The Biological Action of Light.¹

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WHILE the heat spectrum, including infra-red, visible and ultra-violet rays, extends from a wave-length of some 60,000 $\mu\mu$ ² to one of 100 $\mu\mu$, beyond the outer dark heat rays are the Hertzian waves used in radio with wave-lengths extending to a thousand metres or more. The inner dark heat rays merge into the visible, which are of wave-lengths from 700 $\mu\mu$ (red) to 400 $\mu\mu$ (violet). Beyond the visible lie the invisible ultra-violet rays with wave-length from 400 $\mu\mu$ to 100 $\mu\mu$, and beyond these come the soft X-rays and then the hard X-rays and the γ rays of radium with wave-lengths so short as 0.01 $\mu\mu$.

The body of a man is surrounded with a horny layer of skin beneath which lies the living cells of the epidermis in thin layers and myriad in number. Beneath them circulates the blood through close woven networks of capillaries, in streams some 0.01 mm. thick. The epidermis reflects and scatters rays which fall upon it, but some part of the visible rays penetrate and are absorbed by the blood beneath, warming it. The dark heat rays, on the other hand, absorbed mostly by the epidermis, warm it more than the blood in the dermis. Set as windows in an almost impenetrable skin, the eyes have been evolved with extreme sensitivity to a narrow portion of the spectrum, namely, the visible rays. To Hertzian waves we are insensitive; their energy has to be converted into sound and heard. Likewise we cannot feel ultra-violet, X- or γ rays: a latent period of two or three weeks follows exposure to X- or γ rays before an erythema of the skin and irritation results. A latent period also follows exposure to ultra-violet rays, but one limited to hours. While the hard X-rays and γ rays and secondary rays started by these penetrate in part to deep tissues, the active ultra-violet rays are wholly absorbed by the epidermis and exert their effect there.

Sonne found that if dark heat rays are brought to bear on the skin up to the just endurable sensation of burning, the temperature just beneath the skin will be raised to about 43° C. On the other hand, if visible rays alone are concentrated on the skin to the just bearable degree, the temperature just beneath the skin will be raised even to 47° C. This result, confirmed by Argyll Campbell and L. Hill, is due to the greater absorption of dark heat by the surface layer of the skin and a deeper penetration of the visible rays. Sonne ascribes heliotherapy to the local heating effect of the visible rays and has tried to find evidence that such local heating of the blood increases specific antibodies of the body, e.g. the diphtheria antitoxic content of the serum. However, P. Hartley has reinvestigated this matter with great refinement and accuracy of method, both in regard to the diphtheria antitoxin content of the serum and the agglutinin content of the serum against *B. typhosus*, and finds that light baths have not the least effect on such a specific immunity. The baths have power, on the other hand, to increase the general resistance of the body to infection, as was shown by L. Colebrook, A. Eidinow, and L. Hill, who found that a

light bath intense enough to produce erythema put up the hæmo-bactericidal power of the blood as tested *in vitro*. Blood which before the bath killed say 80 per cent. of staphylococci mixed with it, two hours after a light bath killed 100 per cent. Such an effect followed no less when a *lasting* erythema was produced by exposure to heat or a mustard poultice.

In the case of the light bath the relative activity of visible and ultra-violet rays is proved in the following way. If an arclight with "white flame" carbon poles (direct current and about 2500 kilowatts) is focussed sharply through a quartz lens on to the arm, an unendurable burning sensation results almost at once. If the arm is immersed in a quartz vessel full of cold water and the experiment is repeated, no burning sensation results, but if the exposure is continued for five minutes, erythema develops some hours later at the exposed spot, and this may advance even to a blister, to be followed by a long, lasting, brown pigmentation. Repeating the last experiment with a quartz screen filled with 3 per cent. quinine solution interposed between the arc and the arm, all ultra-violet rays shorter than 330 $\mu\mu$ are thus cut out, as can be shown by the quartz spectrograph. In this case no erythema results even after over an hour's exposure. The visible rays then, apart from their heating effects, have no effect on the skin. The ultra-violet rays, acting on the cooled skin, have, on the other hand, a profound effect.

