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ON THE PRODUCTION OF LIGHT BY LIVING BEINGS.

BY DR. MAX COQUE.

November 14th, 1912.

I FELT deeply honoured when I was asked to address you this evening, and it was with very sincere pleasure that I devoted some of my scanty spare time to the preparation of this lecture. Lecture, I say, but really "notes" would be a better way of putting it, for when I came to look at this subject, upon which, you must understand, I lay no claim to being an authority, I found I could only outline the main facts and suggest a few ideas which, I trust, will rouse some of my hearers to pursue the study of this interesting subject still further. Although I quite agree with Prof. Silvanus Thompson when he says that "all who are really interested in any scientific subject, are interested not only in the subject itself, as it stands at the present day and in its future advances, but they are also interested in knowing how that science has come to be what it is, for no sciences have come into being full-fledged," yet I have had to cut out the history of the various theories of optics as opening up matter of too vast a nature to be adequately dealt with in a short address.

Before going into the subject of production of light by living beings, I think a few words on the nature of light, on the chief methods of manufacturing light, may prove useful.

Everybody is acquainted with Newton's great discovery that white light really consists of a mixture of lights of different colours—red,

orange, yellow, green, blue and violet. All ordinary sources of light, natural or artificial, send out these mixtures of colours. To sort them out we have only to look at the light through a glass prism, or to let a beam of light pass through such a prism. The prisms refract the lights of different colours through different angles, according to their wave-lengths, and give us the rainbow coloured patch we call the spectrum.

As it is well known, light consists of innumerable waves of extraordinary minuteness. Light of each colour possesses its own particular wave-length, or, more exactly, light of each particular wave-length has its own particular colour, the colour being to light what pitch is to sound. These wave-lengths are so small that they must be measured in millionths of an inch. Thus, light having a wave-length of 27 to 30 millionths of an inch produces a red sensation in the eye, and we call it red. Waves of about 15 to 16 millionths of an inch give the sensation of violet. Those of 20 millionths of an inch, the sensation of green.

Since all incandescent bodies give out waves of all sorts and sizes, they shine with all the different colours at once and give out white light.

But all our sources of illumination are not equally white in the light they give. This is so, because a true white is not produced unless a proper proportion is preserved between the component colours. If in the mixture there is too much red, the resulting light will be a red-dish white. If too much green, the light will be greenish, and so forth.

For a complete study, then, of the light of any source, we ought not only to measure its candle power but also to analyse the light to find out its composition. This is done in the same way as Newton analysed solar light, that is, the spectrum of the flame is observed.

When we look at a spectrum, we must under-

stand that really the spectrum extends much farther than the visible limits. To the visible rays of longest wave-length is due the red colour of the extreme left.* Waves of somewhat shorter length produce the adjoining strip of orange, and the succeeding colours, yellow, green, blue, correspond respectively to waves of shorter and shorter lengths. Lastly, there comes a patch of violet due to those of the visible rays whose wave-length is the shortest of all. The wave-length of the light of the extreme red is about $1/34,000$ inch, and as we pass along the spectrum the wave-length diminishes gradually until at the extreme outer edge of the violet it is about $1/64,000$ inch, and not much more than half that of the other end.

The two ends of the spectrum gradually fade away into darkness, and the point upon which I wish to insist is this: The position of the boundaries terminating the visible spectrum does not depend upon anything whatever in the nature of light regarded as a physical phenomenon.

Ether waves which are much longer and much shorter than those which illuminate the spectrum, certainly exist, and evidence of their existence is easily obtainable. But we cannot see them; they fall upon our eye without exciting the faintest sensation of light. We are blind to the waves that are either shorter than the violet ones or longer than the red ones. The proofs that there are these invisible radiations are very simple. A thermometer placed beyond the red end will show that there are dark radiations, heat waves, in this region, and a bit of photographic paper placed in the region beyond the violet will be darkened, showing that at that end there are some invisible chemical rays.

The visible spectrum is limited solely by the physiological constitution of our organs of vision,

* A coloured spectrum was projected on the screen.

and the fact that it begins and ends where it does, from a physical point of view, is a mere accident. The spectrum actually projected upon the screen is, in truth, much longer than that portion of it which any one can see; it extends for a considerable distance beyond the violet at one end and beyond the red at the other, these invisible portions being known as the ultra-violet and infra-red regions. Peoples' eyes differ in regard to range of sensibility, just as their ears do. I believe the sensibility of my own eyes to be normal, but if I were to indicate the two points where the spectrum appears to me to begin and to end, a great many persons would certainly be inclined to disagree with me and place the boundaries somewhere else. Some indeed could see nothing whatever in what appears to most of us to be a brilliant portion of the red.

Again, it is by no means probable that in all animals and insects the limits of vision are the same as they are in man. To quote Shalford Bidwell: "We might naturally expect that larger, and perhaps more coarsely, constructed eyes than our own would correspond to waves of greater average length, while the visual organs of small insects might, on the other hand, be more sensitive to shorter waves. The point is not one that can be easily settled, because we are unable to cross-examine an animal as to what it sees under different conditions. But Sir John Lubbock, taking advantage of the dislike which ants when in their nest have for light, has proved by a series of very exhaustive and conclusive experiments that these insects are most sensitive to rays which our own eyes cannot perceive at all. That region of the spectrum which appears brightest to the eye of an ant is what we should call a perfectly dark one, lying outside the violet, where the incident waves have a length of less than $1/64,000$ inch." We shall see presently, however, that all authorities do not agree on this point.

