Luminous Living Creatures*

The Mystery of "Cold Light"

By Dr. Raphael Dubois, Prof. of General Physiology, University of Lyons

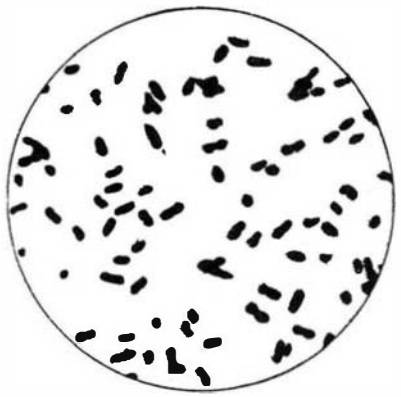
LIVING creatures produce not only motion, heat, and electricity but also light, more or less vital in character, and the glow worm with which all the world is familiar has by no means a monopoly of this manufacture.

In every part of the globe, in the air, in the woods and meadows, in the bosom of the waters, there are living signal lights gleaming with strange and shimmering fires, which are incomparably beautiful and suggestive, not only in the eyes of the poet but even more so in those of the savant, for the scientific researches which have been undertaken in the hope of plucking from nature this marvellous secret of hers are numbered by thousands. Upon the surface of the ocean, sometimes over immense extents, the sea shines with a splendor that rivals the starry firmament, while in the depth of its abysses fairy illuminations suddenly blaze forth among the forests of polyps at the passage of fantastic animals, which are themselves wreathed with shining gems, the strange brilliance of whose fires would put to shame the most sumptuous jewels.

Plants also produce light. In the gloomy galleries through which the miner, ever on his guard against the deadly fire damp, bears his dim and dangerous candle, the myceliums of fungi shine upon old worm eaten beams with a calm, pale, harmless, moonlight gleam. It is these vegetative organs of fungi, also, which in the forests produce the phosphorescence of dead wood and leaves and old stumps. Adult fungi, such as the Agaric of the olive, which is common in Provence, likewise shine in the dark. In Brazil and in Australia the emerald green light of other species is so bright that one can easily read a newspaper or see the time on a watch dial by means of this living torch.

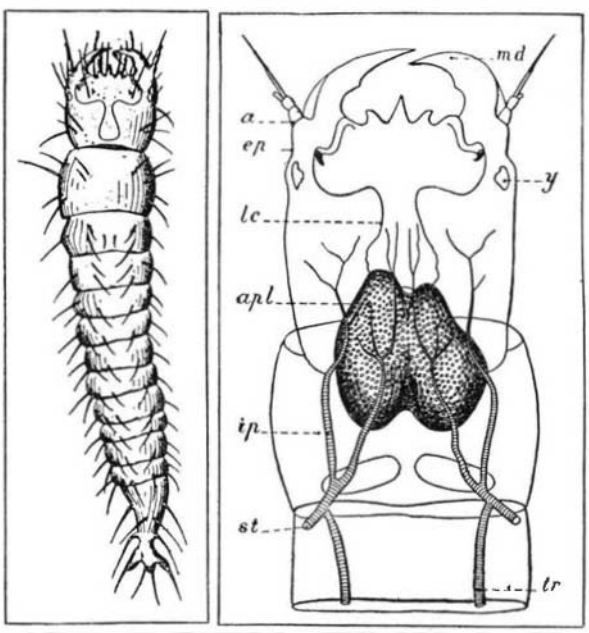
Most extraordinary are those infinitely small fungi, the luminous microbes or Photobacteria. Some thirty species of marine origin are known. They are particularly abundant in the mucus of the skin of sea fishes, but their phosphorescence does not develop, however, until from twenty-four to forty-eight hours after the animal has been taken from the water. It is readily communicated by microbian contagion to butchers' meat. The latter often becomes luminous when it is merely exposed to the air after having been moistened with salt water. The phosphorescence is continuous but is scarcely visible except at night when the eye is rested from the light of day. The first phosphorescent microbe of meat which has been isolated and cultivated in the pure state is that to which I have given the name of *Photobacterium, sarcophilum.* The ingestion of these microbes is not at all dangerous; the frog can never be inoculated with them with impunity, as I long ago demonstrated. The same thing is not true, however, of certain small crustaceans (shrimp, prawns, sea fleas, wood lice), which become entirely luminous after inoculation but soon perish. Gnats and mosquitos sometimes exhibit this luminous malady spontaneously and it might be possible to attempt to destroy by this means these creatures which propagate harmful germs like that of malaria.

