figure 5d. The modification of the light produced may be due to chromatophores of various

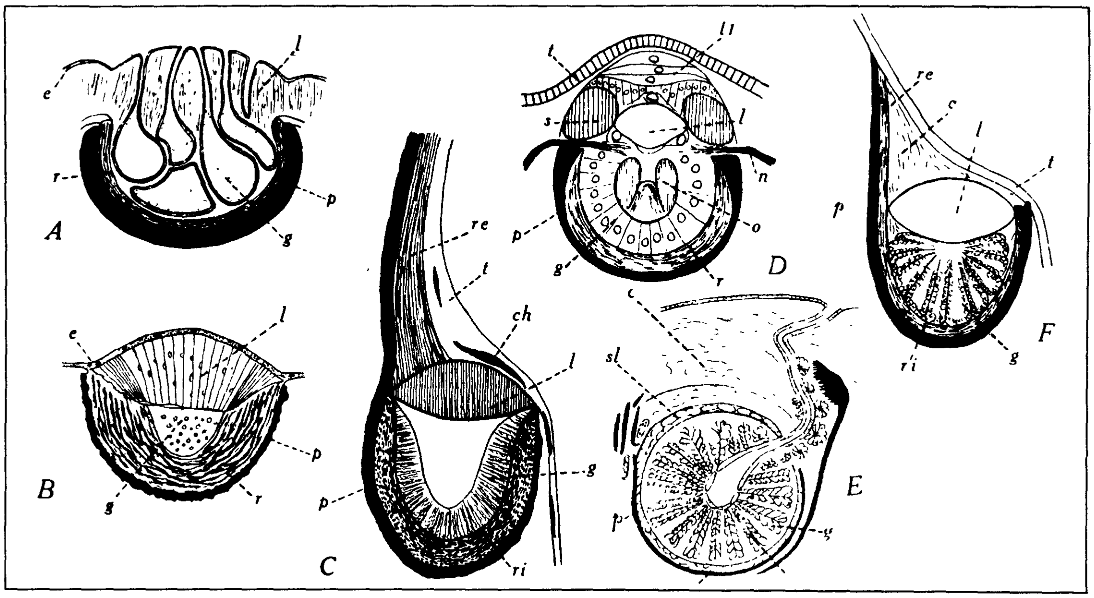

Figure 8 - Luminous Organs Having Optic Mechanisms

A. *Rondeletia minor* (Cephalopoda)
B. *Charybditeuthis maculata* (Cephalopoda)
C. *Histioteuthis ruppelli* (Cephalopoda)
D. Crustacea
E. *Gonostoma* (fish)
F. Another deep-sea fish

c. transparent conjunctival tissue
ch. chromatophore (color bearer)
e. epiderm (upper or top skin)
q. actinogenic (light-producing cells)
l. lens
l_1. outer or "surface" lens (superficial lens)
n. nerves
o. internal striated body
p. pigmented screen surrounding actinogenic cells
r. reflector
r_i. internal reflector
r_e. external reflector
s. annular striated body
sl. refringent substance comparable to a lens
t. skin

From top to bottom, the Cephalopoda reveal their differentiation and their increasing complexity. In A, the luminous light emitted from the gland g can radiate to the exterior. In B, the organ is sealed, the lens better developed and individualized. In C, the structure is still more complex by the addition of two reflectors. The chromatophores ch should be noted; their mobility correlates with the changing of the coloration of the light. The thoracic photophore of a crustacean, generally retaining the foregoing anatomic scheme, differs from the preceding by more complex characteristics (two lenses, two striated or striped bodies). Finally, in the photophores of fish, the same scale of evolution is found as among those of the Cephalopoda, from the primitive type (E), where the actinogenic or photogenic gland is open and exposed, to the most highly specialized type (F), where the structure is remarkably comparable to that of C.

colors interposed, i.e., placed between the light source and the exterior of the organism, similar to the colored glass filter or slides used in theater projectors or "spots."

In general, the light emitted by living organisms is characterized by the extreme shortness of its spectrum. For example, in the case of the *Lampyris*, a type of glowworm, it covers the spectral range comprised between wave lengths of 0.518μ and 0.565μ (0.0000209366 to 0.00002582672 inch).* Therefore, this range of wave lengths falls in the interval between green and red.

The light of the Lampyridae is not polarized. It acts as natural light by producing so-called "tactisms" and "tropisms,"** by furnishing the radiant energy screened by the chlorophyll of plants.

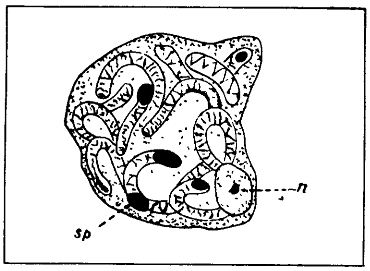

Figure 9 - A Luminous Cell (*Mycetocyte*) of the Pyrosome, Containing Symbiotic Luminous Bacteria

A number of bacteria grouped in colonies resembling rolls or sausages are visible; n is the nucleus of the cell; sp are the bacterial spores.

Finally, the intensity of light produced by living organisms is ordinarily low or weak. Results found and published by various scientists differ. Although the *Pyrophorus* is the most luminous of insects, 38 of them would be necessary to equal the light produced by a single candle, according to research made by Raphael Dubois, cited previously, whereas more than 300 of these insects would be necessary, according to more recent investigations by Newton Harvey.

DOES THE LIGHT EMITTED BY LIVING ORGANISMS SERVE A USEFUL PURPOSE?