Let us briefly examine now the different ways of manufacturing light.

One of the most important directions in which man has subdued the forces of nature is certainly the artificial production of light, which enables him to extend the day far into the night. Not perhaps an unmixed blessing though, since one of the conditions nature has imposed upon man in order that he shall retain his health is that he must rest or sleep during a certain number of hours each day. If he fails to take this rest he will, sooner or later, pay dearly for his disregard of the laws of nature. It would be impossible nowadays to come back to the curfew bell of the good old times, on the ringing of which all lights were to be extinguished and all well-behaved citizens had to be in bed. The world has gone too far for that. The curfew is a thing of the past. Night work is now essential. It is during the small hours of the night, while most people are asleep, that the food products are brought into big towns, that the great newspapers are printed, so that they can be placed next morning on the breakfast table. In fact, should artificial light be no longer employed, the world would be sent back in its civilisation to an extent that would seem almost incredible.

Man's first invention for turning night into day was crude indeed, a mere burning stick snatched from the fire. It was a poor means of illumination, yet it permitted him to go some distance from his dwelling, and, to a certain extent, to prolong the time during which he could attend to his work. The next improvement was the discovery of the fact that animal fat and oils would burn, and that putting a bit of dry wood into a shell filled with oil, constituted a simple lamp. Such primitive lamps, made of rudely hollowed stones, of burnt clay, or of bronze, are found amongst the relics of Egyptian tombs and in the excavations of Pompeii, and may be seen in museums.

Fish oils and animal oils only were used. Although the apothecary of the middle ages knew vegetable oils pressed out from seeds, these oils were not used for illuminating purposes till the 18th century, and for a considerable period the only improvement on the primitive lamp just described was the discovery of the rush light and the candle. It had been found long ago that a piece of wood or a rope of grass dipped into melted fat makes a good torch, and the first candle consisted of a dried rush dipped into molten tallow. To replace the dried rush by a woven wick and to devise means of casting tallow, and later wax, round the wick in a mould, were improvements introduced about the end of the 18th century. Early in the nineteenth century, the invention of coal gas came as a stupendous progress in the problem of illumination; it was in 1810 that the Gas Light and Coke Co. was incorporated to light the streets of London. Very nearly at the same time, Humphry Davy showed the first electric arc lamp in the theatre of the Royal Institution. His source of energy was a battery of 150 pairs of plate. Thirty years later, the invention of the principle of the dynamo by Faraday gave a simple and efficient way of generating the electric current mechanically and rendered practical the use of the electric glow lamp.

In the case of most artificial lights, the evolution of light is the result of *incandescence*. The common process involved is that something is made very hot and shines because it is very hot. In fact, incandescence is the shining of hot bodies because they are hot. It is a well-known fact that if we take any solid thing, say a piece of iron, or a brick, and heat it enough, it will become red hot, that is, it will emit red light. If brought to a higher temperature, it shines more brightly and gives out not only more light, but light of a whiter kind. If it is less heated, it still emits radiations, but radiations of a kind we cannot see, though they can

be felt as heat, by holding one's hand near the object. So in all cases of incandescence the incandescent substance sends out a lot of heat, as well as some light.

As we will see presently, one of the scientific problems of the day is to find a source of light which shall give light without heat. All our sources of light are deplorably wasteful. They burn up a lot of gas or oil, or use up an electric current and waste the greater part of it in emitting heat rays we don't want and utilise very little of it in generating the light rays we do want.

We have seen that all solid bodies when heated hot enough become incandescent. The brightness of the ordinary flames, like that of coal gas, paraffin lamp, candles, etc., is due to there being solid particles in them. If we burn these substances so that no solid particles are present in the flame, we get very little light indeed, but the flame becomes very hot. This can be shown by the atmospheric gas burner—a Bunsen burner. It gives a flame very little luminous, but very hot. Stopping the hole by which air is admitted renders the flame at once brighter, larger, but less hot. A similar effect is observed when the solid particles in a candle flame are burnt by means of a blowpipe.

Everybody has observed that the flame of an ordinary candle or gas jet is not of uniform brightness, there is always a bluish or nearly non-luminous part at the bottom below the bright part, and this blue really extends round the flame. It is here that the coal gas burns with plenty of air, as in the Bunsen burner, and the heat it gives out decomposes the gas within the flame and causes the separation of a sheet of carbon, which glows partly because it is in a very hot region, partly because it burns away like so many bits of charcoal.

Here is a gas flame given by an ordinary batwing burner. Dr. Smithells, of Leeds, the principal authority on flames, has shown that such

a flame consists really of two flat burning surfaces, with two sheets of glowing particles and a cooler layer of unburned gas between. The temperature varies from point to point, and has been mapped out. In some parts, it is sufficient to melt a fine platinum wire, and in that neighbourhood the glow of the carbon particles is, of course, very bright. The temperatures marked at the side are on an arbitrary scale, lower than their true centigrade. The brightness at the upper part is due to the particles of carbon formed in the lower part.