Using a quartz spectroscop and a blackened thermopile for measuring the energy of various parts of the ultra-violet spectrum, it was found by Hausser and Vahle that the maximal power for producing erythema of the skin was with the wave-lengths 300-290 $\mu\mu$, just the region which comes through with the high sun on clear days. Little effect was given by rays 313 $\mu\mu$ and 250 $\mu\mu$. A screen of uric acid (1 in 40,000 solution) in a quartz container absorbs rays shorter than 306 $\mu\mu$ (Dhéré). The mercury vapour lamp through this screen produces no erythema even after giving six times the erythema dose for the unscreened lamp. Lines 275 and 257 $\mu\mu$ of the cadmium spark spectrum produce erythema, but not line 232 $\mu\mu$. Such short rays do not penetrate the horny skin but actively kill infusoria.³

How slight is the penetrating power of the ultra-violet rays is shown by interposing in place of the quinine solution a thin film of the horny layer of the skin taken off a blister, or the mesentery of a rabbit. Such a film protects the skin no less than the solution of quinine.

The active ultra-violet rays penetrate to the deeper epidermic cells but no farther. Among these cells there takes place multiplication and growth, formation of pigment and transition into the horny material which is pushed outwards by the growth of cells within. In these cells the ultra-violet rays provoke changes which we may assume are similar to those which have been photographed in living anthrax bacilli by Mr. J. E. Barnard, using a microscope with quartz lenses and a band of ultra-violet rays from the cadmium spark. Under the ordinary microscope they have been observed

¹ Substance of two lectures given at the Royal Institution on March 12 and 19.

² $\mu\mu = 0.000001$ mm.

³ I am indebted to Messrs. J. E. Barnard and J. Smiles for the use of the spark.

by A. Eidinow and L. Hill on infusoria. An increasing aggregation of particles takes place in the bioplasm; in the case of infusoria this leads to cessation of movement, death, rupture, and setting free of the particles. So, too, the surface film of egg white exposed in a quartz chamber is coagulated by ultra-violet rays. Positive particles are dispersed and negative ones aggregated (Clark).

These rays displace electrons in atoms according to present physical theory and so alter the charge of the particles, some of which are to be seen in bioplasm by dark ground illumination and high microscopic magnification in active Brownian movement. This leads to aggregation started by the displacement of electrons in the atoms. Chemical change in molecular structure ensuing in the epidermal cells after a latent period, reaches such an irritative nature as to lead to dilatation of the subcutaneous blood vessels, exudation of lymph, increase of lymphocytes, and rise in the hæmobactericidal power of the blood. In cases of rickets the abnormally low inorganic phosphorus content of the blood which is significant of this condition is put up also in a striking way. Subsequent to these reactions there results desquamation, due to death of some epidermal cells followed by pigmentation. The pigment melanin is laid down as granules in that layer of living cells which lies close underneath the horny layer. Melanin is stated to be formed by the action of an oxydase in the deeper epidermic cells, as may be seen in the fresh sections of skin (cut frozen) when radiated and wet with a solution of dioxypyphenylalanin; this substance is said to be the specific precursor (Bloch). The closely allied compound, tyrosin, is said to diminish in amount in the blood at the time when melanin is being formed in the skin after a light bath.

Ultra-violet rays act more quickly on warm than on cold skin. Tested on infusoria the coefficient for temperature (for a rise from 10°C. to 20°C.) is about 2.3 (A. Eidinow and L. Hill); for the frog's mesentery it is less, about 1.2 (Argyll Campbell and L. Hill). While heat of the sun may aggravate a sun burn, it is not a necessary adjuvant. Ultra-violet radiation can intensely burn the cooled skin; it is well known that glacier sun-burns may be very severe. Dewar killed microbes with ultra-violet rays at the temperature of liquid air.