I have found non-pathogenic luminous microbes in the interior of the organs of certain animals which are themselves phosphorescent. However, those persons who pretend that these are normal or *symbiotic* microbes which produce physiological animal light have incorrectly interpreted my observations. A very curious circumstance, however, is that when inoculating with photobacteria gelatinous bouillons containing lecithine I have provoked the formation of luminous cells much resembling those of the glow worm in certain respects. They are formed by the agglomeration of a multitude of photobacteria which have lost their bacterial form and become transformed into very small micrococci. The photobacteria are very polymorphous and very polybiotic, which has led some authorities to multiply the species without justification. There are some forms which are immobile and others which move by means of propulsive cilia. In their internal structures these forms resemble the *vacuolids* or microleucites which I have described as being the most simple general form of living substance or *bioproteon.*



A GROUP OF PHOTOBACTERIA OR LUMINOUS MICROBES

The luminous microbes are easily cultivated in liquid or gelatinous nutritious bouillon containing three per cent of salt, by coating the inside wall of large, sterilized glass casks with gelatinous bouillon which had been planted with selected photobacteria, I was enabled in 1900, at the International Exposition of Paris, to illuminate as with the most beautiful moonlight the underground chambers of the Palace of Optics. It was upon the same principle that I constructed my *living lamp.* This is composed of a convex glass vessel whose silvered dome serves as a reflector and into which filtered air passes through cotton wool inside of two aeration tubes. With this little night lamp which will last a month without going out and without consuming more than two cents worth of fuel, one can easily read in the dark or distinguish the objects in a room. Moreover, it is very portable and cannot set anything on fire since it radiates only *cold light.* Unhappily I have not as yet been able to impart sufficient intensity to this method of illumination. At the present time this lamp has scarcely any possible practical ap-

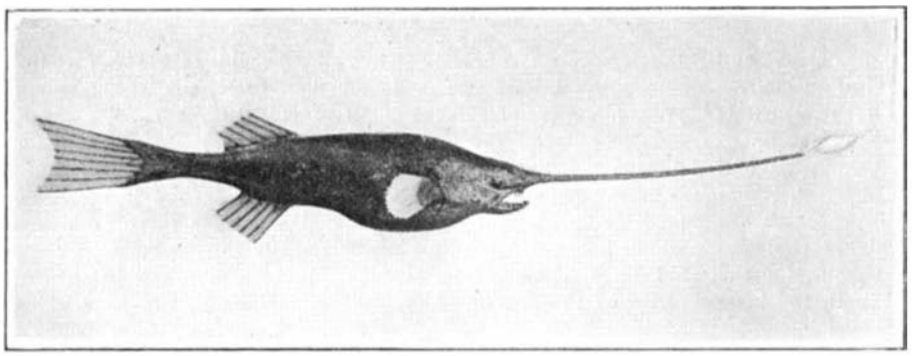


LARVA OF *PYROPHORA NOCTILUCA* AND ITS LUMINOUS APPARATUS

Md. = mandibles; *a* = antennae; ep = epistome *y* = eye; *le* = clear line; *apl* = apparatus producing light; *ip* = insertion of first pair of legs; *st* = level of first stigmata; *tr* =) trachea.