Every flame—that of a candle for instance, is in fact a gas flame, the lower part of the flame and the wick acting as a miniature gas factory, whereas tallow or wax is distilled in place of coal, and when it was recognised that the brightness of a flame was due to radiation from solid matter, it was an obvious suggestion to try to get more light from gas by burning it with the hottest sort of flame, the non-luminous one, and then inserting in the flame a network of fine wire. Forty years ago, the town of Nantes was lit with such burners, consisting of a Bunsen burner, in which a mantle of wire gauze was hanging, but they were not successful, being too perishable.

However, the idea of incandescence was found and the problem was solved in a practical way when Dr. Auer von Welsbach introduced in 1883 the well-known Welsbach mantle, consisting of a light fabric of ramie fibres woven or knitted with an open mesh, soaked in a chemical solution of the rare earths, erbia, yttria, zirconia, thoria, etc. These substances are all white and resemble lime.

I cannot do more than mention incandescence by electricity, and I come to another totally different way of manufacturing light.

So far we have dealt with the production of light by incandescence, light being the consequence of heating, but there are examples in nature of light produced without heat.

It has been known from early times that a substance called Bologna stone possesses the curious property, after exposure to light, of continuing for many hours to emit in the dark a pale light. Bologna stone, or Bologna phosphorus, was prepared by the partial calcination of a certain mineral called heavy spar or sulphate of barium, and afterwards reducing it to a fine powder. The sulphide of calcium, or Canton's phosphorus, possesses the same property to a very high degree. In more recent times, the latter material has been used in the manufacture of what are called luminous paints. Everybody is familiar with such paints coating the surfaces of match boxes. During their exposure to the light in daytime, these paints are so affected that they continue to shine during the greater part of the night, although there is no other light in the room. Another practical application of luminous paints is its use over the surface of a clock dial. It must be observed, though, that in all these cases, the light produced in this way by phosphorescence is exceedingly feeble.

There are many substances which, like Bologna stone and luminous paints, possess, to a greater or less degree, the power of continuing to shine after exposure to light. Some of these, as in the case of the luminous paint, continue to show light for many hours after daylight ceases to fall on them, others continue to shine but for a few moments.

The following substances possess phosphorescence in varying degrees: sulphides of barium and calcium; diamond, a variety of fluorspar known as chlorophane, dry paper, sugar, salts of alkalies and alkaline earths, compounds of uranium, etc.

Phosphorescence can be produced by exposure to all portions of the spectrum; not only to the ultra-violet rays, but also to all the colours between red and violet, and even to the invisible rays in the infra-red and ultra-violet.

Whilst the above phosphorescent substances give light after they have been exposed to the light of the sun or placed in some parts of the spectrum, some other substances are made to emit a beautiful bluish light when the invisible ultra-violet rays of the spectrum are focused upon them. A solution of bisulphate of quinine shows this effect in the most marked manner. Such substances have the power of slowing down the ultra-violet radiations so as to permit them to become visible. When the bark of the common horse-chestnut tree is boiled in water, the clear solution is invisible in ordinary light, but gives out a bluish light when brought into the ultra-violet rays of the spectrum. The simplest way to obtain this light is to receive the spectrum on a sheet of paper soaked in the solution of horse-chestnut bark; the length of the spectrum is then greatly increased, for instead of being visible only between red and violet, it now extends far beyond the violet.

The light of the electric arc lamp produces a quantity of ultra-violet rays greater than that of the solar light. On the other hand, quartz is almost completely transparent to ultra-violet rays and differs in this respect from glass, which is opaque to a large percentage of such rays. If a beam of light proceeding from an electric arc lamp is caused to pass through a quartz prism, the length of the ultra-violet spectrum will be from six to eight times longer than the distance between the red and the violet ends.

If such a spectrum is received on a sheet of paper moistened with the water in which the bark of the chestnut tree has been boiled, the length of the visible spectrum will be considerably increased. A space beyond the violet, of from six to eight times the distance between the red and the violet rays, will now shine with fluorescent light.

Everybody is familiar with the greenish coloured glass, known as uranium glass, the colour of which is due to the presence of a small

quantity of a salt of the metal uranium. This glass has the power of fluorescence to a high degree, and if a beam of ultra-violet rays is thrown within its mass, the path of the rays is made visible as a bright green light, for the rays, as they pass through the glass, become luminous by fluorescence.

Some of the many other substances that also possess the power of fluorescence, are the green colouring matter of leaves, obtained by soaking bruised leaves in alcohol, ordinary petroleum, a solution of turmeric alcohol, etc. Let us mention the fact that the word fluorescence has been given to this peculiar property of light because its effects were first showed in fluorspar.

If a fluorescent substance is exposed in a darkened room to light from different sources, a difference will be observed in the intensity of the fluorescent light produced. While ordinary sunlight possesses this power in a fairly marked degree, it is surpassed either by the light of the electric arc lamp, or by the light emitted by a burning magnesium ribbon. The reason is obvious; it is the ultra-violet rays that produce fluorescence, and the light emitted by the burning magnesium wire, or the electric arc, contains a greater proportion of the ultra-violet rays than does sunlight. A curious experiment can be performed to illustrate fluorescence. If we soak stramonium leaves in water, we get an almost colourless solution, and writing on a sheet of white paper by means of a pen dipped in this solution will be practically invisible, but if the light from burning sulphur or brimstone is allowed to fall upon it, it instantly becomes visible by fluorescence.

