SUNSHINE AND HEALTH

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SUNSHINE AND HEALTH

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SUNSHINE AND HEALTH

CHAPTER I

LIGHT—HISTORICAL

" Hail, Holy Light, offspring of Heaven first-born ! "

Light, as an optical phenomenon, is and has always been the most intense and dramatic experience of man. The subtle and mysterious emanation or radiation issuing from the gigantic orb of the sun, and penetrating, after filtration, reflection, and refraction, the tiny orb of the eye, creates for man a dædal universe of form and colour, and becomes the foundation both of his sensuous and spiritual existence. The thought is almost bewildering ! Here is a fragile little ball about the size of a gooseberry ; and there, 93,000,000 miles away, is another fiery, whirling ball billions of billions of times as large ; and something from the big ball touches the little ball, and the little ball becomes an infinite consciousness filled with visions of suns, and stars, and mountains, and seas—a consciousness able to transmute into thought black marks on a white page. The sunlight enters the eyeball, and in a moment the little orb becomes a bigger and more wonderful thing than the sun, for light mysteriously translated into sight is the greatest part of the conscious being of man. Were it possible to destroy a man's whole body and yet leave alive one eye with all its multifarious nervous connections, there would still be left the radical substructure of a mind. Yet the relationships between light and sight, though so radical, are nevertheless so subtle and so metaphysical that primitive man accepted them without trying to analyse them. He recognised that the light revealed the world to him, and warmed his body, and ripened his crops, and he worshipped the sun and the heavenly bodies as sources of a wonderful and beneficent emanation. His philosophy was as simple as it was wise: "And God said, Let there be Light, and there was Light."

So we find that in primitive times light inspired religion rather than science, and that most early religions were Light religions worshipping in some form or other

"That Light whose smile kindles the universe,
That Beauty in which all things work and
move."

From the Andaman Islands to Greenland, from Pekin to Peru, from Polynesia to Scandinavia, the sun and heavenly bodies have inspired a thousand myths and adorned a thousand creeds. The Kavirondo worshipped the moon and sun; the Maoris and Fijians had their gods of light and darkness; the Hottentots bowed before their god of the red dawn; Amon-Ra and Ra Horakhti, the chief gods of the Egyptians, were sun gods; and worship of the sun was the basis of the high monotheistic religion founded by the great heretic King, Akhnaton. The Taoists and Zoroastrians have always deified light. Every Buddha is believed to be able to illuminate the universe by means of a circlet of hairs between his brows. Helios and Phœbus-Apollo, Ormuzd, Mithra, Anatarenon, Baal, Astarte, and Lug, all are creations of a solar mythology.

As representative of the best in solar religions may be taken Akhnaton's hymn to the Sun.

Thy dawning is beautiful in the horizon of the
 heaven,
O living Aton, Beginning of life!
When Thou risest in the eastern horizon of
 heaven
Thou fillest every land with Thy beauty;
For Thou art beautiful, great, glittering, high
 over the earth,

Thy rays they encompass the lands, even all
Thou hast made.
Thou art Ra, and Thou hast carried them all
away captive;
Thou bindest them by Thy love;
Though Thou art afar, Thy rays are upon the
earth;
Though Thou art on high, Thy footprints are
the day.

. . . . . .

Bright is the earth when Thou risest in the
horizon,
When Thou shinest as Aton by day.
Thy darkness is banished.
When Thou sendest forth Thy rays;
The two lands (of Egypt) are in daily festivity,
Awake and standing upon their feet,
For Thou hast raised them up.
Their limbs bathed, they take their clothing,
Their arms uplifted in adoration to Thy
dawning.
Then in all the world they do their work.
All cattle rest upon the herbage,
All trees and plants flourish,
The birds flutter in their marshes,
Their wings uplifted in adoration to Thee.
All the sheep dance upon their feet,
All winged things fly,
They live when Thou hast shone upon
them.

The barques sail up-stream and down-stream alike.
Every highway is open because Thou hast dawned.
The fish in the river leap up before Thee
And Thy rays are in the midst of the great sea.

. . . . . .

Thou makest the beauty of Form through Thyself alone,
Cities, towns, and settlements,
On highway or on river;
All eyes see Thee before them,
For Thou art Aton of the day over all the earth.

But the acute Greek brain did not rest content with the primitive religious inspirations of light: it soon began to inquire into solar optics and physics, and to busy itself with the nature of the mysterious something which issued from the sun and not only affected the eye across millions of miles of empty space, but also enabled the mind to perceive all so-called visible objects.

The solutions they propounded to the profound and intriguing problem were at least reasonable and ingenious examples of the scientific imagination, and not very far away from the theories of modern science.

Sensation without actual material contact seemed to the Greek mind, as later on to Newton, as inconceivable, and the theories of the Greek philosophers all tried to provide some intermediary between visible bodies and the eye. Briefly speaking, there were four distinct theories. The first, held by Empedocles, Plato, and Hipparchus, supposed that some kind of ray projected from the sun and visible bodies met another ray projected from the eye —as if two hands stretched out to touch each other. The second, taught by Epicurus and Lucretius, supposed that something went forth from the eye so that the eye touched visible bodies as we touch them by means of a stick. The third, Aristotle's, held that light was the act or energy (*energeia*) of a transparent medium, and colour the act or energy of the transparent medium in so far as the medium was a constituent of coloured objects. The fourth, upheld by the Pythagoreans, maintained that visible bodies emitted streams of fine particles which bombarded the eye.

In very early times, too, the Greek mind busied itself with the astronomical side of light and, by aid of geometry and trigonometry, discovered many facts about the motion, distance, and size of the heavenly bodies. More than a hundred years before Christ, Hipparchus discovered the obliquity of the ecliptic and determined the periods of the revolutions of the five great planets round the sun. He also measured the distance of the moon, and described the precession of the equinoxes. And three hundred years later Ptolemy worked out a theory of epicycles and eccentrics to explain the apparent motions of the sun, moon, and planets. That was a magnificent start in the physics of light and in astronomy; but nevertheless for more than a thousand years after the time of Ptolemy no further progress was made. No further attempts were made to solve the nature of radiation of light; and astronomy fell into the foolish, futile hands of astrologists.

But in the fifteenth century—a century which must be classed with the seventeenth and nineteenth as a century of great men—a fresh start was made by Copernicus, a priest and physician of Poland, who maintained that the earth rotated on an inclined axis and with the other planets revolved round the sun, and in the following century, Kepler enunciated his three famous laws. Then came Galileo and the telescope, and the time was ripe for Newton.

In the seventeenth century, when Newton made his historic researches with his prism, the nature of colour was still a moot question, but most thinkers—such as Kepler, Antonio de Dominis, Descartes—followed Aristotle and believed that light was a wave-like motion in a transparent medium and that colour was the resultant of the reaction with the coloured medium; even though certain experiments with prisms had already suggested that white light was compounded of coloured rays. The learned Bohemian, Joannes Marcus Marci de Kronland, had noted in his remarkable work "Thaumantias" (1648) that the coloured rays separated by a prism did not change colour on passage through a second prism; and the ingenious Jesuit, P. Franco Maria Grimaldi, experimenting with prismatic colours, came to the correct conclusion that the colours of coloured objects were in the light, not in the coloured objects, "non esse aliquid reipsa distinctum a Lumine." Nevertheless, he did not really demonstrate his theory, and it was left to Newton to solve the secret of colour.

Newton's experiment was seemingly trivial. He describes its conditions in a few historic words: "In a very dark room at a round hole about an Inch broad made in the Shut of a window I placed a Glass Prism whereby the beams of the Sunlight which came in at that Hole might be reflected upwards towards the opposite Wall of the Chamber and there form a coloured Image of the Sun."

It was a trivial experiment, such as many before him had made, but from it his keen mind drew conclusions which had momentous intellectual consequences. Up to this date, 1666, it had been universally believed that the colours produced by the prism were due to alterations in the light consequent on its passage through the glass, but Newton demonstrated that white light was composed of coloured rays and that they were merely bent or refracted to different degrees in passing through the prism, and thus were separated from each other and made self-evident. There followed the remarkable consequence that coloured objects were colourless, for the colour attributed to them really resided in the rays reflected from them. Indeed, it might even be said to be more correct to call a green leaf red than green, since the leaf keeps the red rays, while rejecting the green.

Newton's analysis of white light into its component colours may be said to be the basis of the whole modern science of radiation, since it led to the measurement of wave-length and to the study of light waves as vibrations of definite frequency.

But the solution of the problem of colour did not solve the question of the ultimate or fundamental nature of light. That problem had remained much as the Greeks had left it many hundreds of years before. Leonardi da

Vinci (1452–1519) seems to have held the Pythagorean theory that light was an emission of fine particles or corpuscles; but almost all the thinkers of the following centuries—Kepler, Descartes, Malebranche, Hooke, Huyghens—were adherents of the wave theory of Aristotle. Strangely enough, Newton threw the weight of his authority on the side of the Aristotelians, maintaining that light consisted of fine particles of various sizes emitted by luminous and visible bodies, though with the qualification that the corpuscles set up waves in the ether which surrounded them. Laplace and Poisson supported Newton, and, despite the opposition of Huyghens and Hooke, the corpuscular theory prevailed in England and made some headway even in France, where the wave-theory of Descartes and Malebranche had a very strong hold.

In the middle of the eighteenth century, Boscovich's theory of action at a distance became popular, but it did not retain popularity long, and in the beginning of the nineteenth century, the wave theory of Hooke and Huyghens was re-established and developed by the brilliant work of Young and Fresnel. The discovery of the interference of light waves (previously suggested by Grimaldi and Hooke) by Young greatly strengthened the position of the wave theory, and from that date and up till quite recent years light has been regarded as transverse wave vibrations propagated in a medium called ether, which fills all space and permeates all matter. Recent discoveries of electrons and of quanta of energy have resuscitated the corpuscular theory of light, and Einstein is disposed to dispense with the ether altogether, but nevertheless to-day the wave theory is almost universally accepted.

In 1659, Roemer, a Danish astronomer, measured the speed of light, and found it to be about 200,000 miles a second (it is now known to be 186,000), and in 1802 Thomas Young made accurate measurements of the various light waves.

The beginning of the nineteenth century was signalised not only by Dr. Young's accurate measurements, but also by the great discovery that there were invisible waves longer than the longest known visible red waves and shorter than the shortest visible violet waves. In 1800, Dr. Herschel found that a blackened thermometer 52 inches from the prism and 1½ inches beyond the red end of the visible spectrum recorded the presence of heat rays, and reported in the *Philosophic Transactions*: "There are waves coming from the sun which are less refrangible than any of those that affect the sight. They are invested with a high power of heating bodies, but with none of illuminating bodies, and this explains the reason why they have hitherto escaped unnoticed."

A year later, J. Wilhelm Ritter discovered the invisible rays, now known as ultra-violet, beyond the visible violet rays of the coloured spectrum. In *Gilbert's Annalen der Physik* he announced his discovery thus: "On the 22nd February (1801) I have also, by means of silver chloride, detected sun-rays on the violet side of the coloured spectrum and beyond it. They have greater reducing power even than the violet rays, and their field of action is greater."

These two important discoveries of invisible light opened up a quite new field for research and exploration, and eventually led to an extension of the visible spectrum on the one hand as far as the gamma rays, and on the other as far as the Hertzian waves.

Almost at the same time, 1802, Wollaston made an equally fruitful discovery in his observation of the dark lines in the visible spectrum. "In the light of the lower part of a candle," he wrote, "the spectrum is distinguished into five distinct portions." A few dark lines in the spectrum might seem unworthy of notice, but they were the beginning of the science of spectroscopy, which has revealed to man the constitution of stars and of atoms.

The new science grew rapidly, and, in 1814, Frauenhofer mapped in the solar spectrum about 700 lines, and labelled the principal ones between the red and the violet " A, B, C, D, E, F, G." Soon it was suggested that glowing gases might be identified by their spectral lines, and Plücker, having identified the lines of hydrogen, boldly asserted that every gas had its characteristic spectrum, " diese spectra ein neues characteristisches kennzeichen der Gase abgeben."

The next great advance in the science of light took place when Clerk Maxwell, one of the greatest geniuses who ever lived, proved mathematically, in 1864, that a brilliant guess of Faraday was correct—that " light and magnetism are affections of the same substance, and that light is an electro-magnetic disturbance and propagated through the ether according to electro-magnetic laws." Twenty-three years later, Heinrich Hertz gave practical proof of Clerk Maxwell's theorem by producing and demonstrating waves in the ether, thus showing the fundamental identity of light and electricity.

In 1895, Röntgen, in the course of investigating the phosphorescence of vacuum tubes, stumbled on the " *X*-ray," which turned out to be light of extraordinary short wave-length, and still further extended the spectrum in the ultra-violet direction. And next year, the great French chemist Becquerel found, in the radiant emission from uranium, rays of still shorter wave-length—the " gamma " rays. It should perhaps be mentioned here that Silvanus Thompson discovered the radio-activity of uranium almost simultaneously with Becquerel.

At this point, then, a spectrum of waves extending from big Hertzian waves to gamma waves infinitesimally small had been established, and though at first there were gaps in the series, these were afterwards filled by the labours of Stokes, Schumann, and others, till to-day there is continuity from one end to the other—from waves of electricity miles long, on the one hand, to newly-discovered Millikan waves which are shorter even than gamma rays, on the other.

Meantime the biological and therapeutic value of light had also been studied.

In 1771, Joseph Priestley discovered that a sprig of mint was in some way able to purify foul air and to add to it dephlogisticated air (oxygen), so restoring its power of supporting combustion, and a few years later Ingen-Housz and Senebier showed the relationship between the absorption of carbon-dioxide and the emission of oxygen, and the former pointed out that the process took place only in the light, and thus laid the foundations of the science of photosynthesis.