*Translated from *Science et La Vie* (Paris).

plication except in powder mills in mines where fire damp is feared, or as a night lamp in those hot countries where even the gentle heat from an incandescent electric light is annoying. The light of this lamp is more feeble than that of the illuminating apparatus of insects, of cephalopods, or of certain fishes, in



MODEL OF THE *GIGANTACTIS VANHOEFFENI*, A DEEP SEA FISH WHICH CARRIES A LUMINOUS TORCH AS A LURE TO ITS PREY

spite of the fact that it is a result of the same reaction; but the luminous organs of these animals are provided with improvements which greatly augment their brilliance. When these organs are crushed they do not shine, unfortunately, with any more brilliance than do the microbes.

Luminous animals are found in almost every degree of the zoölogical scale from the Noctiluca, the microscopic infusoria which produce the magnificent and impressive spectacle of the phosphorescent sea, up to and including the vertebrates. In the bosom of the ocean numerous photogenic Coelentera undulate gracefully like animated flowers made of the purest crystal—Medusas, the cestus or girdle of Venus, the Physalia with their numerous fishing tackle, while upon the surface there float flotillas of light Velellae with their triangular sails, etc., etc.

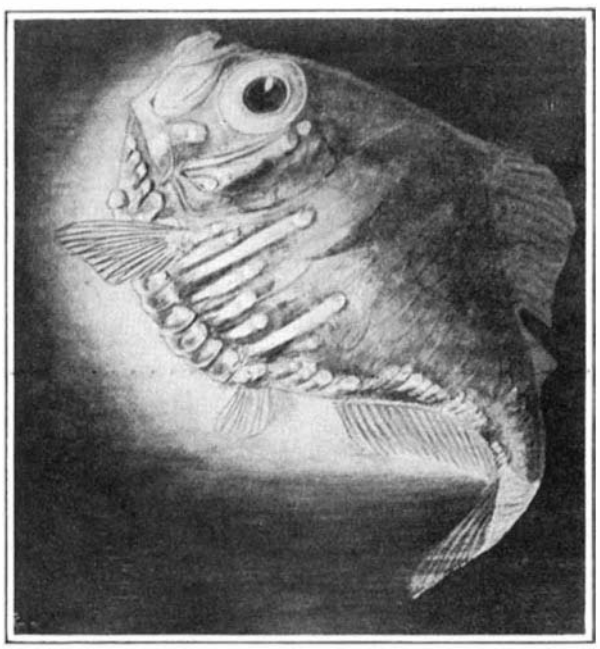
Upon the bottom of the sea and even at the bottom of the abysses there grow the Polypidae, actual luminous shrubs whereupon the polyps resemble gleaming flowers with changing colors which glow with light at the slightest touch.

Then there are the starfish, like the Brisinga which derive their appellation from "Brising," the name of the sparkling jewel which rested upon the bosom of Freia, the goddess of love and beauty in Scandinavian mythology. Quite close at hand in our own gardens we often see at night time the earth worms and the "thousand legs" leaving behind them trails of phosphorescent mucus, and in south Germany I have seen the ground sprinkled with shining sparks like the sand of our beaches, thanks to the presence of the little *Lipuris noctiluca*. But it would require a volume to describe all these curious shining animals, for they are legion.

Among the crustaceans, the Cephalopod mollusks, and the fishes the luminous organs are often situated near the eyes or around them in such a manner as to illuminate clearly the objects which they desire to see. They are then provided with lenses, reflectors, screens, etc., which make of them perfected lanterns called "photospheres."