Some substances possess the power of fluorescence to a high degree. Two of the most remarkable fluorescent substances are the platino-cyanide of barium and the tungstate of calcium. Such substances are employed for covering the screen in the apparatus known as fluoroscope.

Fluorescence and phosphorescence differ in a very marked degree. While fluorescence is only excited by ultra-violet rays, phosphorescence can be produced by exposure to all portions of the spectrum, not only to the ultra-violet rays, but also to all the colours between the violet and the red, and even to the rays of the infra-red portion. When the ultra-violet rays produce phosphorescence or fluorescence, their two rapid motions have to be slowed down until it can affect the eye as light, while in the case of the invisible rays beyond the red, the too slow vibrations or ether waves have to be increased or accelerated, until they have become sufficiently rapid to affect the eye. A very pretty experiment can illustrate the latter point. Let us heat a dull iron plate in a dark room by allowing the flame of a Bunsen burner to fall directly on its lower surface, being careful not to render the plate incandescent. Now, looking at the upper surface by placing our eye in such a position that the flame of the Bunsen burner is not visible, let us throw a few fragments of the variety of fluorspar known as chlorophane, on the upper surface of the plate. Immediately a brilliant emerald green phosphorescent light will be emitted by the fragments. This light has been produced by increase in the rapidity of the heat waves from the iron plate to such an extent as to enable them to affect the eye.

The term luminescence has been coined to denote the production of light by other means than incandescence. The kind of light thus produced by phosphorescence or by fluorescence is called cold light, and the category of such light has been vastly increased in recent years by the discoveries of Sir William Crookes and others, of the possibility of making substances shine in the dark by exposing them to the special kinds of radiation known as Kathoda rays. We cannot enter into this subject. Let us simply state for the present that the phosphorescence of the

sea on a summer night is due to living animals that possess to a marked degree the power of producing phosphorescent light. The exquisite pale blue light produced by the glow-worm, the firefly and some other living beings, is of the same kind and will be investigated a little later.

Before coming to the subject of production of physiologic light, I think a brief review of the influence of light on living beings may be interesting.

The influence of light, that is, of that part of the spectrum to which our retina is sensitive, on living beings, has been the object of numerous researches, but it is not always easy to distinguish in every case the effects produced by the calorific or the chemical radiations from that produced by the light itself.

The influence of light on living organisms is manifested by modifications in the nutrition; by production of electric phenomena; by production of movement; by production of sensations and perceptions.

Our time is too short for me to do more than state the fact that light has a well-known effect on the micro-organisms producing fermentations. The sun destroys the activity of the yeast. The rennet, or ferment, which, when added to warm milk, causes the separation of curd consisting of casein and fat, has to be kept in the dark. Generally the beneficent effect of the solar rays as a means of disinfection is in itself a proof of the powerful effect of light in the destruction of some bacteria.

Light also produces a destructive action on many pigments, especially on the visual purple. This pigment is formed again in the dark and disappears in the light, and this effect enables us to obtain these retinal photographs or optograms, which may be fixed by means of a solution of alum. The discoloration of the visual purple is practically nil in red light; it increases in the green and reaches its maximum

in the blue. To obtain these optographs the exposure must be relatively long, and the discoloration of the visual purple is regarded as but a secondary phenomenon, the purpose of which is probably the absorption of the excess of light entering the eye.

Light has not always a destructive effect on pigments; it often, on the contrary, determines the production of pigments. This is well proved by the effect of the solar light on parts of the skin which are unprotected by our clothes.

If we expose to light one of those curious blind creatures found in the deep caves of Adelsburg, near Trieste, or in the caves of Carniole and Dalmatia, the proteus, the body of which is white in colour, faintly touched with red, it develops a coloration which ultimately becomes almost black. This action may be localised to certain points of the surface of the body which are illuminated, the other parts being protected from light. The coloration is due to the formation of a pigment which becomes deposited in the most vascular parts of the skin, especially around capillary vessels. This pigment appears to be due to an extravasation of the blood. A red light does not cause the production of pigment, and more pigment is produced in green light than in blue light, although blue light is that which the animal tries to escape from, and which, we may infer, is most disagreeable to it. The pigmentation disappears rapidly in the dark. The fact is general; we know that in miners the skin, and even the hair, become discoloured in time, apart from the discoloration observed in cases of anæmia due to a parasite.

It is well known that animals living in tropical regions present the richest and most varied colours, whereas, in polar regions, white is the dominating shade. This predominance of white in arctic regions is probably not a phenomenon of mimicry, but is the result of the insufficiency of the solar radiation.

This point seems established by the fact that the dorsal portion of polar animals is more pigmented than the under portion. Moreover, the molluscs and crustaceans living in the sea at a depth varying from 100 to 200 fathoms are white. It is true that at a much greater depth, of 1,000 and more fathoms, crustaceans and zoophytes of the brightest colours are found, but we will see presently that these abysmal regions are illuminated by the animals themselves.

The proteus likes darkness best, but he does not fear red light, and, on the other hand, it has the greatest objection to blue light, probably because of the chemical rays which accompany blue radiations.