The therapeutic value of light had doubtless been discovered centuries before, for it seems probable that ancient Babylonians, Assyrians, and Greeks used sunbaths, and it is certain that in the ninth century the Arab physician Rhazes treated smallpox with red light, and that a few centuries later sunlight was used in Italy to disinfect clothes infected by the plague. But not till the eighteenth century can phototherapy be said to have been established on a scientific basis. Towards the end of that century, many books and treatises dealing with the therapeutic value of sunlight were published. In the early decades of the nineteenth century sunbaths became quite popular, and Rosenbaum (1835) anticipated modern therapy by advising them for rickets and scrofula, while Picton (1835) reported that good results were obtained in smallpox by keeping the patient in darkness. In 1855 a Swiss doctor, Arnold Rickli, actually started an institution for sunbaths at Veldes in the Oberkrain, and other doctors in other countries followed suit.

In 1876 Downes and Blunt widened and deepened the scientific basis of phototherapy by demonstrating that violet light, both direct and diffused, was fatal to bacteria, and Finsen, who had been studying the effect of red light in smallpox, promptly conceived the idea of using the violet light to kill the tubercle bacilli *in situ* in cases of lupus. Though his theory of bactericidal action has since been proved to be erroneous, his treatment succeeded and is still carried out.

In 1902 phototherapy received a new impetus, when Dr. O. Bernhard of St. Moritz began to use with success light treatment in surgical diseases, and a little later Rollier and Sir Henry Gauvain started to treat surgical tuberculosis by the same means, and attracted great attention to phototherapy by their remarkable results.

A further development of phototherapy occurred in 1919, when Huldschinsky showed that rickets could be cured by sunlight and even more rapidly by artificially produced ultra-violet rays, and to-day treatment by ultra-violet light forms a valuable weapon in the armoury of the physician and surgeon.

The history of the development of man's knowledge of light and its uses is intensely interesting, in that it is indeed a history of the whole science and art of man, for there is no science nor art which has not played a part in the development, and no science nor art that the development has not also developed.

The Dog Star was watch-dog of the Nile

Flood. The Pole Star and the astrolabe guided Columbus in his *Santa Maria* to the New World. Herschel's telescope discovering Uranus, and Koch's microscope hunting out the tubercle bacillus, were optical cousins. A photographic film betrayed the tiny *X*-ray and the tinier gamma-ray. Through the hole in Newton's shutter came the ultra-violet ray that cures tubercular bones and rickety ribs and bald heads, and the searchlight, too, that "spots" the Zeppelin. Clerk Maxwell's mathematical equations prophesied the wireless. The same lamp to-day that cures lupus "cures" leather, and the same accurate technique which shows Einstein's bent light cures the bent tibia. Art and Science and all the practical activities of man find common ground in light, which has made them all possible. To trace all such inter-relations would be impossible, but before the close of this brief historical survey we may point out that at every step, and every turn of scientific progress in the domain of light, we see the gleam and the glitter of glass,—telescope, microscope, prism, spectroscope, vacuum tube, quartz lamp,—and may bless the Providence that put in the crust of the earth some 59 per cent. of silica.

CHAPTER II

LIGHT AND RADIATION

> "Have a glimpse of incomprehensibles; and thoughts of things which thoughts but tenderly touch. Lodge immaterials in thy head; ascend into invisibles."
>
> SIR THOMAS BROWNE.

WE saw in the first chapter how step by step, century after century, from Aristotle to Newton, from Newton to Clerk Maxwell and Hertz, man has gradually evolved a many-sided science of light, or, more accurately, a many-sided science of electro-magnetic radiation. Let us try now to give a brief *résumé* of the science of radiation as it stands to-day.

To-day it is held—though recently with some doubts and reservations—that the sensations light and colour are the results of waves of ether of certain definite wave-length impinging on the retina of the human eye, and that the same waves impinging on certain nerves produce also the sensation called heat. It is further held that the immediate antecedent of the sensations is molecular disturbance in the living tissues, and that similar molecular disturbance due to the same waves is objectively evinced by light and heat (*e.g.* a red rose or a red-hot poker); by expansion (*e.g.* in mercury and gases); by chemical changes (*e.g.* in certain silver salts); and by electrical changes (*e.g.* in selenium).

The waves of invisible light have been carefully and accurately measured, and it has been shown that the coloured waves into which a prism or diffraction grating analyses white light vary in length and refractivity according to their colour, that the waves producing the sensation of red are the longest and least refrangible, that the waves producing sensations—violet—are the shortest and most refrangible, and that the waves producing sensations of orange, yellow, green, blue, indigo, grow *seriatim* progressively shorter and more refrangible. The following table shows the measurements of the various waves of visible light referred to various standards.

COLOURS OF THE SPECTRUM

Name of Colour.	Wave-length in millimicrons (millionth of millimetre).	Wave-length in Ångströms (ten-millionth of millimetre).
Extreme Red . .	810	8100
Red	650	6500
Orange . . .	583	5830
Yellow . . .	551	5510
Green . . .	512	5120
Peacock . . .	475	4750
Blue	449	4490
Violet . . .	390	3900

According to these figures, there are about 40,000 red waves to an inch and about 60,000 violet. But though the waves are so small, and require 40,000, 50,000, or 60,000 vibrations to cover in their advance the length of one inch, yet they ripple along the ether at the prodigious rate of 186,000 miles a second. In the time that a good runner runs 100 yards, the little sprinters of the rainbow can girdle the world at the equator more than seven times. An aeroplane goes 120 miles an hour, but a sunbeam can give it a start of 5,000,000 miles in a five million and one mile race, and beat it. Sound can travel more than 600 miles an hour, but even sound compared with light is as a snail to a swift. The rate at which the tiny waves flow and the number of rises and falls they make in the course of their advance are astounding. As runners with short legs must move their legs quickly to attain a rapid pace, so the short waves must vibrate multitudinously to attain their prodigious velocity, and it is easy to calculate that they vibrate at the rate of hundreds of billions every second. Whether the waves are waves of a size 40,000 to the inch or waves of a size 60,000 to the inch, whether they are red, or orange, or yellow, or green, or blue, or indigo, or violet, they all move abreast through the ether of space at exactly the same rate—like soldiers dressed in various-coloured uniforms, yet "dressed" in line. Well dressed and well drilled indeed are the little waves, which, radiated from the sun and other self-shining matter, and reflected from non-radiant matter, pass into the eye and give us sense of shape and sense of colour, or impinging on the nerves of thermal sense give us sense of heat, or impinging on various chemical substances cause perceptible chemical changes in them. Without them we should be blind and the world would hardly be a world to us at all. Yet it must be understood that the waves themselves are invisible and begin to exist for us only when they strike matter, and, having struck matter, are reflected into our eyes. The sunlight, the main source of the visible light-waves, is known to us mainly through waves that, falling on particles of carbon, or calcium, or iron in its atmosphere, ultimately reach our retina. The waves are set up by matter, and on reaching our eyes from their material source are interpreted by our mind partly in terms of matter, but they themselves are simply invisible electro-magnetic vibrations in the ether, and have nothing, unless size, in their intrinsic character to distinguish them from other electro-magnetic radiations longer and shorter than themselves. Yet because most of them affect the eye and the brain-cells through the eye as no other radiations can, they are of paramount importance in the spiritual and intellectual life of man. Through them the grass is green, and the sky is blue, and the rose red; through them we see the faces of friends and all beauty of form and colour; through them we have knowledge of the starry universe; through them we gain entrance into the whole world of books. But they have more than intellectual and æsthetic importance, they are also—as we shall see later—of vital biological importance, for their heat and their chemical accomplishments are necessary both for vegetable and animal life—at least for such animal and vegetable life as the world to-day possesses.

In face of their importance, it is strange to find that visible sun-waves constitute only a very small part of the whole electro-magnetic spectrum. At the time Newton sorted out the visible solar rays by his prism, their waves (varying in length, as we have seen, between fourteen and forty-two millionths of an inch) were the only radiations known, and so the hypothetical medium which radiated was called the "*luminiferous ether*," and it came as a great surprise when Herschel, in 1800, by means of a thermometer, detected in the spectrum invisible waves—

the infra-red—larger than the visible red rays, and when Ritter, in 1801, by means of a silver-salt film, discovered invisible rays smaller than the violet rays. Yet to-day we know octave after octave of radiations larger than the infra-red rays discovered by Herschel, and octave after octave, too, of radiations smaller than the ultra-violet rays discovered by Ritter. We know not only radiations between fourteen and forty-two millionths of an inch in length, but an almost infinite series of radiations ranging between electric waves miles long vibrating only a few times a second, and gamma rays one three-hundred-millionth of a millimetre in length, vibrating 100,000,000,000,000,000,000 times a second.

It is inconvenient to express the smaller waves in centimetres or even millimetres, for we soon come to absurdly small fractions, and it is usual to express the measurements of the smaller waves by reference to smaller standards, such as millimicrons, equalling a millionth of a millimetre, or an Ångström Unit, equalling a ten-millionth of a millimetre. Expressed thus, red light has a wave-length of 810 millimicrons, or 8100 Ångström Units, and violet light a wave-length of 390 $\mu\mu$, or 3900 Ångström Units.

The symbol $\mu\mu$ is usually used for millimicrons and Å.U. or Å. for Ångström Units.

The following table, from Luckiesh's "Ultra-Violet Radiation," gives a compact comparison of the standards of measurement.

Unit.	Symbol.	Millimeters.	Relative Length.
Ångström.	Å. or Å.U.	One ten-millionth.	1
Millimicron.	Mu or $\mu\mu$.	One millionth.	10
Micron.	μ.	One thousandth.	100

Roughly speaking—for the limits are not always clearly defined—we can divide the electro-magnetic waves into classes within certain wave-length limits, each class within its limit having more or less characteristic properties. Starting at visible waves of 8000 Å. wave-length, and going in the direction of the smaller waves, we have :

(1) Waves between the length of 8000 Å. and 3900 Å. These are the waves of visible light which give to the eye and nerves the sensation of light, colour, and heat. They have also chemical activity and the power of heating cooler bodies. Their heating power is greatest at the red end of the spectrum, where they blend with the invisible infra-red rays, and their chemical activity greatest at the violet end, where they blend with the ultra-violet rays. Their importance to man we have already briefly indicated.

(2) Waves between the lengths of 3900 Å. and 2900 Å. These are known as near ultra-violet waves. They are invisible, but have strong chemical action. They also ionise gases and cause certain substances to phosphoresce, and, as we shall see later, they have important biological functions. They reach us at sea-level from the sun.

(3) Waves between the lengths of 2900 Å. These may be called the waves of middle ultra-violet. They do not reach us from ordinary sunlight and must be artificially produced. In most respects they resemble the middle ultra-violet rays, but they are less penetrative and more bactericidal.

(4) Waves between 1900 Å. and 150 Å. Waves of so little penetrative power that they cannot penetrate air.

(5) Waves between 150 Å. and 0·01 Å. These are the Röntgen rays, which penetrate all matter to a greater or less extent, and which are used in *X*-ray photography. They can be reflected and refracted only by means of crystals.

Thus, starting from the big red waves in the direction towards the violet, we can proceed by ever-diminishing waves continuously through some fourteen octaves to the smallest gamma rays. There is a serial continuity the whole way. The continuity, however, was not easily established. It was a simple matter for Ritter to demonstrate the near ultra-violet rays by means of a prism, for the near rays can penetrate glass; but rays shorter than 3300 Å. cannot penetrate glass, and only by means of prisms and lenses of fused quartz can shorter rays be detected. Further, no rays shorter than 2900 Å. reach us from the sun, since shorter rays are obstructed by the ozone in the upper air, so that artificial radiation had to be used to extend the spectrum. With perseverance and ingenuity, nevertheless, the little rays were hunted out. Schumann—in whose honour the far ultra-violet region between 2000 Å. and 1000 Å. is sometimes called the Region of Schumann—discovered that fluorine was more transparent than quartz to ultra-violet light, and succeeded, by means of artificial light, a lens of fluorine, and photographic films almost destitute of gelatine, in photographing, in a vacuum, ultra-violet rays of a wave-length as short as 1200 Å.—less than a third of the size of the smallest visible violet rays. For twenty-five years thereafter no one succeeded in passing that limit. Then Lyman, dispensing with prisms altogether and using a very fine diffraction grating, detected waves as short as 500 Å., and recently Millikan, an American physicist, got down to rays of 100 Å. by using an electric spark at a tension of nearly 100 volts, thus bridging the gap between the shortest ultra-violet rays and the longer Röntgen rays.

If we start from the visible big red waves in the direction towards the infra-red discovered by Herschel, we find similar continuity, through octave after octave, but can make, nevertheless, some divisions.

(6) Invisible waves between 8000 Å. and 5,000,000 Å. are dark heat waves which can be detected by a delicate bolometer. The spectrum of the sunlight which reaches us does not contain waves longer than 600,000 Å. A kettle of boiling water gives out dark heat of wave-length 0·008 $\mu\mu$ = 80,000 Å., and the human body gives off dark rays of about the same wave-length—0·009 $\mu\mu$ or 90,000 Å.

(7) Waves longer than 5,000,000 Å. (0·5 millimeter) are the electric waves of Hertz, short and long. The longest of these are about 10 miles long, but theoretically there is no limit to their length. Altogether we know now some fifty-seven octaves of radiation—twenty-eight octaves of Hertzian waves (and there are certainly others unknown), nine octaves of infra-red waves, five octaves of ultra-violet waves, fourteen octaves of *X* waves, and one octave of visible waves. The solar radiations, however, which reach us

through the filter of the atmosphere contain, besides visible rays, only a few octaves of infra-red and ultra-violet rays (six octaves of infra-red rays, one octave of luminous rays, and half an octave of ultra-violet), and most of the octaves of radiation which we have enumerated we owe to artificial sources—to carbon arcs, to oscillatory discharges, to jerky electrons, etc.