The power behind the sun was worshipped by the heretic pharaoh, Akhnaton, and modern science leads us back to veneration of this power. The imagination tries to think of the infinitely intricate energy complex which goes to form a living cell, of electrons being displaced in atoms by ultra-violet rays, of molecular movement enhanced by heat rays, of radiation provoking reactions which manifest themselves as life, of the spirit of man ensuing in the evolution of energy transformations.

The law holds that absorption of rays precedes action. Rays which pass through a cell have no action upon it at all. The skin screens itself from excessive light by its horny layer and by pigment. Pigment by absorbing visible and ultra-violet rays screens the deeper cells and blood. It absorbs dark heat rays and converts visible rays into heat, and this heat, stimulating the nerve endings in the skin, may reflexly lessen body heat production while provoking sweating and dilatation of cutaneous blood vessels.

Melanin is a screen, not a sensitiser, transforming light into heat. It is present in a fine particulate form

and scatters and diffusely reflects rays. The spectrograph shows that melanin in fine suspension and thin layers screens off and greatly weakens but does not wholly absorb the ultra-violet spectrum. This is in sharp contrast to a 3 per cent. solution of quinine which in an equally thin layer wholly absorbs rays shorter than $330\text{ }\mu\mu$. A layer of sweat wetting the skin helps to reflect light, while a layer of evaporating moisture surrounding the skin helps to absorb heat rays. The pigmented naked body with sweating skin is thus favourable to the cooling of the native in the tropics, while clothing retards heat loss of the white man.

By local concentration of an arc light on a rabbit's head, it is easy to heat its fur up to 150°F. and its brain even to 107°F. while with the body in the shade the rectum is only 101°F. (Argyll Campbell and L. Hill). Pith helmets prevent local heating of the head and sunstroke in the tropics. There is rarely any danger of sunstroke in Great Britain. The sun is powerful enough only on few summer days, and bare heads offer no risks except on these rare occasions. Heatstroke from overheating of the whole body due to exhaustion of sweating in warm stagnant air is much more common—overclothed as we are for withstanding hot weather.

Downes and Blunt (1877) proved that the bactericidal action of light was due to ultra-violet rays, and much has been made of this. It has been claimed recently by Wiesner that the infra-red rays, apart from their heating effect, have a bactericidal action, but this is not so (A. Eidinow and L. Hill). The only rays which kill, apart from any lethal heating effect, are the ultra-violet rays. The bactericidal power of these rays is not nearly so important as has been thought, for the rays can only kill the surface bacteria. They cannot penetrate into filth any more than through the epidermis. In their curative effect on lupus these rays act, not by directly killing the bacilli, but by increasing the immunising powers of the tissues. This is so, even when the rays are focussed as in the local Finsen light treatment. Nodules so treated, when injected into guinea-pigs produce tuberculosis.

Mr. J. E. Barnard, by photographs taken with ultra-violet rays and a quartz-lensed microscope, has shown structures hitherto unrevealed in living yeasts, bacteria, and blood cells. This is due to the selective absorption by the outer membrane, the nucleus, and certain other granules in the cells. Infusoria vary in their susceptibility to the lethal effect of ultra-violet rays, and this probably bears a relation to the age, nutritional state, and absorptive particles within them. The lethal power on cells increases with shortening of the ultra-violet rays; for example, using the cadmium spark, a 20-minute exposure sufficed to kill infusoria placed in the $275\text{ }\mu\mu$ band, and a 3-minute exposure in the $232\text{ }\mu\mu$ band. The penetration of the shorter rays, however, is far less, and these, therefore, have no action on the skin. Thus, as stated above, while bands 275 and $257\text{ }\mu\mu$ of the cadmium spark produce erythema of the skin, the intense $232\text{ }\mu\mu$ band has no effect.