Everybody knows the peculiar effect produced by solar light, and also by the electric arc lamp, on the portions of our body exposed to their radiations. This effect, termed sunstroke, really consists in an inflammatory process which may go as far as to produce a blister similar to those observed in a burn. This erythema solare, to give it its proper name, is frequently observed in mountaineers, although it has been found impossible to explain why the light reflected from the snow and ice of the high mountains should have a more energetic effect than that of the direct light. Coating the face with a fluorescent substance, like quinine sulphate, or covering it with a red veil, will prevent the ill effect of such a sunstroke. A layer of Indian ink acts in the same way, and this proves clearly that the effect of the sun is not due to the heat radiations, and at the same time explains the usefulness of the black pigment in the skins of negroes.

The effect on the skin of the Rontgen rays and of the emanation radiated by radium is somewhat similar to those of the chemical rays of the spectrum, although they may be much more powerful.

The influence of light in the development of the eye is shown in a striking way by a marine

crustacean, *ethusa granulata*. At the surface the animal has well-made eyes, at the end of a movable peduncle. Between 110 and 370 fathoms, the eyes are still existing, but they consist of a round mass. Between 500 and 700 fathoms, the peduncle does not show any trace of eye.

The influence of light on the mental and psychical condition of man has been the subject of much speculation, but, unfortunately, the few well proved facts we are in possession of are mixed with a considerable amount of fancy and exaggeration.

Black, violet, blue and dark green are said to be sad shades, and are often associated with mourning, while light green, red, yellow, are regarded as gay colours. It is in great part to the light that we owe the different psychical modifications we experience in a dark or a bright day, or in a starlit night, or in a pitch dark one. Everybody knows that red excites a bull or a turkey.

Dor has observed a considerable excitation, and even acute delirium, in neurasthenic subjects directed to look at a red surface, whereas a green surface, even brightly illuminated, did not give such effect. It has been found at the photographic plate factory of the brothers Lumiere, near Lyon, that when the workshops were illuminated in red, the workmen were constantly in a condition of excitement, which has given place to a much sober frame of mind since green light has been substituted. Moreover, they feel much less tired after their day's work.

The effect of light upon the muscular work has not been well investigated, and a dynamogenic classification of the colour has not been possible yet. Griesback, though, found that manual work tries blind people sooner than seeing individuals.

The influence of light on nutrition has long been known, and light baths were used by the Greeks. Herodote states that heliosis—it is the

term he used to denote light baths—were useful to those who need to improve their muscular condition. In our days, baths of artificial electric light have been used in cases of diseases characterised by the low nutrition of the patient, as anæmia, chlorosis, neurasthenia, and especially in diseases of the skin. According to Finsen, the violet and the ultra-violet radiations are chiefly active, especially in parasitic affections.

It is a well-known fact that bacteria are destroyed by light. Hence the beneficial effect of the sun as a means of sanitation.

Conversely though, the chemical radiations are very harmful in certain particular cases. It has been a long standing custom in the East to surround persons suffering with smallpox with red draperies, and recent experiments have shown that red light has a favourable effect on such subjects, as well as in scarlet fever and measles.

Finally, electric light baths, in which the effect of heat is added to that of light seem to have given good results in cases of albumenuria or Bright's disease.

The movements determined by luminous excitation in animals are varied: some animals seem to be attracted by light, others try to avoid it. The name of lucifuge or nyctalophyle is given to the latter, that of hemeralophile or nyctalophobe to the former. But Paul Bert has pointed out the fact that no undue importance must be attached to this classification. According to him, all animals seek light; it is merely a question of intensity. He has shown that some lucifuge animals, for instance, black beetles, when placed in a box quite dark, except in a corner in which a few pinholes admit a feeble light, move towards that part, but, on the other hand, they try to escape a strong light. We do practically the same, since we generally avoid the full light of the sun.

It has been asserted by some physiologists that lucifuge animals avoid light, because of the

chemical rays, and that for this reason they prefer red radiations to blue and violet. According to Paul Bert, however, most animals see exactly the same part of the spectrum as we do. This eminent physiologist does not agree with Lubbock's statement that ants are strongly affected by ultra-violet rays, which are quite dark for us. There may be, perhaps, an effect quite different from those of ocular vision.

In animals possessing eyes, it is clear that ocular vision plays a considerable part in phenomena of locomotion. It is a well-known fact that if one of the lanterns of that curious luminous insect of West India, the pyrophore, is blocked, while the insect progresses in a straight line at night, by its own light, it is seen describing a curve on the side which remains illuminated, but such phenomena of direction are themselves on the dependence of most delicate changes in the retina. We must of necessity leave aside this part of the subject, namely, the effect of light on the retinal elements, as it would involve the study of the physiology of the retina, a subject too large to be taken in the short time I have left.

I will conclude this brief description of the effect of light on animals with a few words on changes of coloration. It has been long known that many terrestrial and aquatic animals have the curious power of altering their coloration to take an appearance more like that of the surrounding medium. In this way they are enabled more or less to escape their enemies, or to approach more easily their prey. The researches of Milne Edwards, of Pouchet and of Paul Bert, have shown that in the chameleon the changes in coloration are due to the displacement of pigmented corpuscles of different colours, or chromatoblastes. These corpuscles, which are of a contractile nature, may also modify the colour of the tegument by their dilatation or contraction. The changes in colour may occur by the will of the animal, by

a reflex action, and by direct luminous impressions.