The discovery of the unity of radiation, mathematically foretold by Clerk Maxwell, is one of the most remarkable achievements of science. It is strange to think that waves, varying in quality as much as a gamma ray, a dark heat wave, a yellow light wave, a wireless wave should yet be all exactly the same in essence—simultaneous electric and magnetic oscillations at right angles to each other and advancing at right angles to both—should all be capable of reflection, refraction, and diffraction, and should all go through the ether at exactly the same tremendous speed of 186,000 miles a second. The tiny gamma wave, one three-hundred-millionth of a millimetre in length and oscillating 100,000,000,000,000,000,000 times a second, trots along at the side of the electric wave yards-long and vibrating only a few thousand times a second, and each of them seems able to maintain exactly the same speed and the same wave-length for ever. Light takes one-fourteenth of a second to travel from London to the Antipodes, and the waves emitted by radio aerial take exactly the same time. The accuracy and unchangeability of vibration rate and speed are surely amazing! Yellow waves from sodium glowing in the sun ripple across 93,000,000 miles of space, always at exactly the same rate, and preserving, all the way, exactly the same length of wave, and when they reach the earth they are found to have exactly the same speed and exactly the same length as sodium glowing on a laboratory table, as can be proved by the phenomenon of interference. According to astronomers, some light which reaches us from the far stars has been travelling about 250,000 years, and therefore must have covered some thousands of millions of miles, and yet its waves have not varied from the normal wave-length. No scientific instrument, no chronometer can match such accuracy.

Why should all these waves go at exactly 186,000 miles a second and never vary their stride? We do not know, but evidently there is a Power behind, "in Whom is no variableness neither shadow of turning."

The explanation and interpretation of light and other radiations as waves of energy transmitted through space by a mysterious invisible undulating medium called ether has great pragmatic advantages, for it unifies most of the phenomena of light, such as reflection, polarisation, interference, and ever since the time of Young and Fresnel it has ousted Newton's "emission" or "corpuscular" theory and held its own against criticism. Nevertheless, it will be well to examine it now, and discover upon what foundations it stands, what are its postulates and corollaries, and what the philosophic conclusions it leads to, for it is perhaps the largest and most instructive conception in the whole range of science.

Its radical postulate, as stated by Newton, is open to debate. "That one body," wrote Newton in a well-known passage, "may act upon another at a distance through a vacuum, without a mediation of anything else by and through which their action may be conveyed to another is to me so great an absurdity that I believe no man, who has in philosophic matters a competent faculty of thinking, can ever fall into it."

That is a strong statement, yet it may be disputed. We venture to say that men, who in philosophic matters have a competent faculty of thinking, *do* think—unless they have prior knowledge of the theory of ether—of bodies falling to the ground as through a vacuum, and, indeed, "vacuum" is just the word applied to a tube emptied of air. Nor can it be said that the conveyance of action to another body is always direct through an active medium. I send a telegram to a friend saying "Come!" and the friend comes. Yet though it may be said that my telegram affects my friend by means of the luminiferous ether, his actual coming to me is certainly not directly impelled by the luminiferous waves, and—except for respiratory difficulties—may quite well be conceived, so far as its causality is concerned, as taking place through emptiness. We cannot, therefore, I think, postulate a medium for action at a distance, on the ground that action at a distance without interaction through a medium is impossible and inconceivable. But, on the other hand, most action at a distance—using the word distance in the sense commonly used—is affected by means of a material intermediary. When we pull a fish out of the water we employ a medium—a fishing-rod and line; when we see little cardboard figures dancing on the London pavement we suppose that there is an invisible hair somewhere; when we see a feather floating we know that it is floating upon an unseen gas, and it certainly makes it easier to handle problems of light and other forms of radiation if we assume that it acts through distance by means of an invisible medium. And the assumption is encouraged if we find that the action takes some time to pass through space, that its behaviour in time and space has the periodic properties of a wave, and that many of its phenomena can be explained, and some predicted, on the assumption that it is a wave motion in a medium having certain qualities. Undulating ether, then, is essentially a useful working hypothesis, justifiable, like all hypotheses chiefly on pragmatic grounds, and quite liable to be overthrown, as was Newton's emission theory, by any hypothesis working more consistently and usefully.

CHAPTER III

LIGHT AND RADIATION (*continued*)

WE must assume for radiation not only a medium, but a medium having certain properties: the properties of a medium like water or air would not suffice to explain the waves of light; and here we find ourselves very soon in the transcendental and metaphysical.

Now what kind of a medium must the luminiferous ether be—what properties must it have to fulfil its functions as carrier of light, heat, and electricity? Plainly it must fill all space from the Pleiades to Piccadilly Circus, from the Southern Cross to the Southern Seas. As Clerk Maxwell in an address on "Action at a Distance" puts it: "The vast interplanetary and interstellar regions will no longer be regarded as waste places in the Universe which the Creator has not seen fit to fill with the symbols of the manifold order of His Kingdom. We shall find them to be already full of this wonderful medium, so full that no human power can remove it from the smallest portion of space or produce the slightest flaw in its infinite continuity. It extends unbroken from star to star, and when a molecule of hydrogen vibrates in the Dog Star, the medium receives the impulse of these vibrations, and after carrying them in its immense bosom for several years, delivers them in due course and regular order and full tale into the spectroscope of Mr. Huggens at Tulse Hill."

The ether, then, must be postulated everywhere, around all so-called matter, and within all so-called matter: it must at once surround and permeate. Further, it must be capable of forming either infinitesimally small or colossal waves; it must be capable of vibrating hundreds of millions of millions of millions of times in a second, and of passing on its vibrations, great or small, at a uniform rate of 186,000 miles a second. It must be imponderable and must let the planets pass through it without friction.

What can such a medium be? Certainly neither a fluid, nor a solid, nor a gas, nor radiant matter. Clerk Maxwell supposed it to consist of tiny, rapidly rotating spheres. Mendelief believed it to be an inert gas with an atomic weight a million times less than hydrogen and with a velocity of 2250 kilometres per second. Professor Osborne Reynolds holds that it "is neither more nor less than an arrangement, of indefinite extent, of uniform spherical grains, generally in normal piling so close that the grains cannot change their neighbours, although continually in relative motion with each other, the grains being of changeless shape and size." He requires the " granules " to be infinitesimally small—smaller even than electrons, and subjected to a tremendous pressure of about 10,000 tons per square centimetre. According to his theory, matter is simply areas of diminished density in the ether—a theory which is something like the direct opposite of ordinary ideas of matter and ether. Dr. Larmer, again, thinks that the ether is a rotationally elastic medium, and is pervaded by a " structure of tangled or interlaced vortex filaments which might resist deformation by forming a stable configuration." Such conceptions of ether surely approach the transcendental, metaphysical, and mystical.

But the greatest living authority on ether is Sir Oliver Lodge, who has spent a lifetime in the study of it. What does Sir Oliver Lodge make of it? He finds that it is something possessing amazing density and even more amazing elasticity. It is a million million times denser even than water, its pressure is millions of tons to the square foot, and its elasticity must be expressed by a million, million, million. The intrinsic energy of its constitution is so prodigious that every cubic millimetre of it possesses what, if it were matter, would be a mass of 1000 tons, and energy equivalent to the output of a million-horse-power station for 40,000,000 years. " Hidden away in its constitution is a fundamental and absolute speed, a speed not of locomotion, but of internal circulation. What it is that is thus whirling we do not know: without the whirl we can have no conception of it. The whirl and the fundamental something together make up the Ether. And we have no power of detaching the one from the other, hardly even in thought. . . . It is the seat of prodigious energies—energies beyond anything as yet accessible to man. All we know of energy is but the faint trace or shadow or overflow of its mighty being."

So wonderful, so mighty, so mystic is the medium whose oscillations at 186,000 miles a second mean to us light, and heat, and electricity! Wonderful as light and heat and electricity may be, they surely seem more wonderful still when we consider the mysterious invisible medium whose vibrations they are. In seeking for the cause of light, we have found ourselves compelled to postulate a supernatural or at least mysterious medium possessing almost infinite energy, and are reminded of the saying: "If there were not a God it would be necessary to invent one."

But, even yet, we are only half-way through our inquiry, for we have yet to determine what it is that produces the amazing electromagnetic oscillations in the amazing medium. What is the source of these energies—light, heat, electricity—which ripple through the ether? Plainly it is due to something occurring in the glowing or heated or charged matter from which the various radiations radiate, and in order to answer the question we must know something of the constitution and behaviour of the atoms of which matter is composed.

The old atomists looked upon atoms as inert and quite unbreakable bricks. Democritus taught that they were "indestructible and invisible." Lucretius considered them "solid and eternal," incapable of being divided or changed. Newton wrote: "It seems probable to me that God in the beginning formed matter in solid, massy, hard, impenetrable particles, of such size and figures, and with such other properties, and in such proportions to space, as most conduced to the end for which He formed them, and that these primitive particles, being solids, are incomparably harder than any porous bodies compounded of them, even so very hard as never to wear or to break in pieces, no ordinary power being able to divide what God Himself made in the first creation." Sir John Herschell declared that the atoms bore "the stamp of the manufactured article." Even the great Clerk Maxwell had no doubts, and stated at Bradford in 1873: "Natural causes, as we know, are at work which tend to modify, if they do not at length destroy all the arrangements and dimensions of the earth and the whole solar system. But though in the course of ages catastrophes have occurred and may yet occur in the heavens, though ancient systems may be dissolved and new systems evolved out of their ruins, the molecules [Maxwell uses the term molecule in the sense of atom] out of which the systems are built—the foundation stones of the material universe—remain unbroken and unworn."

That was the view of atoms till 1896, when the discovery of Henri Becquerel, the famous French chemist, that salts of uranium emitted invisible particles, led eventually to the further astounding discovery that some atoms at least did break down, and that all atoms consist of a central core or nucleus, with other particles or satellites flying round it—to the discovery, in fact, that every atom is a miniature solar system. The core was found to be positively charged and the satellites flying round it were found to be particles of negative electricity, of the same nature as the kathode rays in a vacuum tube. The term " proton " is sometimes applied to the simple nucleus of hydrogen (for of it the larger compound nuclei are built), and the satellites are usually termed " electrons."

It was in two senses a revolutionary discovery, and the greatest minds in science set themselves to extend its scope, till to-day a great deal is known of the intimate structures of the atom. Here is not the place to discuss the structure of the atom in detail, and we shall mention only the facts necessary to explain the modern conception of light waves in their relation to matter.

The proton is of the same size as an electron, but 1850 times heavier. It is the proton, accordingly, that determines the weight or " atomic weight " of the element. The electrons, on the other hand, have little or nothing to do with the weight, but revolve in their orbits at a rate of at least 1400 miles a second, and determine the chemical character of the element. When atoms are serially arranged according to their atomic weight, beginning with the lightest hydrogen and ending with the heaviest uranium, it is found that the number in the series—the " atomic number "—gives the number of electrons revolving round the nucleus. Thus hydrogen has one satellite; helium two; lithium three; oxygen, the eighth in the series, eight; and uranium, the ninety-second, ninety-two. This was shown by the young scientist Moseley, killed by a Turkish bullet at Gallipoli. The satellites in the heavier elements fly round the compound nucleus in circles or ellipses of different diameters—sometimes as many as six—and besides the satellites, there are other electrons incorporated in some obscure way in the nucleus.

This conception of the atom certainly makes matter more mysterious and wonderful. Instead of hard unbreakable bricks, we find little solar systems made of negative and positive electric charges. Round and round their orbits flash the little electrons 7,000,000,000 times in the millionth of a second! It is certainly amazing and sensational, but it does not seem to offer much explanation of radiation. As Sir Oliver Lodge remarks, " A central nucleus with electrons revolving round it appears as a simple quiescent regular system, from which radiation is no more to be expected than from the earth and moon . . . to excite radiation some kind of sudden motion, something analogous to a blow or a collision or a fall, is necessary—something like a projectile striking a target, some sudden or violent disturbance.

Otherwise things will go on placidly like the steady motion of the planets or like well-oiled machinery."

Nevertheless, all radiation is due to this planetary construction of atoms; it is entirely an electronic phenomenon. So long as an electron is moving regularly and smoothly in an orbit or on a linear path, it produces no undulations in the ether, it simply proceeds on its course surrounded by magnetic rings and an electric field, and the magnetic rings give it mass and inertia proportionate to its speed, and possessing mass and inertia it may be regarded as matter, or energy. Its motion confers on it the properties of ordinary mass. When, however, its motion is suddenly stopped or retarded, it surrenders all or part of the mass or energy which was a function of its speed, associated with its electric and magnetic fields, and these fields radiate out into space as an electric-magnetic wave representing the mass or energy surrendered. Briefly, the mass or energy of the electron created by its motion is transformed into the energy of an electro-magnetic wave or radiation undulating through the ether—the radiant energy corresponding to the amount of mass or energy lost in the electron by alteration or stoppage of its movements. Accordingly, if the electron is going at great speed and so has acquired great mass and energy, the electro-magnetic wave radiated when the electron is checked may have great vibratory energy. Thus, when the electron flying across a vacuum at the rate of a few thousand miles a second is suddenly checked by the glass of the tube, its lost mass and energy are changed from the mass and energy of linear motion into the radiant energy of "soft" *X*-rays, while if the electron is flashing along at the rate of 1,000,000 miles a second, the energy and mass of movement lost by its stoppage will produce the more energetic, more penetrating "hard" *X*-rays. The light of an electric lamp, again, is due to the jostlings and collisions of the electric fields of the electrons as they rush along. The light of a glowing solid substance is simply the sum total of the result of the collisions of a disorderly mob of electrons supplied with extra and capricious energy by waves of ether. But in every case the radiation consists of magnetic rings which surround flying electrons and part from them in the form of etherial waves when their motion is stopped or retarded. "Electric charges," writes Sir Oliver Lodge, "clashing together excite radiation. This is probably true even in the comparatively gentle chemical process of combustion and flame."

The magnetic ring, whose emission into the ether makes the electro-magnetic radiation, is in itself a great mystery. Even as a magnetic loop it must be energy in some form. But in what form? Sir Joseph Larmor believes that the rings are rings of ether spinning like fly-wheels at a tremendous rate, and that if the ring be stopped or checked, it expands and thereby generates the waves in the ether which we call ether *X*-rays or light or Hertzian rays, as the case may be.

All this is difficult to explain, and difficult to understand, and difficult to realise and believe, but the facts are wonderful and full of mystic meanings. Light is due to the sudden expansion, translation, and transformation into ether waves of certain rings formed in the ether by the motion of the little particles of negative electricity, when the motion ceases or suddenly slows down.