In the case of the very short rays, Mr. J. E. Barnard finds one anthrax bacillus screens another lying beneath it. With rays of weak intensity, processes of repair may keep pace with injury, and no effect be produced in living cells. A screen which allows ultra-violet rays to pass so as to give an excellent spectrum, as photo-

graphically recorded by means of the quartz spectrograph, may be found to reduce biological action very greatly, as is shown when the lethal power of the screened rays is tested against that of the unscreened on infusoria or the skin. The photographic method is so exceedingly sensitive that deductions cannot safely be drawn from it alone.

It is claimed that immunity is set up in the epidermis by one exposure to a subsequent one, and this long before pigment is formed (Perthes). Thus if an area of the skin be exposed for five minutes and again for five minutes some hours later, and a second area be given 10 minutes exposure all at one time, the erythema will be much more marked in the second area. Choosing a small dose, a second one given a few hours later increases erythema and soreness. Maximal erythema, of course, cannot be further increased by a second dose, but this seems to be true for soreness also. The immunity is no doubt due to coagulation of the outer layer of living cells, whence comes peeling. When pigmentation is still well marked weeks after an exposure, susceptibility of the epidermis may be shown to have returned by the erythema following a further dose of ultra-violet rays.

To measure the therapeutic action of the ultra-violet rays we can use the lethal dose for infusoria contained in a quartz cell at 15-20° C., or the erythema-producing dose for the skin of the average white arm, or the rate of bleaching of a standard solution of acetone and methylene blue. The last has been standardised against the two former, and each degree on the scale is twice to four times that required to produce a moderate erythema. (A. Webster, L. Hill, and A. Eidinow.) The acetone blue solution is exposed in a quartz tube of standard diameter, and after exposure the degree of bleaching determined by comparison with a set of blue tubes of depths of tint 10 to 3. The acetone solution absorbs the ultra-violet rays shorter than 360 $\mu\mu$, and the chemical reaction set up in it bleaches the blue. Observations have been taken daily with full exposure to sun and sky at various places and show the intensity of ultra-violet radiation in clean air and the effect of smoke and pollution. During a fine summer day the quartz tube may have to be changed two or three times in the day, and the highest total reading last summer at Peppard, Oxon, equalled 23. In the Alps a reading of 41 was obtained in one day. In dull cloudy weather of winter the reading may be 1 or 2 and in smoke polluted towns 0.

Using in addition a clock to keep moving the quartz tube together with a small screen to shade it from the sun but not from the sky except that immediately round the sun, we have found that the total ultra-violet radiation from the sky is far more than from the direct sun. Dorno at Davos showed that this was so using a cadmium photo-electric cell for recording the ultra-violet radiation. Even with the sun at its zenith, the ultra-violet radiation from it is only about 90 per cent. of that from the blue sky. With the low sun, the sky yields far the more.

Smoke pollution robs us of half or more of the ultra-violet rays. While seeking to abolish this evil, we require to make the loss good by the use of artificial sunlight baths. Screened as he is by window-glass, clothes, fog, and smoke, the citizen is cut off from ultra-violet rays almost wholly in winter, and in consequence his general health and resistance to disease goes down.

The evil is enhanced by indoor life spent in heated stagnant air of rooms, and by lack of open air, exercise, and by a diet deficient in vitamins. Thus the resistance to catarrhal infections, which spread in the crowded stagnant air of rooms, is lowered. Those who live open-air lives and are well fed, exposed however much they are to weather, are far less often attacked.

It has already been stated that the hæmobactericidal power of the blood (as tested *in vitro*) is put up in an animal by an exposure to ultra-violet radiation which is sufficient to produce erythema. It has also been found by A. Eidinow that if a little blood is withdrawn from an animal, irradiated by rotation in a quartz flask, and then put back again into the animal, this puts up the hæmobactericidal power, and yet the irradiated blood itself has this power actually destroyed in itself by radiation. The hæmobactericidal power depends on the corpuscles and not on the serum. In man it is naturally high, and can be put up less than in such animals as rabbits and pigs. It is known that ferments, serums, agglutinins, and the anaphylactic power of blood are alike destroyed by ultra-violet radiation.