Vision has an evident influence on the skin of the chameleon. If the animal has lost an eye, the corresponding side of the body becomes practically incapable of altering its coloration, or at any rate, preserves a shade much lighter than that of the other side. The removal of the other eye reestablishes the equilibrium.

When a chameleon is exposed to solar light, its colour becomes darker by the direct effect of light. This phenomenon occurs during normal sleep, during anæsthetic sleep, and even after death. On the back of a chameleon sleeping in the dark, Paul Bert placed very carefully a kind of saddle, cut in a piece of paper. Then, without awaking the animal, he approached a lamp. Very quickly the skin became of a dark brown colour, but on removing the paper saddle, the parts which were covered were seen to have kept their original colour. The most refrangible rays of the spectrum produce this effect with the greatest intensity; red light is practically inactive.

Many animals deprived of eyes, are, however, sensitive to light, and certain animals, the eyes of which have been removed, are equally affected by light. Blind frogs avoid light, and place themselves in the darkest available places.

The proteus (*proteus anguinus*) found in the caves of Dalmatia and Carniole, lives and thrives in the dark. By measuring the length of time elapsing before the creature reacts to different radiations, it has been found that the scale according to which its comfort seems to diminish from darkness, in which it appears to be quite happy, to full white light, which is disagreeable, almost unbearable, is the following: Darkness—red, yellow, green, blue, white. The proteus reacts to any kind of radiation by sudden movements, and at the same time the effect of the light is manifested by the formation of pigment in the most vascular parts of the

surface of the body. The researches on the proteus have shown clearly that it is the skin which is acted upon by light in animals, normally deprived of eyes, but it is by a pure hypothesis that this fact has been generalised, and that the existence of such a dermatoptic vision has been admitted in all organisms without eyes.

We have seen that fluorescent substances have the effect of increasing the illuminating power of the violet end of the spectrum and of rendering visible the ultra-violet radiations, which normally are not seen. It follows that a certain quantity of visible light may be produced by spectral radiations. The fluorescent substances existing in animals are, however, very rare. R. Dubois has found in the luminous organs of the pyrophore a fluorescent substance he has called pyrophorine, which appears to serve to increase the light produced by the animal.

The crystalline lens, the cornea, the aqueous humour, and even the retina have been regarded as fluorescent. At any rate, they are very little fluorescent, and were it otherwise this would be more disagreeable than useful for vision. However, the cornea and crystalline lens show a certain degree of fluorescence when they receive ultra-violet rays, and in such cases, as stated by Helmholtz, they emit a pale bluish light similar to that shown by sulphate of quinine solution. The light observed in the eyes of many animals, such as the cat, is only seen in half darkness, never in absolute darkness. The light is probably due to interference of the rays reflected by the tapetum lucidum.

We arrive now to the production of light by living beings. Man found such difficulties in first obtaining fire and its twin brother light, that old legends will have it that a mortal stole it from the sky. Yet it is one of the surprises of nature that numberless creatures belonging to species and families descending lower and lower in the scale of life, can both generate and diffuse light. By means of the light radiating

from their bodies generally, or from special organs, they can illuminate the medium in which they live, whether this is the surface of the earth or some subterranean caves, or again the profound abysses of the ocean.

Amongst vegetables, the production of light or, to use a more scientific expression, the photogenic function, or biophotogenesis, has only been observed in plants without chlorophyll, such as mushrooms, and accidentally in parts of higher vegetables deprived of the chlorophyllian function. The family of bacteria includes a great many varieties forming the genus *Photobacterium*.

Many of these live floating in the sea or on the surface of the body of fishes, crustaceans, cephalopods, etc. It is to those that the phosphorescence of fishes is due, but the luminosity only appears after the death of the fish.

In inferior animals, the photogenic function is diffuse. It is in the protoplasmic mass that the production of light is observed. The noctiluque (*noctiluca miliaris*) produces the phosphorescence of the sea. Mechanical excitations determine the production of light in the mass of these organisms, and it is why the light chiefly appears when the surface of the water is ruffled by the wind.

In abysmal regions, numerous polypes form luminous forests of an appearance really fairy-like, and no doubt it is to this illumination that creatures living at such enormous depths owe their rich colours and the eyes they are possessed of.

Amongst articulated animals, a great many species present the photogenic function to a high degree of differentiation. Many crustaceans are luminous, having on all parts of the body, but especially on the legs, some luminous globules or photospheres, which sometimes are fitted with reflectors and lenses, and have been mistaken for eyes. It may be that such organs

serve at the same time to produce light and to see.

But of all animals, insects offer the greatest varieties of luminous beings. The most known are the *Luciole*, the *Lampyre noctiluque*, or glowworm, and the *Pyrophore*, vulgarly named *cucujis* by the natives of West India.

The photogenic function appears in the larva of the lampyre, or glowworm, the luminous apparatus showing as two small yellowish spheroidal masses on the side of the posterior part of the body. The mechanism of the photogenic function is easy to study on the pyrophore noctiluque. As in the glowworm, the egg of the pyrophore is luminous, so is the larva, but in the adult stage the pyrophore possesses three lanterns, two on the top part of the body, at the junction of the head and thorax, and one on the under surface, at the junction of the thorax and abdomen.