If a man could sprinkle a few particles of negative electricity on his garments, and then, going at sufficient speed, suddenly stop, he would be suddenly clothed in garments of light. That is all that radiation of all kinds is—the energy or mass surrounding a moving particle of negative electricity transformed by the arrest of the motion of the particle from magnetic-ring-energy into ether-wave-energy; and all these millions and millions of particles of negative electricity, revolving like the satellites round the nuclei of atoms, have merely to stop or to jerk to produce radiation. If all the planets in the miniature solar system of the atoms of the world could be suddenly stopped, the ether would become a blazing furnace, or at least a veritable inferno of *X*-rays and gamma rays.

The fact that radiation is a wave-emission of mass or energy from an arrested or retarded, and thus partially dematerialised electron has recently been clearly and beautifully demonstrated by an analysis of the vibrations of atoms.

The radiation of a glowing solid body, as we have mentioned, is the result of the promiscuous jolting and jostling of the electrons revolving in its constituent molecules. The more energy in the form of heat waves or ether radiation we put into the solid, the quicker and more energetic become the vibrations it emits. A little jostling and jolting causes dark heat radiations, a little more causes red waves, a little more green, till finally we get the very rapid vibrations of the violet, ultra-violet, and *X*-rays, and obtain a long, continuous serial spectrum. But the spectrum of a glowing atom is very different from the spectrum of a glowing solid : it gives not a continuous spectrum, but a *line* spectrum —a spectrum showing separate bright lines, each with a definite vibratory rate or energy. The rationale of these lines was difficult to discover. Even the simplest of all the atoms—the atom of hydrogen, consisting of its simple nucleus, the proton, and one single electron revolving round it—presents great difficulties. Ångström discovered in 1862 that the dark lines in the invisible section of the solar spectrum labelled " C " " F " " G " by Frauenhofer were hydrogen lines, and Lyman afterwards discovered hydrogen lines in the ultra-violet, and Paschen hydrogen lines in the infra-red. The lines had a certain regularity of disposition, becoming closer together with increasing vibratory frequency, but it seemed impossible to bring them into causal relationship with the one solitary electron, and someone some years ago asserted that to try to make a model of an atom by studying its spectrum was like trying to make a model of a grand piano by listening to the noise it makes when thrown downstairs. Nevertheless, a few years ago, the genius of a young Dane, Niels Bohr of Copenhagen, solved the problem and gave us new insight into the marvellous world of the invisible. The brilliant idea came to him that the various lines with their various frequencies and energy contents could be accounted for by supposing that the electron could revolve—and did at various times revolve—in certain definite alternative orbits having radii varying as the squares of consecutive whole numbers—2, 4, 9, 16, 25, 36, etc. Granted that the electrons leapt instantaneously from one orbit to the other, the different vibratory lines of the spectrum of hydrogen and other atoms could be precisely and beautifully explained. The idea that an atom could move in various orbits and yet only in certain definite orbits was revolutionary and audacious, for, according to the ordinary laws of physics, the change of orbit would be gradual and continuous. But the theory of leaps was supported by Planck's * quantum theory, and explained the discontinuity of the spectrum with such beautiful precision that it met with acceptance, and it is now universally believed that the lines in the spectrum which distinguish various atoms are due to certain definite leaps of electrons, with energy consequences manifested in radiation of various frequencies, even though in the case of the more complicated atoms it may not be possible to analyse mathematically the behaviour of the electrons.

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* In 1900 Professor Max Planck of Berlin showed that radiant energy increases or decreases in certain definite though infinitesimally small quantities or "quanta," seemingly indivisible units, and suggested that energy, like matter, is particulate.

Revolution in the outer orbits requires more potential energy than revolution in the inner, and by supplying the electron with extra energy by means of radiation, it can be lifted from an orbit with a radius of 4 to orbits with radii of 9, 16, 25, etc., but never to an intermediate position; and less energy than the quantum required to lift it from an inner to an outer orbit will not move it at all, and hence we have in the behaviour of the atomic electron an illustration of the quantum theory. More energy is required to lift the electrons from their inner orbits than from the outer orbits, and in the outermost orbits it requires little addition of energy to separate the electron from the atom altogether—a separation which ionises the atom and renders it electrically positive.

Radiation takes place from an atom when it drops from an outer orbit to an inner one, for in the act of dropping it acquires double the energy it requires for its new orbit, and this surplus energy it emits in the shape of radiation. Further, the electron, even as it requires less energy to lift it between outer orbits, acquires and emits less energy in falling between them, than in falling between inner orbits, and, since frequency of radiation is proportional to energy emitted, the lines of vibration emitted by a fallen electron increase in frequency, as in energy, according to the inwardness of the position of the new orbit. The radiation is thus emitted in a discontinuous manner—every drop producing a squirt of radiation forming a bright spectrum line with a vibration period depending on the height and depth of the fall. It must be noticed, too, that the electron may fall more than one step: it may fall from orbit 4 into orbit 2, or from orbit 5 into orbit 3, and so on, and as a result of the greater fall it will emit radiancy of greater frequency.

These facts are illustrated by the spectrum of hydrogen. Assuming the orbits demanded by Bohr, an electron dropping from orbit 3 into orbit 2 gives the hydrogen line C in the red; while an electron dropping from orbit 4 to orbit 2 gives the line F, of greater frequency, in the green, and an electron dropping a still longer drop from orbit 5 to orbit 2 gives the line G, of still greater frequency, in the blue. Electrons again dropping away down into orbit 1 will give lines of great frequency in the ultra-violet section of the spectrum. The most important thing is the orbit into which the electron drops, and the next most important thing is the orbit from which it falls; and in every case the vibratory results are in accordance with the results which would be produced by electrons dropping between the various orbits postulated by Bohr—the Newton of the atom.

The rapidity of the electron of any atom in the innermost of its orbits varies directly as the square of its atomic number, and therefore is much greater in the elements of high atomic number. Accordingly, the lines produced when an electron of an atom of high atomic number drops to its innermost orbit will have the high frequency of an *X*-ray wave.

The analysis of the atom and the interpretation of its radiations as drops in the orbits of its electrons is one of the most brilliant achievements ever accomplished by the human intellect. Even if the electrons were magnified a million times, we could not see them : they revolve in orbits with a radius of something like a hundred millionth of a centimetre, making about 7,000,000,000 revolutions in a millionth of a second, and covering about 1400 miles every second, and yet man has been able to discover that they jump about between definite orbits, and that each drop they make they give off radiations whose frequency and energy can be counted and predicted : he knows exactly what leaps are made by the electrons of the atoms in the rainbow in order to radiate their various colours, and has evolved an atomic astronomy as definite and indubitable as the astronomy of the starry heavens.

But the most extraordinary thing, perhaps, about the modern scientific conception of radiation is its implication that matter is energy and energy matter—that light is the stuff that matter is made of, and matter the stuff that light is made of.

The wonderful electron as it moves through the ether and surrounds itself with magnetic loops increases in mass or inertia as its speed increases, and loses mass or inertia as its speed decreases, and there can be no doubt at all that the increase and decrease in mass or inertia depend simply on the magnetic loops, which, as we have seen, are rings (probably *spinning* rings) of ether. But mass and inertia are the distinctive qualities of matter and also the distinctive qualities of energy, and therefore it would seem that mass, inertia, matter, and energy are all interconvertible qualities of the ether. The electron increases in inertia, in mass, in energy, in *matter* at the expense of the luminiferous ether : it gives up its adventitious inertia, mass, energy, to matter, in the form of etherial waves. In a sense, therefore, radiation is the ghost of matter and matter the embodiment of light, and all phenomena—matter, light, energy, are just various states of the one mysterious medium ether, or various forms of one fundamental energy.

Formerly it was believed that matter was indestructible and uncreatable, that it changed form, and that its vibrations produced light, but now it is believed that matter can be made by the moving electron (or at least made so far as mass is concerned) simply by acceleration of its speed, and that the matter so made can be changed into ether waves again by retardation of the electrons' movement.

It is probable, indeed, that the fiercest and most energetic radiation we know in the universe—the radiation of the great hot suns—is the product of a particular case of the magical metamorphosis of matter into radiation. Scientific men believe to-day that the nuclei of all other elements are built up out of the nuclei of hydrogen. But the weight or mass of an atom of helium, which almost certainly consists of four nuclei of hydrogen, is less than the weight or mass of four nuclei of hydrogen by 0·032. In the making of an atom of helium, accordingly, the nuclei of hydrogen have lost part of their weight or mass or inertia, and this must at some time have been converted into the energy of radiation. The amount of radiant energy obtained by the conversion of mass into radiation is measured by multiplying the loss of mass by half the square of the velocity of light, and this obviously represents an enormous amount systems is very small, and is much the same as the proportion between the heavenly bodies and the space in which they move. All the electrons and protons—all the materialised ether, that is to say—in the body of a man, would not fill a salt-spoon. His body is just a few specks of matter in a mighty ocean of ether, and though the atoms seem essential to his corporeal being, yet all his conscious life depends on the mediation of the ether. It is just as correct to say that a man is made of formless ether as of formed atoms.

We have talked of *collisions* of electrons, but that was just a *façon de parler*, for electrons never collide; the collision takes place merely between their fields of force in the ether. We imagine that our material bodies touch other material bodies, but the electrons and protons never touch, there are always buffers of ether between. We imagine that the rays of light fall upon our retinas, but the etherial rays of light never reach the differentiated particles of ether which we call matter. In fact the atoms seem nothing more than the pegs a miner uses to peg out a gold claim. It is the ether that counts. It is ether that holds the atoms together; it is waves of ether acting through waves of ether which produce sensations; it is waves of ether which impel the electrons in their orbits.

In one sense we are bounded by our skins, but in another sense we are bounded only by the ether, and are just as much in contact with the farthest star as with our hats and collars. We are not here or there, we are everywhere; our conscious personality is in no way limited by our skins; our eyes, as some ancient philosophers taught, do reach out by ether arms to the stars. "So that," in the words of Plotinus, "everywhere there is all, and each all, and infinite the Glory; . . . and there is no distinguishing between the Being and the Place." So that, too, in the words of the Dnyaneshvari, "without moving is the travelling on this road. To whatsoever place one would travel, that place one's own self becomes." Nor is it impossible that death may bring a fuller consciousness of personal continuity with the æther of space, and give some subjective significance to its prodigious intrinsic energy, which is outside our present bodily experience.

It may be said that all this analysis of light and matter is merely destructive—as destructive as to pull a rose to pieces in order to demonstrate its structure, and that our minds and senses are made to enjoy light and colour and all the beauty and divine meaning of material things as synthetic phenomena, not as discrete vibrations. It may be asked, What is the advantage of all this abstract punctilious analysis? We may answer that it has been of great practical utility. These analyses have led to spectacles, and the modern telescope, and microscope, and spectroscope, and ophthalmoscope, and to wireless telegraphy, and wireless telephony, and actinotherapy, and radiotherapy, and there is little doubt that they will yet lead to the utilisation of the almost infinite power which they have discovered in the atom and in the ether. But, further, they have opened up new prospects to philosophy and religion, and have brought us almost into the presence of the Creator of the universe, and by this alone would wisdom be justified of her children.

Let us turn for a moment to the philosophy and religion of radiation. Matter, which seemed so heavy and gross, has been shown to be energy congene with the energy of light and with the hidden energy of the ether; but when we analyse matter into energy or force, we necessarily dematerialise it and make it equivalent simply to *cause*. When we say, " Matter is a form of energy or force," we can mean nothing more than that it is the creation (in the percipient mind) of a *vis motus*, a *vis a tergo*, a *cause*. In reducing matter to etherial force we have stripped it of every-thing except the immaterial activating cause which the intellect demands. No intellectual instinct is stronger than the instinct to attribute cause, and matter in its last analysis becomes simply the cause of the forces which act upon us and give rise to the sensations of light, heat, solidity, etc.—it becomes simply, as Schopenhauer asserted, "*pure causality*," "*the cause of the actual.*" But, further, the moment we identify matter with causal energy or causal force, we identify it with conscious will. "In that peculiar mental sensation," says Sir John Herschell, "clear to the apprehension of everyone who has ever performed a voluntary act, which is present at the instant when the determination to do a thing is carried out into the act of doing it (a sensation which, in default of a term more specifically appropriate to it, we may call effort), we have consciousness of immediate and personal causation which cannot be disputed or ignored; and when we see the same kind of act performed by another, we never hesitate in assuming for him that consciousness which we recognise in ourselves . . . in every such change (change occurring in matter) we recognise the action of Force. And in the only case in which we are admitted into any personal knowledge of the origin of force, we find it connected (possibly by intermediate links untraceable by our faculties, but yet indisputably *connected*) with volition, and by inevitable consequences with *motive*, with intellect, and with all those attributes of mind in which personality consists."

Schopenhauer holds similar views, but lays more stress on volition. "I consider," he says, "every natural force as a Will. Will is essentially identical with all the forces which act in Nature, the various manifestations of which belong to the species of which Will is the genus. It is the direct consciousness which we have of Will which alone conducts us to the indirect knowledge of the other forces." And Fourier writes: "The ether means perhaps the all-embracing, all-connecting soul of the universe."

When we talk of a blind unconscious force, we are guilty of a contradiction in terms, for force necessarily connotes action. We cannot empty the term and the idea of this physical significance, for both term and idea are derived from our own conscious action. The moment we identify matter with force or energy, we identify it with the action of conscious Will. Causal force is the conscious action of the Will of God. Very wise is Leibnitz's saying, "Neque male docetur conservationem divinem esse continuatam creationem ut radiis continue a sole prodit." All existence is action, every molecule is a maelstrom, and in the *vis motus* we must recognise the conscious Will in Whom we live and more and have our being.

The scientific analysis of light and of radiation, in divesting them of sensuous attributes has given them spiritual value. The difference between ultra-violet and red and blue is reduced to little more than a numerical difference, and little more than an abstract numerical difference, for certainly waves one three-hundred-millionth of a millimetre in length, vibrating 100,000,000,000,000,000,000 times a second, and an electron going round its tiny orbit 7000 times in a millionth of a second and leaping from orbit to orbit, have *qua* vibrations, *qua* electrons no significance for the senses and very little meaning for the imagination. Pythagoras found in number the source of all things and the science of light reduces the universe to little more than abstract numbers, but still behind number as cause is force, and out of number as results are the wondrous contents of man's consciousness, and we are encouraged to believe that vibrations, as means to such an end, must have behind them a spiritual and divine driving power. The visible has shown us the invisible, the ponderable the imponderable, the material the spiritual : the ether has become—in some sense at least, poetic and religious if not strictly scientific—" the all-embracing, all-connecting soul of the universe," or, in Sir Oliver Lodge's words, " the vehicle of soul, the habitation of spirit . . . the living garment of God."