Although less complicated than these photospheres the lanterns of the insects are very brilliant. That of the female glow worm can be distinguished for a long distance. But nothing can equal in power and in beauty the signal lights of the Pyrophora of the Antilles. This sturdy and magnificent *taupin* possesses three of these—two upon the corselet and one underneath the abdomen. It makes use of the first two when walking, of the third when swimming, and of all three at the same time when flying. These beautiful insects produce a very strikinng effect when they fly along the edge of the woods or sugar cane plantations in the eveninng. One of them which arrived at Paris with some wood from these islands in September, 1766, produced quite a little revolution in the Faubourg St. Antoine, where it was taken for a shooting star! The author of *The History of the French Antilles* (*Histoire des Antilles française*) P. Dutertre, wrote in 1667: "They are like little animated stars which in the darkest nights fill the air with an infinity of beautiful lights which shine and gleam with more brilliance than the stars in the heavens. . . . These little candles often relieve the poverty of our good fathers who lack both oil and candles for the greater part of the year. When they are thus reduced each of them grasps one of these shining flies and reads his matins with as much ease as if he had a candle." Then he adds further: "If these flies were incorruptible like precious stones and could retain their light it is certain that diamonds and rubies would lose their value." It is not astonishing, therefore, that the beautiful Mexican ladies keep these little creatures captive to make of them living adornments.

When the New World was discovered the Indians enclosed them in perforated gourds hung in their cabins, both to light them by night and to drive away snakes and mosquitos. In time of war they made use of these signals which are extinguished neither by rain nor wind to carry on a sort of optical telegraphy, of which art they are thus the real inventors. It was these sturdy coleopetera, of which I received a number of living specimens from Guaduloupe when I was a preparer for Paul Bert at the Sorbonne, which enabled me to make a complete anatomical and physiological study, thus discovering the secret of the intimate mechanism



MODEL OF THE *OPISTHOPROCTUS SOLCATANUS*

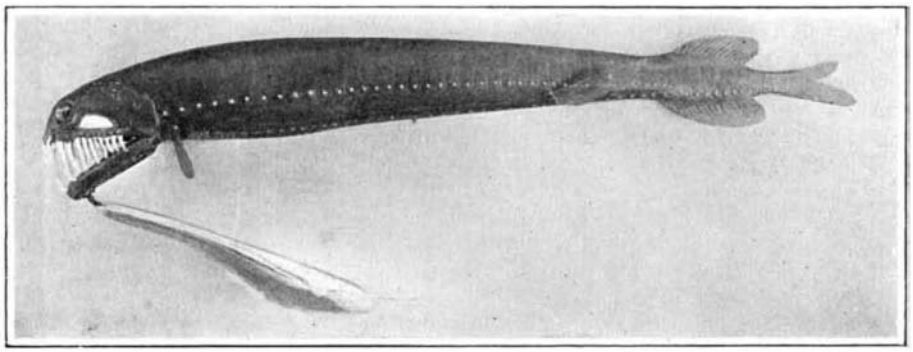
of their curious lanterns and obtaining a definite analysis of the physical properties of their beautiful light. In the very heart of Paris I have seen them lay their luminous eggs from whence issued larvae likewise luminous, so that in the case of these extraordinary insects, as in so many other photogenic animals, phosphorescense is transmitted like the flame of life itself without ever being extinguished for a single instant from generation to generation throughout the ages.

The molluscs likewise afford curious specimens. The *Eunoploteuthis diadema* is a cuttle fish caught at a depth of 1,500 meters. It is provided with 24 lanterns, five of which are situated around each of the two eyes. These give forth a light of the most incomparable beauty. One might imagine the body of the animal adorned with a diadem of precious stones of varied color and of the finest water. The median points

