What Makes the Glow-Worm Glow?

What Recent Investigations Reveal in the Matter of the Luminous Organs of Various Insects and Sea Life

By William Crowder

THE nature of phosphorescence in light-producing animals has been a phenomenon which has engaged the attentions of investigators from a time far antedating the history of modern science. It was only recently, however, that the attempt to fathom the mystery was met with any appreciable degree of success.

Contrary to the popular opinion, the peculiar property of emitting phosphorescent light is by no means a rare one or confined to a narrow range of individuals. In the animal kingdom, in groups ranging from the protozoa to the vertebrates, there are more than three hundred genera which contain one or more species that are known to be phosphorescent. By far the great majority are those forms which live in the sea. Of these, perhaps the best known are Noctiluca, a microscopic animal which causes the phosphorescent light in the wake of a vessel; jelly-fishes, which produce flashes of light when colliding with a boat or struck with an oar; marine worms and small crustaceans.

As may be suspected, from their higher development, the fishes which inhabit the deep sea contain types which have the luminous organs specialized in a manner well-nigh perfect in their arrangement. The complexity of these organs may be understood when it is stated that in some individuals they function somewhat after the fashion of an eyeball; that is, they can be rotated to direct the light or turned completely to shut the rays off. In others there is an apparatus similar to an eyelid which acts as a curtain by which the light can be shut off or turned on at will. It is significant that those fishes distinguished by these extraordinary organs spend their entire lives at great depths far below the point penetrated by the light of day.

Of the land forms perhaps the most familiar phases of luminescence are to be found in the fireflies and their larval young, the glow-worms. From the preceding statement it is evident that the "glow-worm" is not a worm; neither is its cousin the "glow-worm" of Europe, so often met with in prose and poetry. The latter is merely the wingless female of a Lampyrid beetle. In fact, all fireflies belong to the *Lampyridæ*, a name derived from a Greek word which means "to shine." It may surprise some to learn that this subfamily has more than fifteen hundred species of fireflies; and two hundred and thirty of these, distributed among forty-two genera, are from the United States alone.

To what purpose many light-producing animals are endowed with this remarkable power is open to much conjecture. Where an apparently valid reason can be ascribed in some instances, the same cannot be maintained in others. Thus, for instance, in fireflies this function was presumed to enable the sexes to identify each other in the darkness of the night, at which time their activities are greatest. If this be true, why, in the case of those species where the female is wingless, does the male emit light? Her inability to approach him surely would seem to indicate that the flashing of his lantern avails him nothing.

Another instance of the purposelessness of this power is to be found in those abyssal types of crustaceans which are totally blind. In this connection, however, it may be mentioned that these sightless creatures are devoid of complex photogenic organs; their phosphorescence being due to a luminous secretion.

Again, certain deep-sea prawns were recently found whose luminous organs lighted only the gill cavities of the animal. What function they perform for the benefit of the owners, located as they are, impossible of shedding any external light, defies speculation.

Perhaps the most intensely luminous animal for its size is the small marine ostracod crustacean, *Cypridena hilgendorfi*. So powerful is the light from this creature that one part of the luminous gland in one billion six hundred million parts of water will give a visible glow to that medium. If a man possessed an organ which gave the same proportionate volume and intensity of light as in *Cypridena*, he could illuminate the area of a fair-sized city.

It has long been known that many fats, ethereal oils and alcohols emit light when these substances are slowly combined with oxygen at certain temperatures. With this hint it was inevitable that phosphorescence in organic materials could be produced artificially and in a way that would bear a close analogy to the principle involved in the organs of light-producing animals. Therefore the "pyro experiment" became a classic achievement in this direction.

Pyrogallol, an organic compound of vegetable nature, is commonly known through its use as a developing reagent in photography. If pyro or gallic acid and hydrogen peroxide be mixed with the juice of any ordinary vegetable such as a potato, turnip, etc., a decidedly phosphorescent light occurs. Now as pyro is noteworthy for its property of combining with oxygen, it is at once apparent that what takes place here is a process of oxidization. It is remarkable, nevertheless, that although many compounds can be oxidized by a peroxide mixture, so far as known only pyro and gallic acid will oxidize with the production of light.