The production of light by the pyrophore, like that of the lampyre, is intimately connected with the fluctuation of blood in the luminous organs, and appears to be independent to a great extent of the working of the stigmata which correspond to these organs. If a pyrophore is excited its respiration ceases and its lanterns become immediately illuminated.

If we except the rare cases of luminosity, probably of parasitic origin, occasionally observed in men, the photogenic function in vertebrates is only found in fishes, especially those living in abyssal depths. The photogenic organs may be situated in very different regions, and by their positions and structures they resemble those of the crustaceans. The waters in which these creatures live are so deep that they are far beyond the reach of the remotest ray of sunlight. The sun itself would not appear to these creatures even as a single star of the fifth magnitude. In this region of darkness, some of the living beings have lost their eyes entirely, as might be expected. But others have not only eyes, but

very large eyes, some of which are made in a very special manner. As so many of the creatures, including those with eyes, carry light-giving organs, the conclusion is that these animals which spend their life in regions where there is no natural light, are able to see their ways by the artificial light given out by numberless living lamps affixed to themselves and other animals.

A fish dredged from 1,000 fathoms, in the South Atlantic, has eyes so arranged as to be absolutely unique. It is thought that they are modified and arranged on a most elaborate plan, so as to make use of the special class of light emitted by luminous animals.

Another called *malocosteus niger*, a small black fish, brought up from a depth of some 4,500 feet, has two light-projecting organs below its eyes, which probably illuminate its path through the dark ocean as the lamp of a motor illuminates the road. But by far the most striking of these light-bearing creatures is a carnivorous and formidable little fish, called *stomias boa*. From its elaborately carved jaws to the extremity of its body, it has on either side, below the middle line of the body, a double row of lamps or luminous holes, so close together that the luminous plates must light up the water round it far more brightly than the lights of a steamer illuminate the surface waters. It must look like a brilliantly lighted submarine train. This fish has very large eyes and a probably luminous tentacle, like the barbule of a barbel. As no vegetable growths exist in the deep seas, all the creatures living there are carnivorous. Consequently, while the development of light may aid one to find its food, it also betrays it to any others which may probably be hostile. This fact presents some difficulty. In the ordinary light of day, every creature has to take its chances against its enemies. Many, therefore, have become nocturnal, and the eyes of the enemies (as of the cat, the owl, the fox) have been

improved in order to catch them. But we do not know whether most creatures in the abysses of the sea are luminous or not. They may be covered with luminous mucus, giving out a strong light at great depths, or otherwise rendered visible; though some which have light producing organs in addition may have great advantage over others in the struggle for existence.

According to the creature which emits it, the colour of the light produced may vary. In the photogenic bacteria it is sometimes white, more frequently bluish, or greenish, or may even have an orange shade. The co-existence of two differently coloured lights has been observed in some cases. Certain beetles have two lanterns giving red light near the head and two others giving blue light in the middle part of the body. But what is more curious still is to see in the same animal all the colours of the spectrum succeed each other without interruption. Such is the case for the pyrosore.

Most of these variations are due to corresponding modifications in the photogenic mechanism. The coloration of the light may also be due to circumstances independent from the method of production, for instance, to the colours of the tegument of the blood. Thus, in injecting some eosine in the blood of the pyrophore, the light originally green becomes reddish.

The light produced by luminous insects shows a continuous spectrum, without bands or lines, and in which the different component radiations are clearly visible. The spectrum of the pyrophore, for instance, is striking when the animal is very luminous. Fairly extended on the red side, it ends at the level of the first blue rays. Its limits may be given as the ray B of the solar spectrum on one hand and the ray F on the other.

The impression produced on our eye by the light of a pyrophore shows clearly that the con-

stitution of this light is not the same as that of our sources of illumination. It is easy to verify this prevision by giving a beam of artificial light, by means of a diaphragm properly adjusted, a photometric intensity about equal to that of the light of the pyrophore, and by comparing the two spectra produced. The graphic representation of the results thus obtained may serve to give an idea of the respective composition of the two lights, but it is obvious that such a method is most imperfect, as it is impossible to compare, by photometric means, two lights widely different in their compositions.

The spectrophotometric analysis, on the contrary, has shown that if curves are drawn taking the wave-length as abscissa and the intensities of the rays corresponding to these waves as ordinates, the area included between the curve and the axis of wave-length is, for the light of the pyrophores, almost entirely occupied by green and yellow rays. The maximum intensity corresponds to the wave-length 0.52856μ . Now, this wave-length is precisely that which represents for our eye the maximum brightness in the solar spectrum. In the case of a candle, on the other hand, the maximum of luminous intensity corresponds to a wave-length of 0.48568μ , and is therefore rejected on the side of the most refrangible rays. The result would be the opposite if the spectrum of the pyrophore were as it is, simply because of the weakness of its total intensity, because, in this case, the blue rays would be the most abundant. Finally, the area limited by the curve of intensities of the candle and the line of wave-length is only occupied by yellow rays in the narrowest part.

By comparing these areas themselves, it is found that the spectrophotometric value of the two protothoracic lanterns of the pyrophore is about $1/400$ th of a candle. If we admit, which is about true, that the ventral apparatus has an illuminating power equal to twice that of the

protothoracic ones, we see that we should require about 37-38 pyrophores, giving light by their three lanterns, to get an illumination of one candle.