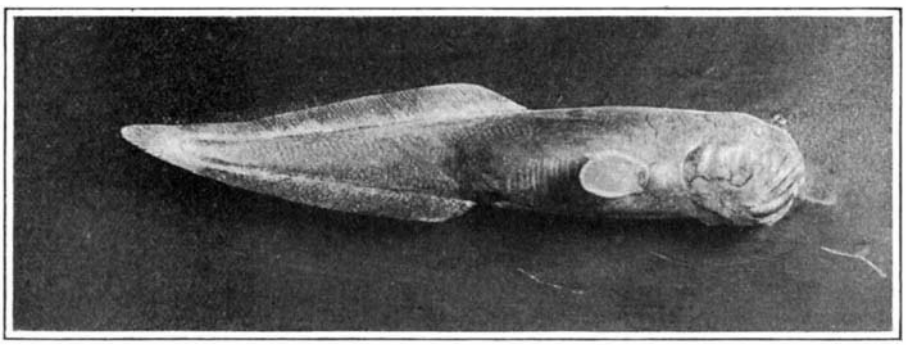
shine with an ultramarine blue, while the lateral ones show the tints of mother of pearl. The abdominal organs send forth rays of ruby red, while the posterior ones are white as snow or pearly in tint, with the exception of the median point which shines with a celestial blue. But it is only among the fishes that we find organs so highly complicated. The *Stomias* present a double row of them on each side of the body, as does the curious *Stylopthtalmus paradoxus* which also possesses lantern eyes borne upon long movable tentacles.

In the Melanocetus of the abysses the signal-light is placed at the end of a movable wattle, and probably serves as a lure to attract within the huge and well-armed jaws of the little monster the organisms upon which it commonly feeds. In other cases, as in the *Photoblepharon palpebratus*—a surface fish of the Dutch East Indies, whose fishermen utilize the luminous apparatus as bait—the signal-lights are situated below the eyes and are movable like the latter, which enables the animal to mask them whenever it so desires.

MODEL OF THE *MELANOSTOMIAS MELANOPS* STUDDED WITH LIGHTS WHICH



LOOK LIKE PORTHOLES OF A SHIP AT NIGHT



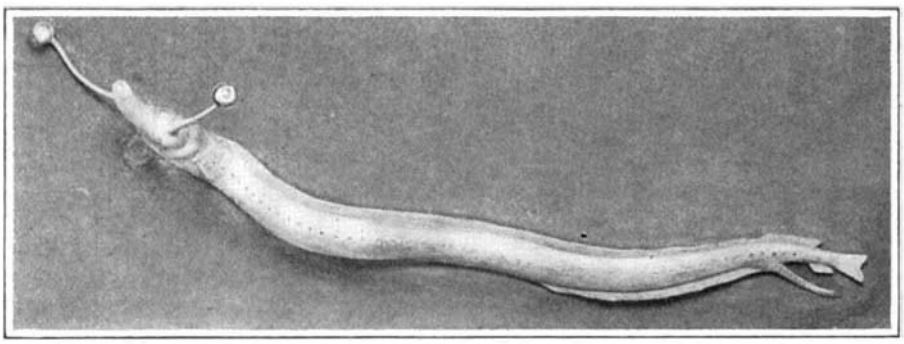
MODEL OF THE LUMINOUS DEEP SEA FISH *BARATHRONUS DIAPHANOUS*

Apparently phosphorescence does not exist among vertebrates higher in the scale than the fishes. The cases in which luminosity is exhibited by cadavers, by wounds, by sweat, by urine, and by excrement are pathological in nature and call for more extended study. In all cases of organisms which are normally luminous the photogenic organs, when they are differentiated, consists of glands, which discharge either outwardly, as in the earthworm and the wood-louse or "thousand legs," or else internally, as in the fishes, the cephalopods, and the insects, their magnificently luminous secretion.

The ventral photogenic organ of the *Pyrophorus noctilucus* is a type of the internal secretion luminous gland. It is in the form of a cushion traversed by a sinus at T. At the instant when it functions the small lateral muscles draw apart by means of traction the walls of the sinus, into which the blood at once rushes, causing the instant appearance of the light. The muscles are activated by nerves coming from certain nerve centers and it is by means of these that the reflex or voluntary contractions which control the illumination and the extinction of the light are operated. The gland is constituted of rows of cells whose disintegration yields the liquid of the luminous secretion, which, upon contact with the oxygenated blood, produces the light, by a process which will be explained further on. The trachea, which are abundant in these organs, play merely an accessory part, for they do not appear in the egg, which is luminous nevertheless, nor in the analogous apparatus of the cephalopods and the fishes. Doubtless the trachea serve here as elsewhere to aerate the blood, an especially important operation in this instance.