CHAPTER IV

THE SUN. ASTRONOMICAL

The Physics and Metaphysics of the Sun.

> "This world was once a fluid haze of light,
> Till toward the centre set the starry tides
> And eddied into suns, that, wheeling, cast
> The planets."

From earliest times, the sun and the stars have fired the imagination and curiosity of thinking men, and astronomy may be considered the doyen of all the sciences. Even before the Christian era, Hipparchus discovered the length of the year, the obliquity of the elliptic, the distance of the sun, and the precession of the equinoxes; and many of the greatest minds of succeeding centuries—Ptolemy, Copernicus, Tycho Brahe, Kepler, Laplace, Newton—were all wooers of Urania. But astronomy did not long remain self-contained; even Hipparchus required the assistance of geometry and trigonometry; and century after century it drew into its orbit more and more of its younger sister sciences. Every advance it made enlarged the whole intellectual horizon of man, and every advance made by other sciences was quickly enlisted in its service. Newton's prism, Lippershay's telescope, Leeuwenhoek's microscope worked together; J. J. Thomson in his Cavendish laboratory carried on the work of Galileo in his turret, and to-day we cannot understand the sun without consulting the chemist, the electrician, the physicist; we cannot understand the atom without understanding the sun, nor the sun without understanding the atom.

The subject of the sun and its system is indeed become so huge that here we can attempt only a general survey.

There are many theories of the birth of the solar system, but on the whole it seems most probable that the sun and all its planets were formed by the accretion of nuclei in a spiral nebula formed by the tidal disruption of a larger dead sun; and to-day the sun and its satellites form a self-contained system in space. With a mean diameter of 865,000 miles, it is huge compared with its satellites—a thousand times as large as the largest planet, Jupiter, and a million times as large as the earth. Its surface temperature is over 6000° C. Yet among the million stars of space there are others far larger and far hotter. Betelgeuse has a diameter 300 times as great, Alpha Hercules a diameter 900 times as great, and Rigal gives 10,000 times as much light. But the sun is at least large enough to hold the planets in their orbits and hot enough to maintain life upon earth. Spectroscopy tells us that it is composed of the same elements as the earth, but even at the surface temperature of 6000° C. they must all be in a gaseous condition, and so, though the sun has a million times the bulk of the earth, it has only 300,000 times the earth's mass. According to Eddington, the temperature at the interior of the sun reaches 18,000,000° C., and the heavy gases there must be under prodigious pressure—a pressure of many thousands of atmospheres. Against this tremendous pressure of gases work the expansive energy of the gases in the interior and the outward pressure of the light, so that the whole mass of the sun is under tremendous tension.

This mighty orb of flaming gases spinning on its axis rushes through space towards the constellation of Hercules at a rate of about 12 miles a second, and carries with it the earth and other planets revolving round it.

The earth revolves round the sun at a mean distance of about 90,000,000 miles, and the radiations from the blazing gases travelling at 186,000 miles a second reach the earth in eight minutes. Ninety-three million miles seems a great distance; but the light from Rigel requires 400 years to cross space, and there are far-off suns whose light takes thousands of years to reach us.

The amount of heat radiation emitted yearly by the sun is prodigious. Dr. C. G. Abbot calculates that it is equal to the amount of heat furnished by 200,000,000,000,000,000,000,000 tons of anthracite coal, and would suffice to melt 40,000,000,000,000,000,000,000,000 tons of ice.

Such rows of figures, however, convey very little to the mind, and we can perhaps form a better idea of the heat of the sun from Sir Robert Ball's picturesque comparisons. "Think first," he says, " of a perfect modern furnace, in which even steel itself, having first attained a dazzling brilliance, can be further melted into a liquid that will run like water. Let us imagine the temperature of that liquid to be multiplied sevenfold, and then we shall obtain some conception of the heat which would be found in that wonderful celestial furnace, the great sun in the heavens." Again, " Every portion of that stupendous desert of flame is pouring forth torrents of heat. It has indeed been estimated that the heat which issues from an area of two square feet on the sun would more than suffice, if it could be all utilised, to drive the engines of the largest Atlantic liner between Liverpool and New York." Yet again, "We are giving deliberate expression to a scientific fact when we say that a conflagration which destroyed every particle of coal contained in this earth would not generate as much heat as the sun lavishes in the tenth part of every single second." And yet again, "The radiation of heat from a single square foot of the solar surface in the course of a year must, therefore, be equivalent to the heat generated in the combustion of 11,000 tons of the best coal. If we estimate the annual coal production of Great Britain at 25,000,000 tons, we find that the total heat which this coal can produce is not greater than the annual emission from a square of the sun's surface of which each side is fifty yards. All the coal exported from England in a year does not give us as much heat as the sun radiates in the same time from every patch on its surface which is as big as a croquet ground."

These impressive and imaginative pictures give us at least some idea of the tremendous heating power of the mighty furnace of the sun.

Now the sun has been shining brightly and burning fiercely for 100,000,000, perhaps 1,000,000,000 years, and it may be asked, "How does and how did it generate its heat, and how much longer can it burn and shine?" That is one of the most fascinating problems of astro-physics. Huge though the sun be, its available fuel is not inexhaustible. A globe of molten iron the size of the sun, radiating away heat at the present rate of the sun's radiation, would cool down to freezing point in less than fifty years. If the sun consisted of hydrogen and oxygen in the proportions in which they are contained in water, it would form the most fiercely burning chemical combination known; yet even if the sun were composed of these gases in these proportions, it could not keep up its present rate of radiation for more than 3000 years. Indeed, calculations soon showed that no process of chemical combination or combustion could maintain the heat of the sun for any length of time, and the great physicist Helmholtz suggested that a good deal of its heat could be accounted for by the shrinkage of its mass. Every body as it contracts gives off heat, but further, as it contracts, the heat still remaining is contained in less mass than before, and may be as great or greater in proportion to its mass than before, and therefore maintain or even raise the temperature of the contracted body. And so the sun, in contracting, might retain or even increase its temperature in spite of loss of heat by radiation, and Helmholtz estimated that a contraction of 16 inches a day in the sun's diameter would suffice to retain the sun's temperature. At that rate the sun would lose only about 5000 miles of its 885,000-mile diameter in 50,000 years. Even so we cannot give the sun a span of life much longer than 100,000,000 years.

The discovery, however, of the enormous energy given forth by radio-active elements suggested another source of energy to the sun which permits us to increase its past and future almost indefinitely; while the relationship between loss of mass and production of energy described in the last chapter adds immensely to its longevity.

In that chapter we pointed out that the nucleus of helium consists of four hydrogen nuclei which, in process of amalgamation, have lost a small fraction of their mass. Now under the enormous pressure in the centre of the sun it is probable that this welding of hydrogen nuclei into helium, with consequent loss of mass and production of energy, is taking place; and it is possible, too, that heavier atoms are also forged in the solar crucible and that their formation is also accompanied by loss of mass and emission of energy. It is even possible that, apart from such synthesis, the matter of some of the atoms exposed to the terrific heat of the sun is changed into radiation. Plainly at a temperature of 18,000,000° C. and a pressure of thousands of atmospheres, *anything* may happen.

If the heat of the sun represent solar mass transmuted into radiant etherial energy, the total loss of solar mass required to retain the sun's heat at its present level will be 4,000,000 tons every second. Four million tons every second—over a hundred billion tons a year—seems a large and serious loss, but it means very little in proportion to the mass of the sun, and is much less than the twenty thousand billion billion tons that, as we have seen, would be required to produce the heat by ordinary combustion. In this connection, Sir Oliver Lodge makes the following general calculation. "The amount of matter even in the earth is 6000 trillion tons, that is 6000 million million million tons: the sun has three hundred thousand times as much as that; and there is no difficulty in supposing that it has been losing at much the same rate as now for ten thousand million years. Less than one-tenth of its substance would have gone away in that time." The greatest part of the radiation of the sun, then, probably comes from a synthesis of helium and other atoms associated with transmutation of part of the passive mass energy of the compounded constituents into the active wave energy of ether radiation, another part probably comes from the disruption of radioactive elements, another part from oxidation (like the oxidation of coal), and a very considerable part from the ordinary emission of radiation by the falling of electrons in excited atoms, and yet another part from gravitational shrinking.

The whole aetiology of sunlight as seen by the eye of science makes a great appeal to the imagination. Ninety-three million miles away is this mighty globe of light and heat, 300,000 miles in diameter, large enough in volume to hold a million earths, yet its titanic energy is merely a multiplication and summation of the infinitesimal quanta of energy emitted by its individual atoms. Every atom there is more perfectly timed than a chronometer and as perfectly finished as a thistle-seed. Every electron there runs in its appointed orbits, as faithfully as a star in its circuit, and each lawful leap from orbit to orbit emits or absorbs its exact quanta of vibrational energy. The electrons leap in the atoms of the sun's hydrogen, and the ether carries tiny waves of energy to the earth, and lo, carbohydrates are produced in a prehistoric tree, which, thousands of years later, become burning coal in the furnace of a *Mauretania!* At the core of the sun, that mysterious etherial energy called gravity forces hydrogen nuclei together into helium atoms, with loss of some of their substance, and 93,000,000 miles away the wave-energy thus generated comes to us as the colours of the rainbow. In the sun a few electrons drop in their orbits; on the earth a sunbeam drops upon a butterfly. In the sun destruction of matter; at earth delivery of energy and creation of colour! Enormous though the sun be, it is potent simply by the added potencies of the invisibly small atoms composing it; bright though the sun be, the colours it sends us are due to the punctilious vibrational accuracy of the electrons composing it, and all the energy which reaches us from the electrons is translated and transmitted by the mysterious medium ether. Our planetary orbit, our interstellar position in space, almost all the heat and the light we enjoy, the beauty of colour, the energy that animates living things, are due to vibrations in ether caused by the loss of mass in one way or another of infinitely and invisibly small particles of electricity—the same particles that, jostling, and jerking, and jolting, and jumbling in the filament of an electric lamp produce the radiations of electric light. All the energy in the world is produced by particles of electricity infinitesimally small, and all the energy in the world is produced as multiples of a definite infinitesimal quantum.

When we consider that our sun is only one of some thirty or forty billions of suns, some a thousand times larger, that there are some stars 14,000,000,000,000,000 miles away, that all of them are surrounded by ether, and that all of them send wave energy through the ether, we get some notion of the infinite total energy of radiation which eternally undulates through space; and yet the atoms themselves and the resolution of electronic mass in radiation are merely tiny visible samples of the infinite intrinsic invisible energy of the ether.

Why is it that these little islands of the ether—the suns alive and dead of space—have come forth out of the invisible in the shape of matter? What force differentiated the atom and filled it with that special form of orbital energy whose fluctuations, known through the mediation of waves, mean for us sensible matter, hard or soft, or red or green, as the case may be? A great part of the total energy of our special sun may have resulted from the tidal pull of a passing sun on a cold dead orb; but even a cold dead orb, like a corpse, is full of orbital energy. Why did only little islets of ether, millions of miles apart, acquire these extraordinary atomic planetary motions which mean to us matter and radiant energy? Why did only insignificant fractions of the whole infinite energy of the ether become nuclei of whirling electrons? Why did not the whole ether, why *does* not the whole ether, dance into atoms and suns? Is such transformation of the intrinsic invisible squirm of the ether into miniature and into massive solar systems taking place to-day? Why is all the vast intrinsic energy of the ether meaningless to us till it assume the persistent form of atoms known to us through transitory mediation of radiations? Is it not possible that after death the same consciousness that now has perceptions through radiations of the ether, and so hears and sees—is it not possible that after death it may have some perception through the *intrinsic* motion of the ether?

These are great questions—the greatest questions in the world—and no man is really educated, or has really faced the facts and mysteries of life and death, who has not put them to himself. Even though they be unanswerable, they at least suggest the Power of the Will behind all things, and the great potentialities of conscious life which may one day become as actual for us as are light, and sound, and form to-day. Our senses cannot get behind the ether, cannot get even beyond the ether to the electrons and protons which we believe to be moving it, but our mind can at least find in the infinite power manifestations of some greater, mysterious, invisible, divine Reality. Power, as well as Beauty, can awaken in man a Sense of the Infinite.

Leaving these great issues—which it is not possible even in science entirely to evade—let us look at some larger telescopic physical features of the sun with special reference to its emission of radiation.

When Galileo examined the sun through his telescope, it was not long before he noticed the spots on it, and these spots have since been the object of much investigation and have helped us to determine the constitution of the great luminary. The spots have a central dark area known as the "umbra," and a lighter-coloured peripheral collar known as the "penumbra," and they represent gaseous cyclones or whirlpools in the outer gaseous strata of the sun. Often they are large enough to engulf the earth, and some have been measured 3000 miles long and are huge enough to engulf more than a hundred of the smaller planets. In these great whirlpools the whirling gases ascend, and as they ascend, they expand and cool, and hence the spots look darker than the rest of the surface of the sun, though in comparison with ordinary white objects they are of a dazzling whiteness.

The detection in the umbra of the spectra of magnesium hydride, and calcium hydride, and titanium oxide—compounds which decompose at 3500° C.—prove that the umbra must have a temperature much below the temperature of 6000° C. which is found in the photosphere.

There can be no doubt at all that the sunspots are the sites of tremendous solar tornadoes which burst through the glowing clouds of carbon and calcium and hydrogen which surround the sun. Probably an internal eruption drives a column of hot gases upwards towards the surface of the photosphere, and the vortical or spiral motion is due to the circumstance that the gases ascend on a rotating globe which, like all rotating globes, has different surface velocities at different latitudes. Indeed, the spiral movements of terrestrial and solar tornadoes are due to exactly the same cause, and both in the earth and the sun they whirl in different directions in the North and South Hemispheres.