Recent research on rickets has shown that the diseased calcification of the growing bones results from a diet deficient in antirachitic substance and lack of ultra-violet rays. If young rats are put on a diet deficient in antirachitic substance and having a minimum of salts of phosphorus, the latter is not absorbed from the gut. Either the addition of antirachitic substance in cod-liver oil or ultra-violet radiation for a few minutes a day will wholly stop rickets developing and cause a minimal amount of phosphorus in the diet to be absorbed and utilised in bone building (A. Webster). It has been proved that the antirachitic substance present in cod-liver oil is not vitamin A, and that it can be put into an inactive food by ultra-violet radiation (Hess, Steenbock). Thus, inactive linseed oil, casein, flour, and lettuce leaves can be made effective as cod-liver oil in preventing rickets, by rotating them in a quartz flask in front of the mercury vapour lamp. Water, fat, starch, sugar, mineral oil, glycerine, cannot be so activated. Oils retain their acquired antirachitic power for months. It has been claimed that "active" food substance on oxidation gives off ultra-violet rays, but this is not so. The error has arisen through the fluorescence of certain quartz screens used in the photographic tests (A. Webster). Drummond has shown that radiated cholesterol makes an extremely active antirachitic substance, and possibly in all food stuffs shown to be activated by radiation this is the activated body. Possibly radiated rats absorb this from the skin.

We have no evidence so far that radiation can endow an inactive food with the growth qualities pertaining to vitamin A. If this prove possible, the margarine makers will have found a fresh source of fortune in being able to claim that their product is made equal to butter. Rickets can be prevented by making the diet more adequate, *e.g.* by cod-liver oil, and also by teaching mothers the need of exposing infants' and children's bodies to the sunlight and by the use of artificial sunbaths at infant welfare centres.

Prolonged exposure to intense ultra-violet rays either of the sun or an arc light produces destruction and sloughing of the white skin. While the visible rays, beside their heating effect, have no lethal effect on the

normal living animal cell, it is easy to produce a most powerful effect from these rays by sensitisation of the cells. Many fluorescent dyes have this effect, eosin, erythrosin, etc., forming a compound with the bioplasm and so making the latter absorb and be affected by rays longer than the ultra-violet.

The most interesting sensitiser is hæmatoporphyrin, an iron-free derivative from hæmoglobin, closely allied to phyloporphyrin, a derivative of chlorophyll. Traces of porphyrin (uro- or sterco-) are present naturally in the body and may possibly give to the skin some very slight natural sensitivity to visible rays. An excess of porphyrin is present in some rare individuals endowing them with an unfortunate sensitivity which causes skin eruptions and even ulceration of extremities on exposure to bright light—a disease called *hydroa æstivalis*, which has to be met by the greatest care against their exposure to sunshine or bright daylight.

When the mesentery is exposed in a cool glass irrigation chamber to concentrated visible rays of an arc, no effect results, the ultra-violet rays being filtered off by the glass. Add now a trace of hæmatoporphyrin to the bath (1 in 10,000) and in a very few minutes stasis occurs in the blood vessels. The lymphocytes gather to form thrombi which block the vessels (Argyll Campbell and L. Hill). While pigmented animals are protected, albinos made sensitive by injection of hæmatoporphyrin die after exposure to light. Meyer Betz was daring enough to inject some hæmatoporphyrin into himself and suffered from œdema of the face and hands on exposure to light. He remained sensitive for weeks. It seemed possible that sensitisation might prove useful in light therapy, but we have obtained no evidence of this. Animals do not stand well the exposure of the shaved skin to light after even very small doses of hæmatoporphyrin have been injected. Painting patches of lupus with glycerin and eosin has been tried so as to endeavour to secure a greater local effect from light treatment, but definite evidence for this has not been found (A. Eidinow and L. Hill).