The next step in these most interesting experiments was taken with the photogenic organs of the animals themselves. Of all the light-producing animals, perhaps none has lent itself more to inquiry than one of our commonest fireflies, *Photuris pennsylvanica*.

Dissection of this insect shows that the photogenic organ consists of thin layers of light colored transparent tissue which overlie a deeper and opaque region. The function of the former seems to be for the transmission of the light, and the latter is both a reflector and the fuel generator. For intimately connected with this area is a network of air tubes, nerve terminals and the glands which secrete the globules of luminous compounds. These compounds have been separated in the laboratory and have been found to consist princi-

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Correspondence

The editors are not responsible for statements made in the correspondence column. Anonymous communications cannot be considered, but the names of correspondents will be withheld when so desired.

White Yolks of Eggs

To the Editor of the SCIENTIFIC AMERICAN:

I hope you will pardon some further correspondence from me concerning pigments, but a note entitled "White Yolks of Eggs" in the May 14th issue of the SCIENTIFIC AMERICAN has attracted my attention. It struck me as most peculiar that it was necessary for the SCIENTIFIC AMERICAN to quote the German *Umschau* in regard to work by *American* investigators. The work which was cited was published by me in a series of three papers in the *Journal of Biological Chemistry*, Vol. 39, pp. 299-377, 1919, and also in the *Proceedings of the National Academy of Sciences*, Vol. 5, pp. 582-587, 1919. The experimental work was performed at the University of Missouri with which I was formerly connected.

I have noticed that scientific data sometimes gather inaccuracies in restatement a good deal like the proverbial stone. Permit me to point out several such errors in the article entitled "White Yolks of Eggs" which was evidently a translation from the German.

The first error is inconsequential, but pertains to the reference to myself and Professor Kempster as poultry breeders. This may apply to Professor Kempster, who is Professor of Poultry Husbandry at the University of Missouri. I have no objection to the title for myself, but I fear that the men actually in the profession would resent my being so considered. Another trivial error is the reference to the ear lobes of fowls as *earlaps*. I am sure the poultry folks would not agree to this terminology. A third error is more serious for it involves a scientific fact. The natural yellow pigment of egg yolk is *not* carotin, but xanthophyll, the carotinoid which is closely related to carotin and almost always associated with it in plants. It so happens, however, that carrots contain very little xanthophyll, so little, indeed, that when carrots are fed to laying hens, there is practically no effect on the color of the egg yolk (see paper by me in *Journal of Biological Chemistry*, Vol. 23, p. 261, 1915). On the other hand, yellow corn is very rich in xanthophyll with very little carotin so that the feeding of yellow corn greatly enhances the color of egg yolks. Both carotinoids are present apparently in green feeds so that the latter readily increases the color of egg yolk when fed to laying fowls.

A curious physiological fact in connection with these relations is that the natural yellow coloring matter of milk and butter *is* carotin and this carotin bears similar relations to the feed of the cow that the xanthophyll of egg yolk does to the feed of the hen. In this case, however, carrots greatly increase the color of butter, but yellow corn has no effect (see papers by me in *Journal of Biological Chemistry*, Vol. 17, pp. 191-249, 1914).

Finally, the whole story of white yolk eggs is not quite true after all. As far as being free from natural yellow pigment derived from the feed is concerned they were white. The yolks of cooked eggs were perfectly colorless, but the raw yolks contained a very slight amount of yellow coloring matter which could be extracted with suitable solvents, so in reality from a strictly scientific point of view the yolks were not *absolutely* colorless. This "trick" is, I fear, hardly attainable, for the hen apparently makes a little, although very little to be sure, of her own egg yolk coloring.

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The Lunar Zodiacal Light

To the Editor of the SCIENTIFIC AMERICAN:

My attention has been called to an item, "Lunar Zodiacal Light," in your issue of June 11, summarizing part of my report to the director of the aurora and zodiacal light section of the British Astronomical Association. The following comment by Mr. Gavin Burns, director of that section of the B. A. A., is quoted: "As the light of the full moon is only about one-millionth the intensity of sunlight it is difficult to believe that the phenomenon described can be due to the light of the moon."