The sunspots show a cyclic variation, a period of about 11·1 years elapsing between maximum and minimum activity, and when they are very active there may be an increase of as much as 3 per cent. in solar radiation. On the other hand, sunspot activity is usually associated with cloudy and rainy weather over much of the earth's surface, a fact remarkably recorded in the seasonal woody rings of old trees, which show increased width of woody growth each eleven years, at times corresponding with sunspot maxima. The whirl of the electrons in a sunspot creates a magnetic field which, during sunspot activity, causes magnetic storms on earth, sometimes, indeed, serious enough to interrupt telegraphic services; and the aurora, as we shall see later, has a close relation to this aspect of sunspot activity. The sunspots, of course, move round with the rotating sun, and when a specially large group passes the centre of the sun, there are particularly brilliant aurora and particularly strong magnetic storms, as on March 22, 1920.

The Aurora Polaris, or, as it is called when it occurs in the Northern Hemisphere, the "Aurora Borealis," is such a beautiful and instructive light phenomenon that we must devote a few paragraphs to it.

Why should tornadoes in the sun cause a shimmering iridescent glow on the dark side of the Polar regions of the earth?

The answer to this question was really found by Professor Hale when he discovered that the spectra of certain of the sunspot gases showed a widening and duplication of their lines (the Zeeman effect demonstrated by Zeeman in the case of glowing gases exposed to a strong magnetic field), and when he noted that sunspots occur in pairs of opposite polarity whirling in opposite directions, and that hydrogen flocculi are often arranged round the sunspots and along their lines of magnetic force, in the same way that iron filings arrange themselves round the poles of a horseshoe magnet. The observations proved that there is a strong magnetic field in the sunspots, and, since moving electrons create magnetic fields, Professor Hale suggested that the magnetic field of a sunspot is created by electrons circulating in its whirlpool, and pointed out that electrons would flow in rapidly from the hotter periphery to the cooler centre.

There are plenty of free electrons available in the sun, for there are radioactive elements in it which break up into "alpha" particles and free electrons, and free electrons, too, are emitted by the glowing carbon and calcium of its flocculi. There is therefore every reason to believe that Professor Hale's theory is right, and that there is a swirl of free electrons in the sunspots. On the same theory it is easy to believe that during periods of sunspot activity there are increased discharges into space of electrons from the vortices of the sunspots or from their bright margins. In this way we can explain the magnetic storms and electrical disturbances as invasions of the upper atmosphere by electrons from the sun, which act as electric currents and cause induction currents in the crust of the earth, and can interpret the auroræ as the luminous vibration of air molecules violently bombarded by the same solar electrons.

What are the gases which glow under the bombardment? Endeavours have been made to identify them by means of their spectrum, and when, in 1898, it was noticed that the newly-discovered gas " krypton " had a bright green line resembling a line in the spectrum of the aurora, Sir William Ramsay sent induction charges through krypton in a globe suspended between the poles of an electromagnet, and produced an aurora-like light. " The light," he said, " evolved from pure krypton under the influence of such discharges is of a whitish, steel-blue colour, with occasional green and lilac flickers, and it recalls the appearance of the natural aurora." But krypton is a heavy gas which, under

Dalton's law of partial pressures, could not mount to the height at which the aurora appears, so it is practically certain that the green line in the aurora is not the green line of krypton. What, then, are the gases? The green line may be the green line of a gas resembling coronium and called, from its resemblance, "geo-coronium." At its lower levels the auroral spectrum shows the red line of nitrogen, and the red and green lines of hydrogen, and the yellow line of helium. At higher levels the yellow line of helium goes, and only the green line characteristic of hydrogen at lower pressure remains, and to these is added the green line already mentioned of geo-coronium. At a height of more than 400 kilometres, only the spectrum of geo-coronium appears. Thus the aurora both gives an interesting object lesson in the law of partial pressures and also intimates the existence of a gas otherwise unknown.

All questions, therefore, seem to be satisfactorily answered, and we are justified in believing that the light of the aurora polaris is due to the vibration of atoms of nitrogen, hydrogen, helium, and geo-coronium bombarded by electrons ejected by the sun in times of sunspot activity.

But this is a digression, and the sunspots have led us a long way from the sun. Let us now return to our consideration of its astronomical characters.

With the exception of specially bright areas bordering the sunspots, the rest of the glowing surface of the sun or photosphere has a granular or speckled appearance, and above and beyond the disc or photosphere is the sun's atmosphere, which, because of its yellow and rosy colours, has received the name of chromosphere.

The chromosphere is 3000 to 5000 miles thick, and around its periphery, which has a serrated or jagged outline, are the so-called solar prominences, like great tongues or plumes or fountains of eruptive flame, or like cirrus cumulus clouds. The flame-like prominences are in rapid motion, and rush out into space, sometimes at a rate of 200 or 300 miles a second. They may be only 9000 or 10,000 miles high, but sometimes are much higher. A prominence, observed in October 1880, was estimated to extend 350,000 miles into space; another one, observed in October 1920, reached a height estimated at 516,000 miles, and another, which occurred during the eclipse of May 29, 1919, shot up to a height of 470,000 miles. Many of these eruptive prominences appear to have a spiral structure like a whirlwind, and they seem to be connected with the whirlpools of sunspots. The cloud-like prominences are more permanent and show no signs of violent action. Examination by spectroscope shows that these prominences are composed of hot hydrogen, helium, and calcium vapours, while the chromosphere contains, besides these hot vapours, also hot vapours of sodium, iron, titanium, magnesium, and strontium. It may be mentioned that helium (which forms the basis of the protons or nuclei of atoms) was found by Lockyer in the sun's atmosphere some years before it was discovered on earth. Cloud-like masses of hydrogen and calcium which have been named " flocculi " are also seen floating in the atmosphere of the sun. Outside the chromosphere of the sun comes a circlet of light like a halo. It is known as the " corona," and its spectrum, which is continuous, shows a strong bright line in the green, which has been supposed to be emitted by an unknown gas called " coronium," probably related, as we have said, to geocoronium. The corona is believed to be chiefly sunlight reflected from some fine dusty material. Its form varies with the sunspot cycle.

The photosphere and chromosphere of the sun would thus seem to be continually in violent motion—whirlpools, and whirlwinds, and clouds of flaming gases, and gigantic jets of flaming vapours flung sometimes hundreds of thousands of miles across space! This turbulence provides the earth with light and heat. The beauty of the rainbow, the colours of the flowers, the sunbeam, and the moonbeam are all products of atomic storm; yet in the typhoons of the sunspots, in the whirlwinds of the chromosphere, in the colossal flames of the prominences, the real actors are ever the tiny electrons leaping between their atomic orbits—mainly orbits in the atoms of hydrogen and calcium—or swirling and clashing in the swirl of the sunspots, or flashing across the ether, and in every instance we have the translation of moving mass energy into etherial radiation, and the transformation of the radiation in the slower atoms of the cooler earth into moving mass energy again, with all the consequences in radiation and sensation of such transformation.

What an amazing illustration of order in disorder is offered by the sun's flaming orb!

What could possibly be more turbulent, more disorderly to all seeming than the mighty whirlpools and tornadoes in the photosphere of the sun, and the gigantic flames flaring forth from its chromosphere thousands of miles into space? Yet all the millions of electrons, free or bound, leaping and falling there, leap and fall according to law. Not a single one in its lawful orbit completes a circle too few or a circle too many. Not a single electron halts without emitting its quanta of energy. The flaming red chaos with its whirling gases is as law-abiding as a white lily. The rainbow colours, the red of the rose, the blue of the sky, the little granules of starch in the green leaf, bear testimony to a punctilious, unswerving observance of stringent prescient law. And when out of such turbulence come colour, and light, and beauty—when in such a wild, fierce, furious furnace are forged the sunbeams, and the moonbeams, and the rainbow, it cannot be difficult to have faith that in the ultimate scheme of the universe there reigns, despite storm and tumult, a law of love and beauty which some day, somewhere, somehow will also be made manifest.

CHAPTER V

RADIATION OTHER THAN SOLAR

PRIMITIVE man was almost entirely dependent on the sun for light. Besides the sunbeams, he had only the faint light of the moon and the stars, and the gleam of phosphorescent animals, and the glow of volcanoes. But one day a volcano set a forest on fire, or some bold barbarian lit a dry branch with red-hot lava, or with his flint struck an unexpected spark, or by friction produced an accidental flame, and so the science and art of making artificial heat and light was initiated. With his wood-fire, primitive man warmed his toes, and cooked his food, and smelted his copper or iron ore. With his torch he lengthened his days by adding a few hours of light to the night; and gradually, by artificial heat and light, he effected great civilising transformations in his daily existence.

Who Prometheus was, in what nation the fire and the torch first " blazed " a way out of the dark jungle of savagery, history does not relate; but " necessity is the mother of invention," and one may perhaps hazard the guess that the fire and the torch appeared first in lands with severe dark winters, for without light and heat a long, dark, cold winter would be almost intolerable.

Heat, as radiant energy and as thermal sensation, is at least as important as light, which in everyday life and experience must be regarded solely as a specific optical sensation; and the history of man's discovery and conquest of caloric agencies—the history of wood, and peat, and coal fuel, of the steam-boiler, and the electric furnace, and the Bunsen flame —would make an interesting chapter, but this volume deals mainly with light, and to the development of artificial light we must devote most of the space at our disposal in this chapter.

The first artificial light was almost certainly a wood-fire, while torches of resinous wood or of other inflammable materials must have soon followed, and how near we still are to barbarism we realise when we consider that in Alaska fat fish are still used as torches, and that last century in England link-boys carrying torches made of pitch or tow used to light citizens to their homes on dark nights.

Doubtless the inflammability of various oils, such as rape-seed oil, sperm oil, and nut-oil, was soon discovered, and little cups of clay or metal such as the Scotch " crusie," and wicks to soak up the oil, were natural developments. In the Orkneys till quite recent years an even simpler technique served—and the oily Stormy Petrel with a combustible substance in its mouth was quite a common source of illumination.

Tallow and wax candles came later than oil lamps, but they were in use at the beginning of the Christian era, and there is some reason to believe that they were used by the Phoenicians at a still earlier date. About 1750, spermaceti candles appeared, and in the middle of the last century paraffin and stearine came into vogue. The manufacture of candles was naturally much stimulated by their use in religious rites and festivals.

The candle, however, though handy and decorative, was hardly an effective illuminant, and the argand lamp, with a cylindrical wick and a glass chimney, invented in 1784, brought the lamp into favour again, and in the middle of the nineteenth century, the lamp, provided with the new oil, paraffin, was the chief source of artificial light, though, even then, a new and powerful rival was in the field.

As long ago as the seventeenth century, Dr. Richard Watson had noticed the inflammability of coal gas, and, towards the end of the eighteenth century, an inventor named John Clayton distilled gas (which he called the spirit of coal) from coal, collected it in bladders, pricked holes in the bladders, and set the issuing jets of gas on fire. An ingenious Scotchman, William Murdock, went a step further, and not only distilled gas from coal, peat, and wood, but actually conveyed the gas in pipes from his retort to his house, where he used it for lighting purposes. Eventually he used gas to light shops and factories, and was able to prove that the new illumination was much cheaper than lamps. So successful, indeed, were his pioneer efforts, that by 1817 over 300,000 cubic feet of coal gas were used in London.

The match is a small thing, but it has lit many flames; and we may mention *en passant* that the first friction match was invented by John Walker of Stockton-on-Tees in 1827, and that the first phosphorus match was invented a few years later by a Hungarian chemist named Janos Irinyi.

The invention in 1885 of the incandescent mantle gave a big impetus to gas-light. The light emitted by coal gas is due mainly to incandescent particles of carbon, and attempts were made to increase the radiancy of the gas by the introduction of other incandescent particles. The gas mantle, invented by Dr. Auer von Welsbach, utilised this principle: it was made of two very incandescent earths, thoria and ceria, and, when perfected, was found to increase the illuminating value of the gas five or six times.

In 1910 in the United States alone 100,000,000,000,000 cubic feet of gas were used for lighting purposes, and over the whole civilised world, the sunlight stored in the decayed wood of prehistoric vegetation was utilised as illuminant.

But even gas in its incandescent mantle did not long remain without a dangerous competitor.

In 1808, at the very time that Murdock was distilling his gas, Humphry Davy, using a battery of 2000 zinc and copper cells, produced an arc of light between two carbon points. In Humphry Davy's own historic words:

"When pieces of carbon, about an inch long and one-sixth of an inch in diameter, were brought near each other (within the thirtieth or fortieth part of an inch) a bright spark was produced and more than half the volume of the carbon became ignited to whiteness, and by withdrawing the points from each other, a constant discharge took place through the heated air in a space equal at least to four inches, producing a most brilliant arch of light, broad and conical in form in the middle."

That was the beginning of the most wonderful illuminant man has discovered, but for some years the new light received little attention, and it was Paris which first saw and proved its potentialities. On a foggy evening towards the end of 1844 people passing through the Place de la Concorde suddenly found themselves in a blaze of light. It was carbon-arc light, and in a short time there were electric lamps on the Pont Neuf, on the Arc de Triomphe, on the Palais Royale, at the Porte St. Martin, and at the Opera House.

The arc lamp was excellent for railway stations, and large public buildings, and squares, and bridges, and the necessary current could easily be generated by a dynamo; but the light was too powerful to be used in houses and small shops, and not till Swan and Edison invented, in 1879, the incandescent bulb—an incandescent filament of carbon in a vacuum bulb—did electric light achieve universal popularity. The Edison-Swan lamp made electric lighting simple. Lord Kelvin at once saw its value, told his electrician, " Go through the whole house; wherever there is a gas-burner put in an electric light," and was able to boast " that the first house on this planet in which the whole lighting was done by electricity was his house in the University of Glasgow."

Step by step the electric bulb was perfected. The carbon filament was replaced by the osmium filament, and this again was superseded by the tantalum filament, producing twice as much light at the same cost. Finally came the tungsten filament in argon gas—a rare element in a rare gas. To-day the tungsten lamp is the best illuminant known, and tungsten lamps are made of 2000 candle-power.