The light emitted by luminous insects is not polarised, but it contains a fair proportion of chemical radiations in spite of the presence of the fluorescence pyrophorine, which transforms a part of such radiations into visible rays. That the light of the pyrophore contains chemical rays in sufficient quantity to affect a photographic plate, is shown by this photograph of a paper pattern taken by the natural light of a pyrophore. It must be observed that five-minute exposures are necessary to obtain, even with the lantern of the under part of the body, the brightest of the three, a negative with a gelatino-bromide plate, requiring a fraction of a second exposure in solar light.

The amount of heat radiated by the lantern of a pyrophore is infinitesimal, but not absolutely nil. Prof. Raphael Dubois has been able to detect a few calorific radiations by means of a thermo-electric battery of great sensibility, taking all precautions to avoid experimental cause of error. He has found that this small quantity of heat is practically twice that which would be given up in the ordinary way, and at the same time by the body of the animal, when it does not radiate light. The existence of these calorific radiations has been further confirmed by the use of Langley's bolometer, the most sensitive instrument to detect heat in infinitesimal quantities. Langley and Verey estimated in this way that the quantity of heat radiated during 10 minutes by the most brilliant pyrophore is but seven millionths of a calorie.

On the whole the researches of Raphael Dubois have fully justified the conclusion he had drawn as far back as 1886, namely, that whilst in the case of the best artificial light 98% of the energy spent is used to manufacture invisible radiations, especially calorific, and but 2% are

used to produce light, in the case of physiologic light, 98% of the total radiations is made of visible light and 2% only are lost.

Besides this immense economic superiority, we have also to consider the exceptional qualities owing to which the pyrophores themselves prefer their own light to any other. This light cannot be put out by wind or rain; with it the danger of fire is eliminated. It must be understood that these little lanterns which the pyrophores always carry with them, which are always available, do not involve a great physiological expenditure. Twenty pyrophores, after having shined many hours, during a period of three days and three nights, have only lost a weight of a little over half a gramme, which represents a loss of three centigrammes, or half a grain per insect, and during that period they had spent more energy in movements than in producing light; moreover, they had not consumed any food.

The practical use of the cold physiologic light in illumination has been shown by Prof. Dubois at the Universal Exhibition of Paris in 1900. To illuminate a vast hall he has employed big glass vessels containing liquid media, in which photobacteria developed, and also glass vessels, the inside walls of which were coated with gelatine inoculated with the same bacteria. He has been able, in this way, to obtain an illumination equivalent to a fine moonlight, and to take photographs by this light.

My assistant, Mr. Firth, has made a lantern slide, showing a photograph of the bust of the great physiologist, Claude Bernard, taken by Prof. Dubois by means of the light just described. Objects viewed in this light appear exactly as they show in the photograph, but an exposure of at least 12 hours is necessary with an instantaneous plate, if a good negative is expected. The reason of this protracted exposure is found in the fact that physiologic

light contains a very small amount of chemical radiations.

Here is another slide representing the living lamp of Raphael Dubois, based upon the principle just explained. It consists of a glass vessel with a flat bottom. The upper part is covered with tinfoil, forming a reflector, and the internal walls are coated with a gelatinous layer made luminous by photobacteria. The openings in the neck above and on the side are closed by means of a wad of cotton wool, serving to filter the air passing through the vessel. The circulation of air must be assured by means of an india-rubber ball and tube, especially if the vessel is filled with liquid medium. This lamp may serve as a night light during several weeks, without any interruption.

Mr. Guillaume has tried to find approximately the photogenic efficiency of the electric arc lamp, and has found it to be $1/40$; that is, only the 40th part of the energy spent to excite the lamp is utilised to give light. The practical efficiency is still lowered if we take into consideration the amount of energy corresponding to the weight of combustible spent to work the machinery supplying the current, and if we estimate the loss resulting from the different transformations of energy involved. Looking at the question from this point of view, Guillaume has drawn the following table, giving the relative efficiency of different sources of light:—

Pyrophore	...	...	...	1.0
Sun	...	...	...	0.14
Arc lamp	...	...	...	0.0025
Incandescent electric lamp	...	...	...	0.0005
Candle	...	...	...	0.00014

As we see by this, the production of non-luminous radiations is dear, and beside, from the point of view of illumination, the ultra-violet radiations are always harmful and the dark calorific radiations very often are. To conclude, we can see that the physiologic light

is produced without the simultaneous production of heat. The practical meaning of the superiority of physiologic light will be emphasised when it is stated that in Great Britain the sum spent annually in manufacturing light reaches, according to Prof. S. Thompson, the gigantic total of from 10 to 20 millions of pounds. Now, at least 99 per cent. of this enormous amount is thrown away in producing heat. It is strikingly obvious that there is room for future development, although again quoting Silvanus Thompson, "the cheapest source of light still remains to be the commonest and most universal, the light of the sun, which shines alike on rich and poor and gives us a light the dominant wave-length of which is just that wave-length to which our eyes have become, in the long evolution of the eyes, the most sensitive. By no artificial process can we manufacture light so cheaply that it would not be still cheaper to adjust our social habits to the hours of sunlight and do our day's work while it is yet day."

Mr. President, ladies and gentlemen, I have endeavoured to put before you this evening only a few facts in connection with the subject, with the purpose, as I said before, of causing some of my hearers to search still further into the secrets of nature.