Sudden exposure to ultra-violet rays stimulates to contraction such an organ as the uterus of the guinea-pig or the stomach of a frog. The excised iris by pigment is made sensitive and contracts on exposure to visible rays. Ultra-violet rays do not pass through the cornea or lens, and when the retina is damaged by over-exposure to an arc light or to sun (as in viewing an eclipse without smoked glasses) it is injured by excess of visible rays acting on its extremely sensitive substance. The specific sensitivity to different wave-lengths of the alkaline metals, sodium, potassium, etc., as shown in the photo-electric cell, is suggestive in regard to the theory of colour vision. Photo-electric effect produced by rays acting on a specific retinal substance or substances may be the first stage in the excitation of vision. Russ has claimed that the owl's eye transmits ultra-violet rays. This is not the case with the cat's eye, which has good nocturnal vision, nor with the cod's eye, a fish which swims in dim lights of somewhat deep water. Tested by putting the cornea in a band of active ultra-violet rays, using the cadmium spark, none reach a fluorescent screen placed at a window cut in the posterior part of the eye (A. Eidinow and L. Hill).

It has been suggested that there is a biological inter-

ference between infra-red, or visible rays, and ultra-violet rays. Hess found a longer daily exposure to the mercury vapour lamp necessary in order to prevent rickets in young rats (fed on a deficient diet) when a glass screen was interposed which let red and yellow rays through as well as ultra-violet, than was the case with a glass screen which only let ultra-violet rays through. The photographs of the spectra of the two screens seemed to show equality of the ultra-violet radiation, but a difference in intensity is the most probable explanation. Pech claims that both bleaching of cotton and production of erythema by ultra-violet rays is delayed by a concomitant beam of infra-red rays. Infusoria seemed to move actively longer in the light of a mercury vapour lamp when red rays were also thrown on them than without these rays. The lethal times, however, on further trial came out to be the same in the two cases, and further research on the circulation in the mesentery and on infusoria exposed to ultra-violet bands in the cadmium spark spectrum proved negative. Not the least evidence of interference with the lethal effect was found (A. Eidinow and L. Hill: Argyll Campbell and L. Hill).

Ultra-violet rays improve the growth and breeding power of fowls. Acting directly on embryos they produce monsters. The loss of breeding power in man and domestic animals such as cattle is probably due largely to indoor life. It has been established by abundant clinical experience that light treatment is excellent for surgical tuberculosis, rickets, and wounds (O. Bernhard, Rollier, Gauvain, and others). Trials recently made on many other diseases have shown that we have in artificial sun treatment a powerful stimulant to general health and in particular of the defensive mechanism of the body against chronic infections. Skin diseases such as psoriasis, ichthyosis, eczema, and boils, chronic anæmias of obscure origin, nutritional weakness and wasting in infants, chronic bronchitis and the fat flabby condition of the sedentary over-fed middle-aged person, chronic phthisis, the debility following acute infectious disease, etc., are alike greatly benefited (A. Eidinow and L. Hill; P. Hall, etc.). The open-air sanatorium and school have shown how ailing feeble children can be turned into happy vigorous ones.

A very great benefit to general health can at once be secured by the installation of arc baths in schools and public baths. If in winter all children stripped but for a loin cloth, danced to music for fifteen minutes twice a week a yard or two away from and round a powerful arc lamp, e.g. one taking 100 volts and 30 amperes with white flame carbons, a great improvement in vigour, alertness, and health would be obtained. It is by such means that our misty, smoky, winter climate can be immediately remedied. At the same time, we can set about to secure and use smokeless fuel and clean away the hideous smoke pollution of the air. We can also set into windows and sky-lights of schools, hospitals, and nurseries the new "vitaglass," which lets the ultra-violet rays through, and use such glass for the bulbs of incandescent tungsten filament lamps, which would then be a source of ultra-violet rays of mild intensity.

Many interesting experiments are now being carried out concerning the growth of plants and fruits with and without ultra-violet rays, and on the effect of continuous lighting.