Electric lamps have, indeed, placed at man's disposal an almost limitless supply of light. In 1907 the Niagara Falls were lit with batteries of arc-projectors aggregating 1,115,000,000 beam candle-power, and this display was surpassed at the Panama Pacific Exhibition, where forty-eight arc searchlights, 3 feet in diameter, gave forth light totalling 2,600,000,000 beam candle-power.

Tinder-box, crusie, candle, lamp, gas-jet, tungsten-argon lamp—each marks a step in the progress of civilisation from darkness to light, and each step has meant more efficiency, more security, more cleanliness, more happiness, more health.

Even yet there is room for progress, for there are animals and plants able to make a better illuminant than man has ever produced. In the Animal Kingdom there are some thirty or forty orders which contain self-luminous animals. Various sponges, jelly-fish, worms, centipedes, beetles, octopi, and fishes can all light themselves up. In the Vegetable Kingdom there are luminous bacteria and moulds. Most of the luminous animals and plants belong to ancient orders, and it is possible that some were evolved when the earth lay under heavy clouds, and therefore found artificial light a vital advantage. Others, again, live in the depth of the sea, or in caves and subterranean places, where the sunlight cannot penetrate.

The most plentiful and in some ways the most sensational of all luminous animals is the tiny Noctiluca—the " night-light " of the sea. It is a speck of jelly-like matter the size of a pin's head, but occurs in incredible myriads, and may illuminate immense areas of the ocean. The Italian exploration ship *Magenta* ploughed its way for more than 25,000 miles —Naples, Rio de Janeiro, Straits of Banca, Port Jackson, Valparaiso—through galaxies of these living stars.

The Noctilucæ form what may be considered as the Milky Way of the sea; but the sea has also its meteors, and moons, and suns. Luminous jelly-fish have, indeed, been christened the Meteors of the Sea, and sometimes are almost as thickly and widely sown as the Noctilucæ. A ship has been known to sail for five or six weeks through water lit up by them. Luminous sea-pens, sea-fans, sea-plumes, and pyrosomes also occur in vast numbers. A sea floor with sea-fans and sea-plumes has been likened to " a cornfield covering hundreds of acres, the ripe ears emitting a fitful, vivid lilac light."

Luminous fishes usually dwell in the depth of the sea, and the best known of them are the so-called " lantern fishes," which have varied and extraordinary illuminating arrangements. Some have luminous spots like rows of buttons on their sides, or luminous glands on their head or tail, or a luminous snout like the headlight of an engine. Most extraordinary of all, perhaps, are several angler fishes which have jutting from their heads a luminous projection like a fishing-rod, which they perhaps use as a bait to attract small fish.

Luminous land animals are not so numerous as luminous sea animals, but they include the fire-flies, their larvæ, the glow-worms, certain centipedes, and millipedes. The only luminous vegetables are certain bacteria and fungi.

Whatever may have been the nature of the evolutionary process which produced luminous animals and plants, and whatever the use and purpose of the luminosity, certainly it has ended in the production of a wonderfully efficient illuminant. Nevertheless, it is too weak to be used by man in practical life, though Indians sometimes travel by night with fire-flies attached to their hands and feet, and Spallanzani wrote by the light of a luminous ooze squeezed out of a jelly-fish, and Humboldt read by the light of a goblet full of Noctilucæ. About forty fire-flies would be required to supply light equal to one candle, and if all the dome of St. Paul's were smeared with luminous bacteria it would have about the same illuminating value.

It is not the strength of the light, but its amazing economy which renders it efficient, and suggests that man may some day produce an illuminant better and cheaper than even electric light.

When we wish to make a poker or a carbon wire or other solid incandescent, we must heat it to 523° C., which means a great expenditure of unproductive energy; whereas luminous animals produce light without expending energy in first producing heat. They do not first produce the long infra-red waves: they produce the shorter waves of visible light straight away. The fire-fly, for instance, in producing its yellow-green light gives forth only an infinitesimal amount of heat. The light accordingly is two hundred times as economical as an ordinary carbon electrical lamp, and twenty-five times as economical as a tungsten-argon lamp. Theoretically, therefore, it might be produced at about one twenty-fifth the cost of the cheapest electric light in use to-day.

The secret of the luminosity of animals is in some cases already solved. It is known to be the result of the chemical combination of two substances contained in the glands of luminous animals, and the substances can be extracted and used to give light outside the animals and plants. So potent are the substances, that an extract of them from a little luminous crustacean will give visible light even when diluted with 3,000,000 parts of water. In three or four cases it has been proved that a ferment-like substance called luciferase acts inside or outside of the animal on another proteinaceous material called luciferin, with the result that cold light is produced. In some other cases the luminescence seems to be due to luminous bacteria in the animal.

When chemists have learned how to manufacture chemico-luminous substances like luciferase and luciferin, mankind will enter on a new epoch of artificial illumination; and it is not impossible that some day lamplighters may carry buckets of luminous fluid, and that we may have luminous garments, and books, and buildings, and flowers, and even fountains of luminous spray.

Finsen's successful treatment of lupus by special lamp-light, and the subsequent discovery that ultra-violet rays had a curative and preventive action in rickets have led to an extensive therapeutic use of lamps which emit ultra-violet light, and to the manufacture of glass—such as quartz-glass and "vita-glass"—pervious (as ordinary glass is not) to the ultra-violet rays of about 3000 Ångström Units, which are believed to have special therapeutic value. The lamps chiefly used in actino-therapy may be divided into two classes: (*a*) carbon-arc lamps, (*b*) mercury-vapour lamps.

Carbon-arc lamps radiate infra-red, visible, and ultra-violet rays, and to increase their ultra-violet radiation, metal cores of iron, tungsten, aluminium, and other metals are added to the carbon. Eidinow, Angus, and Hill proved that tungsten is four or five times as effective as carbon, measured by its power of killing infusoria, of producing erythema of a white skin, and of bleaching a standard solution of acetone methylene blue. The Percy Hill Tungsten Arc Lamp has one element of carbon and one of tungsten. Visible and infra-red rays in such arc lamps increase the physiological effect of the ultra-violet rays.

In mercury-vapour lamps the arc is formed in mercury vapour within a quartz tube pervious to the ultra-violet rays, and either air-cooled or water-cooled. In some lamps, such as the Cooper-Hewit and the Alpine Sun Lamp, the tube is a vacuum tube. The water-cooled Kromayer Lamp is used for local treatments, and its quartz window may be pressed against the skin, thus rendering the part anaemic and increasing the penetration of the rays.

It is difficult to say which type of lamp has most therapeutic value. T. H. Humphris states that the spectrum of the carbon more than the spectrum of mercury vapour resembles the spectrum of the sun; but, on the other hand, the mercury-vapour lamp and the tungsten-arc lamp are richer in ultra-violet rays.

In later chapters we shall have something to say on the clinical side of actino-therapy.

CHAPTER VI

THE EYE AND COLOUR

> "Wären nicht die Augen sonnenhaft wie können sie dann die Licht erblicken."
>
> "And all the things the eye perceives behind the eyelid curtains are."

We owe almost all our knowledge of the outer world to the eye—a little circular sac composed of cartilaginous, epithelial, and nervous tissues which is situated in a cavity under the brow, and which is brought into connection with intricate nerve ramifications and cell centres in the brain by means of the large nerve called the "optic nerve." Histologically this sac is merely beautifully specialised skin. In the beginning skin and nervous system were one, and though now there is differentiation, yet there is still continuity, and even in the specialised structure of the eye the continuity is very marked—so marked that it is difficult to say where the skin ends and the nervous system begins. Anatomically it is curiously and wonderfully constructed to fulfil its visual functions, and it is certainly the most ingenious optical instrument known to man. The round eye-ball is made of very strong, tough, opaque, fibrous tissue known as the "sclerotic," able to stand a good deal of pressure and violence, as every boxer demonstrates, and has anteriorly a little circular aperture, the "pupil," which is protected in front by aqueous humour and the firm, transparent "cornea," composed of fibrous tissue and epithelium. A little way behind the corneal window is placed a transparent elastic biconvex lens, called the "crystalline lens." The lens is carried perpendicularly in a tightly-fitting transparent membranous bag, and round the bag, in a circlet concentric with the edge of the lens, radiate little muscles, the "ciliary" muscles, which are attached to the bag in that position and have the power of tightening it by pulling upon it, and so reducing the curvature of the elastic crystalline lens within it. The interior of the eyeball sac is filled with a jelly-like substance known as the "vitreous humour," and in front, filling the tiny space between the lens and the cornea, there is, as we have mentioned, a fluid called "aqueous humour." Round the margin of the lens like a little annular curtain, is the pigmented iris, which, by means of muscular tissue, is able to contract or relax, thus increasing or diminishing the aperture by which light passes to the lens—

acting much as the diaphragm used in photography. In this way the size of the pupil can be reduced from $\frac{1}{32}$ inch in diameter in bright sun to $\frac{3}{8}$ inch in diameter in pitch darkness. The eyeball is set in a bony socket, and can be moved freely in various directions by six little muscles attached to it. It is guarded by the eyelids, and is kept moist and clean by a fluid secreted by the lacrymal gland, and this fluid drains from the eyeball into the nose by a special duct, the " lachrymal duct."

All this ingenious apparatus serves to collect light and focus it on the " retina "—an intricate nervous layer spread over the back of the interior of the eyeball. Though the retina is only $\frac{1}{120}$ inch thick, no less than twelve layers can be distinguished in a microscopic section. The deepest layer is made up of cells about $\frac{1}{1000}$ inch long and $\frac{1}{10000}$ inch in diameter, like rods and cones standing close together side by side, and is therefore often called the " layer of the rods and cones." There are estimated to be 3,000,000 rods and even a greater number of cones—some estimate 10,000,000 altogether—and light falling upon them causes some photochemical change in them which is transmitted in some way by the optic nerve to the brain, and is translated by cells there into sensations of light and colour.

The optic nerve, which carries the photochemical disturbance to the sight cells in the brain, contains 500,000 nerve fibrils, and it is quite close to the rods and cones, but there is no direct connection, for between the rods and cones and the nerve are interposed several layers of curious branching tendrils and cells—which makes the intimate and precise relation between brain and eye all the more mysterious.

The rods contain a purple pigment known as "visual purple," and this pigment no doubt plays a part in the photochemical processes of the nerve impulse, for it is bleached by exposure to light, and out of the light quickly regains colour. The visual purple, through its sensitiveness to light, renders the retina a kind of photographic film, and photographs of a kind can be taken on it and fixed. For instance, if a rabbit's eye is cut out and placed in front of a lighted window, and if it is afterwards dissected and treated with a 4 per cent. solution of alum to fix the photograph, an inverted picture of the window and its crossbars will be found on the retina.

There seems some reason to believe that the cones are responsible for colour vision and for the perception of light of higher intensity, while the rods are receptors for light of low intensity. The rods are most plentiful in outer regions of the retina and the cones most plentiful in the central region. It is therefore probable that a faint star can be seen best by looking at it not quite directly—out of the corner of the eye—and for the same reason objects seen by faint starlight or moonlight are colourless or almost colourless.

The crystalline lens, the aqueous humour, and the vitreous humour, all refract and focus the light, but most of the refraction is due to the lens which, as we have said, can alter its focusing point by altering its curvatures. In the normal eye when the ciliary muscle is relaxed the eye is focused for distant objects, and to see near objects the muscle must be tightened in order to increase the curve of the lens and reduce its focal distance. In old age, when the lens loses its elasticity, its curvature can be no longer increased in this way, and so the eye can no longer be focused on near objects; and spectacle lens, to further refract the light from near objects, become necessary. The alteration of focal length by the ciliary muscles is a reflex action and is called accommodation.

Shortsightedness is due to too great elongation of the eyeball, so that rays of distant objects, instead of being focused, as in normal eyes, on the retina, are focused in front of the eyeball.

Longsightedness is due either, as already mentioned, to loss of elasticity in the lens, or to insufficient length of the eye, which causes light from near objects to be focused beyond the retina.

Astigmatism, or inability to focus at the same time equidistant horizontal and vertical lines, is due to a greater curvature of the lens in one meridian than another.

This brief survey of the anatomy and physiology of the eye will suffice to show that it is at least an ingenious optical instrument with features, such as a lens of changeable curvature, which art has not yet succeeded in imitating.

But the eye in its cerebral context is much more than an optical instrument: it is a mysterious transformer by which the transformation of light into sight is initiated; it is the most sensitive and responsive surface of contact between the ether and the conscious being. The skin and all the other senses are also points of contact, but the skin knows the ether-waves only as heat, or cold, or touch sensation, and the ear knows the ether-waves only as sound, and the taste knows the ether-waves only as flavour, while the eye knows them as light, and colour, and visible objects, and the black symbols of thought and speech. The skin can feel only as far as the sun, and the ear can hear only as far as sound can carry, but the eye can pierce into the depth of space and can detect light billions of billions of miles away that has taken thousands of years to reach it. Its gamut of sensibility is also remarkable, and far surpasses that of the other sense organs, for it is affected by the light of a star of sixth magnitude, and also by the light of the sun, and the sun on a clear day has an intensity of 10,000 foot candles and is 1,000,000,000,000 times as bright as the star. Yet the eye is sensitive not to radiations of all wave-lengths, but only to the radiations having wave-lengths between 4000 and 7600 Ångström Units—to the light waves of the visible spectrum. Some people, especially young people with sensitive eyes, get a sensation of light from waves as short as 3900 Ångström Units, and in the old, when the cornea and lens are less clear, light of shorter wave-length than 4200 Ångström Units cannot be discerned. Also very intense radiation of wave-length longer than 7600 Ångström Units may produce a sensation of colour in some people. But on the average 4000 to 7600 Ångström Units measure the limit of visibility.