The function of light emissions by living organisms has been interpreted variously. According to various investigators, it serves as a medium of recognition among individuals of the same species, or to distinguish

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* Translator's Note: The symbol μ has been assumed to be a "micron," as a measured length of 1/1000 mm, or 0.00003937 inch.

** Translator's Note: The term "tactisme" means the influence exercised by certain substances or by certain forms of energy on the development of unicellular organisms. The term "tropisms" denotes the phenomena known in botany by which vegetable organisms make an adjustment to their environment.

physical objects, in particular to detect prey, to attract its prey by trapping it (the light serving as a lure), to escape from danger, to frighten its enemies, or to attract members of the opposite sex for reproduction purposes.

Many of these interpretations which ascribe a precise utility to the photogenic phenomenon appear simply to be manifestations of anthropocentrism. In the first place, with present apparatus, even with W. Beebe's bathysphere which permits exploration and study to depths of more than 1000 m (3280 feet) below the surface of the ocean, but which is not used very extensively, these varied interpretations cannot be checked very precisely. We are absolutely ignorant of any possible use that the production of light could have for an organism as primitive and rudimentary as a bacterium which absorbs and assimilates its nourishment over its entire surface. Furthermore, we have no way of determining whether the fish of a given species recognize each other in the gloomy abysmal depths of the sea in much the same way that switchmen and yardmen do in railroad stations and terminal yards by waving colored lanterns in semaphore fashion. We also do not know whether in these abysmal depths of the sea, where the struggle for survival is merciless, as all its denizens are carnivorous, a photogenic organism is able to illuminate and extinguish itself (or its lights) at will and instantaneously. Moreover, we are no more aware whether certain organisms attracted by these twinkling lights, such as are moths by lamps, thus become more easily the prey of light-producing organisms. However, it must be admitted that nonluminous individuals of the same species recognize one another and congregate as easily as those which possess the ability to function photogenically. In the great depth of the sea, nonluminous fish appear to struggle for life and livelihood just as successfully as the others, for only about one-fourth of the species so far distinguished are known to be luminescent.

Admitting our almost complete ignorance of possible utility of luminous organs, it is fitting nevertheless to mention the close relationships existing in the case of some organisms between the phenomena of light production and reproduction. Observations have shown particularly that the light of certain lombrics was either greatly localized or much more intense in the region of their genital band or waist. Moreover, in the former case, i.e., where localized, the production of light ceased after copulation. However, it is among the luminous Coleoptera principally that these relationships between actinogenesis and virility, i.e., reproductivity, have been shown precisely. Many species of Lampyridae perform "luminous dances," according to the scientist Paulian. The winged males emit intermittent flashes of light, to which the females, which are generally apteral (wingless) and larval, respond synchronically. The male, but not the female, allows himself to be deceived by the substitution of an artificially produced light similar to that emitted by members of the opposite sex. The oscillating flashes of the males and females coincide very precisely with each species. Their duration and intensity vary from species to species. Curves plotted for the light emission of the two sexes permit detecting instantly with which sex one is dealing. In all these examples, the light produced obviously serves to promote union of the sexes for reproductive purposes. On the other hand, R. Dubois has demonstrated that the ***Pyrophorus*** uses its light to find its way. These are the only instances where a well-defined useful function can be assigned to actinogenesis.

IS THE LIGHT PRODUCED BY LIVING ORGANISMS SUSCEPTIBLE OF PRACTICAL EXPLOITATION?

According to the Spanish explorer and navigator, Oviedo y Valdés, who flourished in the XVIth Century, certain indigenous foreign peoples, West Indians and Haitians especially, used luminous pyrophores which they termed cucuyos, as lanterns. This they achieved by imprisoning the insects in cages which they suspended in their hats. In times of war, these aborigines suspended these caged luminous insects from their heads much in the manner of a miner's lamp.

Later, it was narrated that these natives used these same insects as lures for fishing by night and to rid their habitations of mosquitos; also that the West Indian women embellished and ornamented their dress and hair with fireflies (***Pyrophorus***), using them especially as necklaces and earrings.

Closer home, and betraying rigorous scientific zeal rather than the more or less inflamed fancy and imagination of an ancient explorer, we may recount that R. Dubois photographed a bust of Cl. Bernard by the light of the ***Pyrophorus***. Moreover, this same biologist illuminated a large hall sufficiently to permit reading by coating the interior surfaces of large glass spheres with luminous bacteria. The latter demonstration was made at the Paris Exposition, in the year 1900.

Thus, beyond a few curious examples, it does not appear that actinogenesis of living organisms is at present exploitable practically, although some have believed that it might be used efficaciously in extremely dangerous mines, where any other type of light might cause detonation of mine damp.

Aside from the positive information which has been obtained concerning these creatures, a great many unsolved problems still persist. For example: Is not the light produced by living organisms just as is heat energy, purely the result of metabolic reduction or simply of metabolism? Or is, as claimed in some quarters, actinogenesis a residual atavistic trait, which formerly flourished widely among living organisms and has since progressively disappeared to become vestigal, owing to the disadvantages it entrained in the struggle for survival? So many questions persist. Evolution, too, has its reason which human mind has not been able to grasp.

SUGGESTIONS FOR SUPPLEMENTARY READING

For additional reading, see the article on Phosphorescence, Encyclopedia Brittanica, Fourteenth Edition, 1929, which is followed by a brief bibliography.

The same subject is treated in popular style in an article entitled "Nature's Neon Signs," by Ivan T. Sanderson, Saturday Evening Post, 1 June 1946.

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