Chaplain Jones, U.S.N., was a specialist in zodiacal light observations. His report of observations made during the U. S.-Japan Expedition (1853-1855) forms Vol. III of the Expedition Report published in 1856, and contains 328 observations charted and described. The range of latitude extended from 42° N. to 53° S. Nearly 50 per cent of the observations were made within the tropics. He is very particular in describing what he calls the moon zodiacal light which he witnessed in the tropics. He also witnessed what he termed a joint sun and moon zodiacal light. In his report of one of these observations he says: "The moon quartered today (March 6, 1854; lat. 25° 26′ N., long. 139° 42′ E.). At half past 7 I was astonished to see the zodiacal light fully displayed. It was no doubt a joint sun and moon zodiacal light. . . . My mind was perfectly satisfied that it was clearly a zodiacal light. It differed from the ordinary zodiacal light in not being brightest at its lowest end but was all the way down of a fairly uniform brightness. It was quite distinct. The upper end was lost in the moon's superior light. The night was very clear." Naval officers corroborated this and similar observations. As to my observation in southern Maryland on the evening of February 21, 1916, of which I retain a vivid recollection. The moon was three days past opposition in right ascension 12 h. 9 m. and declination 5° 42′ S. The fact of the light was unmistakable. The sky was cloudless and the seeing remarkably good. The moon was the only source of light sufficient to produce the effect. Hence it seems quite appropriate to describe it as a lunar zodiacal light.

Baltimore, Md. W. E. GLANVILLE.

Substitutes for Wood in Papermaking

To the Editor of the SCIENTIFIC AMERICAN:

In connection with my paper article in your issue of June 11th, may I point out that in considering substitutes for rags, wood and straw, it is important to bear in mind that, while many plants, grasses, reeds, etc., are capable of being utilized in the manufacture of a satisfactory paper pulp, freight charges from point of production to mill must be less than the freight charges on pulpwood; a sufficient yearly growth must be assured to operate a mill continuously; and the cost of chemicals used in production must not, for example, exceed that involved in the pulping of straw; while a *sine qua non* is that the yield of cellulose fibers must amount to more than one-quarter of the total bulk of material treated. This at once rules out many of the hasty and ill-considered suggestions and propositions that have been put forward.

New York. THOMAS J. KEENAN.

Pulling the Mississippi's Teeth

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The wood work of the boat was also well preserved. The water does not seriously injure the metal or wooden parts of a sunk ship; it is the mud which effects the bulk of the damage. Wrecks which are not imbedded in the mud and sand survive decomposition for many years. During the periods when snag work on the river is not pressing, the snag boats occasionally assist private companies in the raising of river boats which have been sunk at sections of the river adjacent to the open channel. Such assistance is furnished at actual cost.

Despite the great increase in labor costs, Congress appropriates the same amount for snag removal from the Mississippi today as 30 years ago. The consequences are that the two snag boats which are supposed to patrol the river from St. Louis to New Orleans are not able to work a full season—the snagging season usually lasts from July until March. Lack of funds is halting this essential work just at a time when the Mississippi River is being used more than ever before. It is now highly necessary to keep the channel clear and navigable and to do everything possible to promote the increased utilization of this wonderful inland waterway. It would seem that Congress might allot a few thousand dollars more a year to this meritorious cause.

Just to show that the money used in the past has been effectively expended, it may be cited that during a normal season, the two Government snag boats on the lower Mississippi will pull and destroy between 300 and 400 snags, the average weight of these obstacles being between 30 and 40 tons. In addition, they will break up anywhere from 10 to 20 drift heaps which—if neglected—are inimical to navigation. The crews of the two boats in addition will cut between 200 and 10,000 trees which fringe the banks and are liable to be undermined and washed away by the river and ultimately converted into dangerous snags. The conquest against snags in the open channel is well in hand, at this time, and with sufficient funds to continue the work it will be possible to keep the number of acidents due to snags down to a minimum. However, to neglect the work at this stage of the game due to lack of funds is a costly, senseless and unnecessary error. The American public desires that Congress reduce expenses along sane and sensible lines. It does not wish our legislators to rob Peter to pay Paul in the style evidenced by the 1921 lack of adequate appropriation for the complete and efficient removal of snags from the Mississippi.