If the luminous organ be crushed in a little water so as to entirely destroy all trace of cells a liquid is obtained which remains luminous for a considerable length of time, but which is instantly extinguished by any physical or chemical agent capable of destroying the zymases and the proteic substances. When filtered this luminous liquid is opalescent—like all colloidal solutions—and contains very fine granulations which are termed zymasic *vacuolids*.

As early as 1886 I succeeded in demonstrating the fact that in the last analysis the luminous phenomenon results from the conflict between two substances, a zymase and a proteic substance, which exhibits, after the action of the zymase, the xantic reaction of nitrogenous organic bodies. This had to be made more definite—but Pyrophoras were lacking, and furthermore their provision of luminous substance is much too scanty for extensive chemical research. I turned my attention, therefore, to a lamellibranch Mollusc, the dactylated Pholas, which is abundant in the vicinity of the maritime laboratory of physiology founded by me at Tamaris-sur-Mer, near Toulon. The photogenic glands of this shell-



THE *STYLOPHTHALMUS PARADOXUS* WITH LANTERNS AT THE ENDS OF TENTACLES WHICH MAY BE EXTENDED OR RETRACTED AT WILL

fish secrete an abundance of a luminous mucus which exhibits the same reactions as the secretions of all other luminous organisms, in which the fundamental nature of the photogenic process is always the same. Not without great difficulty and repeated efforts, I was finally able to extract, isolate, and determine the chemical characteristics of two principles which I have termed respectively *luciferase* and *luciferine*. The first is an oxidizing zymase, while the second is a natural

albuminoid. When either of these is shaken separately in contact with air and with water no light appears, but upon mingling the two aqueous solutions a very beautiful glowing light is at once produced. But if the water is saturated with sugar the two solutions can be mingled without producing light, since this condition paralyzes the action of the oxidizing zymase. The syrup can be kept quite a long time without undergoing alteration, but as soon as water is added the luminous glow appears; the glass in which the reaction takes place can be used for a night lamp. . . .

The luciferase can be replaced by various oxidizing chemical substances, a fact which clearly indicates its mode of action; among these are permanganate of potash, broxide of lead, hydrogen peroxide containing a little blood or hermatine or simply a ferric salt, etc., etc.

Synthesis follows upon analysis—the former would be complete if we could manufacture luciferine artificially. However this is not necessary to occasion the appearance of cold light in a liquid medium by means of oxidation. These phenomena of "oxyluminescence" are even quite numerous, but the most beautiful of all is that which I have obtained with esculine, a fluorescent chemical principle extracted from the chestnut tree.

Now that its principle is known, it is possible therefore to imitate "living," or rather physiological light. It must be admitted that the light obtained *in vitro* is not so powerful as that from the lantern of the Pyrophora, in spite of the fact that the chemical process involved is the same. But, as we have seen in the foregoing remarks, these insects, like the cephalopods and the fishes, possess accessories which make for improvement. One of the most curious of these is that discovered by me in 1885; it consists of the presence of a fluorescent substance in the luminous organs of the Pyrophora and of the Luciola: this is a *luciferescein* whose effect is the transformation of the dark rays, which are both useless and injurious, into illuminating rays, which superpose themselves upon the fundamental photogenic reactions, just as sonorous harmonics or overtones superpose themselves upon the fundamental note of a sound. It is in this manner that sounds acquire an agreeable *timbre*, and in the same way fluorescence imparts to the light of the Pyrophora a shimmering effect of the greatest beauty, while at the same time much augmenting its power.