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pally of two substances which are termed "luciferine" and "luciferase."

It was formerly believed that since phosphorescence took place on the oxidization of oils in alcoholic solutions of an alkali, that the material which was oxidized in photogenic organs were fat droplets; but since the separation of luciferin and luciferase, neither of which can be reduced by such fat solvents as ether, benzol, etc., it is, of course, now known that such is not the case. Of the two substances liciferin is the more stable. It will withstand long continued boiling, and will remain unimpaired in its light-producing quality for months. Furthermore, after it is oxidized it is converted into "oxyluciferin," and this latter product can in turn be reconverted into luciferin. Luciferin, however, will oxidize with light production only in the presence of luciferase. Luciferase, on the other hand, is very unstable and deteriorates rapidly.

It will, of course, be obvious that the presence of oxygen is necessary in order that luminescence in the photogenic organ can take place. Therefore, we may with great probability determine by inference just what takes place during the flash of the firefly's lantern. As the insect has stored in the glands of its organ a supply of both luciferin and luciferase in a combined form, there is always maintained a more or less steady glow due to the oxidization of the luciferin in contact with the ordinary oxygen absorbed from the air and the oxygen normally contained in the tissues. When the moment of the flash occurs there is an accelerated production of luciferase, during the combustion of which it is rapidly used up, and by a respiratory process the air tubes flood the photogenic cells with a copious supply of oxygen, no doubt operated under pressure.

Exhaustive tests with the bolometer and the spectroscope have shown that the light of Photuris, unlike our artificial illuminants, contain no heat rays and no light rays extending into the infra-red or the ultra-violet. That is to say, it is what is termed a "cold light" and that the only light rays which are emitted are those which are visible to the eye. In this respect, as an illuminating device the light of the firefly is tremendously greater in efficiency than any artificial light yet constructed. How great this efficiency is will be seen when the comparative values of some of our modern illuminants are given. In a photometric curve worked out some years ago it was found that the efficiency of the carbon glow lamp was 0.43 per cent; the tungsten lamp, 1.3 per cent; whereas the firefly had an efficiency of 99.5 per cent. It is evident then that our most efficient artificial light is not more than 4 per cent as efficient as that of the firefly.

A natural question here arises as to whether the light of phosphorescent animals can ever be artificially produced in a way to make it available for domestic and industrial use. To dismiss with contempt the possibility of synthesizing animal light would ill become anyone who has seriously reviewed the achievements of the past century. And confidently to anticipate that at no long distant date this will be accomplished, would be neither vain in the man of science nor presumptuous in the layman.

Reporting the Life Story of Rails

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and the latter can be swung in under the head of a rail to grip it and to hold the machine firmly in place while making a record. The present instrument uses cards while the older machine traced the lines on tin plates which were subsequently inked and prints made therefrom. Besides being heavy and otherwise objectionable, the tin plates were expensive. Finally, the Duel mechanism, with its adjustable features, can be set to allow for wear. This insures the making of reliable records at all times and greatly prolongs the serviceable life of the device.

In the reading of wheels, whether car or locomotive, there is an auxiliary attachment called a punching frame, a triangular affair carrying three steel points. This is first fitted over the tread and flange, and a hammer blow on each punch leaves an enduring mark on the rim of the wheel. Next, an aluminum yoke or tire base is centered upon these three indentations, and then the rail-section machine is secured to this base. With this done, it is an easy matter to reproduce the outline of the wheel's tread and flange. The cards employed for this work are larger than those used in recording rail sections, and they can be repeatedly inserted in the apparatus with precision so that subsequent tracings can be made thereon to illustrate the various wearing stages of the wheel. Whenever this is done the instrument is set at the same spot on the wheel, as indicated by the permanent marks made by the punching frame.

On one face of every wheel there is a