It is thanks to the Pyrophora that it has been possible to make a complete and authoritative analysis of the physical properties of physiological light. Its enormous superiority over that of all other known sources of light, including the sun itself, has become a classic fact, today, and the correctness of the results already published by us has only been confirmed by the latest researches of physicists of the highest ability, such as MM. Very and Langley in America.

It is incontestably established today that this living or physiologic light may properly be called *cold light*, since the radiations emanating from the photogenic organs contain only infinitesimal amounts of heat. If we add that the actinic power of the visible and ultra-violet radiations whose presence I have demonstrated scarcely exceeds one ten-millionth part of a candle power we may claim that the work done by this marvelous lamp is almost 100 per cent, while with the most improved quartz mercury lamp not more than one per cent of light is obtained, according to the extremely exact calculations of MM. Fabry and Buisson, the rest of the energy expended being consumed in the production of heat and chemical energy, which are always inconvenient and sometimes actually injurious. Let us remind the reader also of the extremely low price of my living lamp which will light a room as with fine moonlight for a month for but two cents.

Gas with its necessary pipes and its accompanying dangers of fire and of asphyxiation, and electricity with its wires and its non-transportable apparatus, as well as our lamps and candles, are destined to disappear, since the process by which physiologic light produced is now perfectly understood and classed among the oxy-luminescences, why may we not hope that the day will come when we shall be able to imitate and even to surpass that made by natural means? We are certainly far nearer the practical solution of the problem than were Galvani and Volta at the time of their immortal discoveries.

[*We are indebted to the American Museum of Natural History for the photographs illustrating this article.*—EDITOR.]

The Effects of Light on Plants*

Light As a Catalyzer

By San. Rat Dr. Fritz Schanz

MAN has undoubtedly recognized from the very beginning that light is an essential factor in life. Light acts upon living cells as a chemical stimulus. We recognize this by the reactions which it occasions in living tissues. The chemical alterations which it thus produces have been known to us only very recently. The first insight into the effects light exerts upon the living organism was vouchsafed to us when Finsen proved that the alterations of the skin which occur when the latter is exposed to intensive light waves are produced chiefly by the rays of short wave length which the human eye is incapable of perceiving as light—the rays which we term ultra-violet because they lie beyond the violet end of the spectrum. By means of such rays Finsen produced reaction in the skin through which certain *loci* of disease are destroyed. The fact thus demonstrated that light could be employed as a curative agent, induced physicians to study more extensively the effects of light upon the human organism. Their zeal along this line was increased when it was shown, particularly through the researches of Bernhard[1] and Rollier[2], that internal maladies likewise can be favorably influenced by sunlight in spite of the fact that their loci cannot be reached by direct radiation.

Our knowledge as to the effects of light upon living organisms was still further materially advanced by Van Tappeiner[3] and the students under him. It was observed by them that infusoria contained in certain dyestuffs perish when the latter are extremely dilute, while they frequently remain alive in much higher concentrations of the same substances. The cause of this appeared to depend upon whether light was acting upon the infusoria. This effect was termed *photo-dynamic* by von Tappeiner and was demonstrated in the case of eosin, erythrosin, and a great number of other dyes. A condition of such action appeared to be the fluorescence of such substances. It was also found that toxins, ferments, and similar substances derived from animal and vegetable organisms are destroyed by light under similar conditions; furthermore, the cells of higher organisms (red blood corpuscles, ciliated epithelium) can be seriously injured in this manner. It is possible, likewise, to make warm blooded animals including even men highly photosensitive by such means and thus injure them so greatly in a brief period of time by means of exposure to light that they

*Translated for the Scientific American Monthly from the *Biologisches Zentralblatt* (Berlin).

[1] Heliotherapie im Hochgebirge, Verlag von Emke in Stuttgart 1912.

[2] Korrespondenzblatt Schweizer Aerzte (Journal of Correspondence of Swiss Physicians) 1904, no. 12.

[3] Strahlentherapie Bd. 2 (The Art of Healing by Radiation, Vol. II).