The eye has the power, not only of discerning as light waves of these lengths, but also of interpreting or translating wave-lengths into colour. Or rather, we should say, the sight cells have the power of seeing various colours when variously excited through the photochemical changes in the cones. The sense of colour in its last resort must depend on changes in the cells in the sight centres of the brain; and a sensation of colour does not necessarily follow simply because a light wave of this or that length and frequence enters the pupil and impinges on the retina. Indeed, we know that some people are blind to certain colours, and it is highly probable that the same colour, even if seen as colour, may mean quite different sensations to different people. It is possible, too, that the colour sense may be developed to different degrees in various natures. The Greeks talked of "wine-coloured" sea, and it is noticeable how rich is Scottish poetry in adjectives of colour.

It may be noted that the retina is most sensitive to radiations of about 5550 Ångström Units, producing the visual sensation of yellow green.

The sensations of different colours indicate extraordinarily sensitive discrimination by the cells of sight in the brain. For the vibrational difference between waves of adjacent colours of the spectrum is the difference between, for instance, waves of a wave-length of eighteen millionths of an inch and nineteen millionths of an inch, and this infinitesimal difference has to be detected not directly, but through their different effects on the minute cones as conveyed to the brain by the optic nerve. Discrimination of this kind, entering into consciousness as a distinctive sensation, implies very advanced physiological and psychological development.

The idea accepted by most people that birds and mammals and insects see colours in any sense as we see them is rather absurd, for it supposes a minute similarity in cerebral centres such as is certainly not present. It is not unlikely that the lower animals have no colour sense at all in the psychical meaning of such words, and it is quite possible that some insects are affected through their eyes more by ultra-violet, to which their eyes are pervious, than by the rays which are visible to us.

Von Hess, indeed, has proved experimentally that fishes and many invertebrate animals act towards the visible rays of the spectrum like totally colour-blind persons, and has shown that ultra-violet rays cause a brilliant fluorescence of the crystal ball of the faceted eyes.

In the eyes of some ants there are 1000 lenses, and in a butterfly's eye, which is about the size of a small pinhead, there may be over 5000 different lenses and as many nerve fibres. Yet a butterfly seems unable to recognise a butterfly by sight at a greater distance than 3½ feet.

Thomas Young and Helmholtz analysed colour vision into three primary sensations of red, green, and violet. They showed that sensations of white and all other colours could be produced by blending those three colours in right proportions, and, starting from this principle, they elaborated the trichromatic theory of colour vision which assumed that there were three different kinds of cones in the retina, one kind producing the sensation red when stimulated, another kind producing the sensation violet, and a third kind the sensation blue; all three kinds equally stimulating the sensation white, while other colours could be produced by exciting the three kinds in various proportions; thus, red + green = yellow; blue + red = magenta; green + magenta = white; green + blue = peacock-blue. Peacock-blue, magenta, and yellow are called the three complementaries, since each of them combined with one of the primaries gives white. Another theory of colour vision holds that there are six primary colours, black, white, red, green, yellow, blue.

We have mentioned above that some people are colour-blind to certain colours, and as the famous chemist, John Dalton, who founded the atomic theory, was colour-blind, the visual defect was formerly called " Daltonism." To Dalton the colours red, orange, yellow, and green looked alike, and he called them all yellow. Blood appeared the same colour as bottle-green to him, and a laurel leaf looked the same colour as red sealing-wax. The defect is congenital and hereditary, and occurs in families, usually skipping a generation, and it is much more common in men than in women—in fact some doubt if it occurs in women at all. It is inherited in a strange way. A man does not pass it on to his sons or to his son's sons, and he does not pass it on to his daughter, but nevertheless it reappears in his daughter's family. Most colour-blind people do not know that they are colour-blind, and the condition was not noted till 1777. Dalton did not discover his deficiency till he was twenty-six years of age.

These cases of colour-blindness suggest that even in those who are not actually blind there is probably a percentage whose sensitiveness for colour and discrimination for colour are below the mean.

For the great majority of people, however large idiosyncrasies and personal equations may be, colours are among the most beautiful experiences of life, and a world all one colour would be for most people almost intolerable. The colour of a flag has been to many nations an inspiration, the colour of an iris has decided the fate of many a man or woman. Sense of colour, indeed, is one of the most important items in the intellectual and temperamental life of civilised nations, and it is rather strange that the psychological values of colour have not been more carefully studied by psychologists.

"A dragon in the water," says the Chinese aphorism, "covers itself with five colours, therefore it is a god"; and there can be no doubt that æsthetic pleasure in brightly-coloured garments is at once a spiritual and physical stimulant to many people, and that many, perhaps most people are affected in their mood by the colour of their environment, but, on the other hand, there does not seem much consensus of opinion as regards the psychological effects of certain definite colours, and it is probable that effects of colours may vary with the individual or with special individual associations of colours and experiences.

Association certainly plays a big part in the psychological value of colour, and Luckiesh, who made a special study of the question, points out or suggests that green is psychologically inactive because the human eyes have had large areas of green before them for ages, that blue and blue-green are cold colours, because of their association with blue-green waters and similar cool things, that yellow is always a cheery colour because associated with sunlight, that orange and orange-red are warm colours because they recall flame and heat, that red as the colour of blood suggests valour, danger, tried manhood, that purple looks regal because known to be an expensive dye. The colours, too, he finds to be more potent in proportion to their purity.

But in some cases, especially in cases of the hypersensitive and neurotic, there is probably a direct psychological effect through the special vibrational energy of the colour. In 1875 Dr. Ponza, director of the lunatic asylum at Alexandria, acting on the advice of P. Secchi, the famous astronomer, fitted several rooms with either violet or red glass open to the sunlight several hours a day, on the theory that violet light was depressant and sedative, and would soothe violent cases, while red light would cheer up the melancholic. In some cases the colours had the desired and expected effects.

Goethe experimented on himself with variously-tinted eyeglasses, and came to the conclusion that yellow, red-yellow, yellow-red glasses disposed the wearer to be brisk, lively, aspiring, while blue, red-blue, blue-red cause restless, tender, and longing feelings. Goethe also met an educated Frenchman who stated " that the tone of conversation between himself and his wife altered after she had exchanged the blue coverlets of her furniture for red ones." It is said, too, that workers in photographic factories who work in red light are unduly excitable.

Very interesting investigations were made some years ago by the Russian physiologist, Apopenko, on the influence of various coloured lights on the rapidity of the mental processes, such as counting up numbers, and on the spirits. He found that the colours at the red end of the spectrum accelerated, and that the colours at the blue end retarded mental processes, and that the colours at the red end raised the spirits and those at the blue end depressed them. He found especial depression of mind and spirits in violet light, and found, too, that a long exposure to such light often caused headache.

Before, however, very definite conclusions can be come to, it will be necessary to make some objective tests, *e.g.* on the effect of various coloured lights on blood-pressure, heart-rate, temperature.

Though the psychology of colour is still inchoate, it is certain that the pleasure people take in colour and light has, like the pleasure taken in music, its physiological equivalent in some sort of stimulation of the vital functions by the cells of sight in the brain. Some people on suddenly going into sunlight sneeze, showing some reflex stimulation of certain parts of the respiratory centre, and it may be assumed that even when no sneeze ensues some stimulation takes place, for it has been proved that exposure of the eyes to sunlight is followed by an increase in the respiratory quotient. The flash of magnesium light is followed not only by a twitch of the eyelid, but also by contraction of other muscles, and probably many functions are stimulated. All afferent impulses are followed by efferent, and it would be strange if such a large afferent nerve as the optic, associated with nerve ramifications and nerve centres and causing so much conscious cerebral activity, had not many efferent reflex connections. Quite apart from general or local insolation, too, light through the eyes has certainly therapeutic value. One of Nansen's Polar party wrote: "The last winter in the ice was simply awful. We had our fill of the darkness. We got sleepy and indifferent and shaky on our legs: we were not ill, but weak and dead beat, and the doctor was anxious about our brains. When the day came with the sun it was like a resurrection for us all. We were electrified when we saw him. Nobody knows how fine the sun looks but those who have been six months in darkness. Then we came to strength again."

It can hardly be supposed that the Polar party took sun-baths on the ice, so we must assume that they "came to strength again" partly through an improvement in their spirits, but mainly through the effect of visible rays reaching the brain through the eyes. It is to be remembered that the retina contains blood-vessels as well as cones and rods.

We have been discussing the relationship of the eye to the light of the visible spectrum, but sunlight and artificial light contain waves beyond the visible spectrum, both at the red and violet ends—the rays of the sunlight reaching as far as waves of 2900 Ångström Units into the ultra-violet and as far as waves of 600,000 Ångström Units into the infra-red. To these rays beyond the visible spectrum the eye is not sensible, or we should rather say that these rays do not give rise in the eye to the sensation of light; but, nevertheless, rays outside the visible spectrum do penetrate the eye. On the ultra-violet side, in young and middle-aged persons, waves as short as 3500 Ångström Units reach the retina. The cornea transmits rays, even shorter rays, as short as 2950 Ångström Units, but the lens filters out all shorter than 3500 Ångström Units. In old people as the lens becomes more opaque it usually stops all radiations shorter than 4200 Ångström Units.

The shortest ultra-violet rays in sunlight therefore are absorbed in the cornea, and it is probably irritation of the corneal conjunctive by these short-waved rays that causes snow-blindness. Ultra-violet rays shorter than 2900 Ångström Units produced by quartz-mercury arcs and other artificial sources of light are destructive of animal tissue, and produce extremely painful irritation and inflammation of the external tissues of the eye. The most irritative radiations seem to be between 2800 and 3100 Ångström Units. An exposure of less than a minute to a therapeutic ultra-violet lamp will cause severe conjunctivitis. It is easy to protect the eye from these irritative short-waved rays, as glass is opaque to rays of shorter wave-length than 3000 Ångström Units.

The ultra-violet rays that reach the retina produce no sensation; but doubtless they have some physiological value.

It is rather strange that such a large part of the sun's ultra-violet rays should be held back from the retina, and also that the most extreme ultra-violet rays in the sunlight should irritate the exterior of the eye. One would have expected that in the course of hundreds of thousands of years the retina would have accommodated itself to the whole solar spectrum—certainly that the cornea and conjunctiva would have done so—and the fact that they are still intolerant might suggest that the atmosphere has not always been transparent to ultra-violet rays. It is quite possible that in the course of ages the retina will receive more and more ultra-violet rays and that new sight centres in the brain will be able to see them and see with them, as happens now in the case of ants, which are able to see and carry on their work without visible light. As things are at present, it is fortunate for man that the atmosphere filters out and attenuates the ultra-violet rays from the sun.

Infra-red radiations shorter than 14,000 Ångström Units are partially transmuted, but infra-red radiations of longer wave-lengths are absorbed.

The eye can see a star billions of miles distant, and with the assistance of lenses can see the mountains in the moon and the swirling whirlpools of the sun, and it is not at all impossible that the day will come when a man in England will be able not only to talk with a man in New Zealand, but to look into his eyes as he talks. We can create big waves of ether and send them half-way round the world, and capture and use them again, and waves of light, as we have seen, are simply small electro-magnetic waves, exactly the same in all essential characters as the waves used in wireless telephony, and though the light waves reflected from a face have not energy enough to penetrate far into the air (the light reflected from a human face illumined by lamps of 1000 candle-power is less than the light of a single candle), and though even a powerful searchlight cannot penetrate many miles, yet some practical method of mediate transmission by relays and transformations may be discovered. If we can use electro-magnetic waves in the ether to convey the vibrations of a diaphragm in London to a diaphragm in New York, surely some way should be found to transform little waves into big ones and to retransform them into little ones again—some way of translating light and colour into electric waves and of retranslating the electric waves into light and colour, or at least of effecting some equivalent process.

In the " optophone," light has been already turned into electricity by utilising the peculiar electrical properties of selenium, and inventors have recently succeeded in using the same metal to turn electricity into light. By ingenious contrivances and by transformation of infra-red rays into rays of visible light, Mr. J. L. Baird has actually attained some measure of success in wireless "television," and to-day there is a Television Broadcasting Station in London and a "television" receiving station at Harrow, nine miles away, and people seated before the transmitter in London are televised to Harrow and seen upon a screen.

In his little brochure on television, A. Dinsdale states: "There is no limit to the distance to which television can be transmitted other than the limits which to-day govern the distance over which wireless telephony can be conducted. All Baird requires for the purpose of the actual transmission of television is any circuit, wire or wireless which will transmit intelligible speech. The length of the circuit or distance between the transmitting and receiving station does not matter in the least, so long as the requirement of speech intelligibility is met with. The problem does not lie in the transmission circuit. It lies, as we have seen, in the successful transformation of light waves into electrical impulses and their retransformation again at the receiver into light waves."

As in telephony, so in television, electrical distortion may occur, but it is easily remedied by adjustment of the receiver.

Wireless television is still in its infancy, but it has been conceived and born, and in time it may be as practicable as wireless telephony.

Before leaving the eye, let us touch again on the mystery of radiation and vision. Why should radiations from a sodium atom beating on the retina produce yellow in a man's consciousness? The electron drops to a lower orbit, and as it drops, part of its mass changes into undulating motion in the ether, and the undulating motion goes through the cornea and lens and vitreous humour to the retina, and is changed into molecular motion of various sorts as it goes, and finally there is colour. That is how science analyses it. But that does not explain colour. There is no colour in the electron of the sodium atom; there is no colour in its fall from an outer to an inner orbit; there is no colour in its magnetic loops; there is no colour in the invisible waves of ether into which the loops are transformed. Nor does there seem to be any relation between the molecular movements in the retina or in the brain, and light and colour. We believe that when certain molecules in certain cells of the brain are made to vibrate or alter in certain ways, light and colour come into the consciousness, and we say that some molecular alteration is the cause of the conscious experience. But why and how? We may magnify the molecules till the electrons are as large as planets, and may watch the planets leaping and clashing in their orbits or flying off into space; but we will not see them yellow or red, and will discover no reason why, when they perform certain movements, we should have sensations of colour. Tyndall supposed Bishop Butler to argue: "I can visualise the waves of ether as they cross the eye and hit the retina. Nay, more; I am able to pursue to the central organ the motion thus imparted at the periphery and to see in idea the very molecules of the brain thrown into tremors. My insight is not baffled by these physical processes. What baffles and bewilders me is the notion that from these physical tremors things so utterly incongruous with them as sensation, thought, emotion can be derived. You may say or think that this issue of consciousness from the clash of atoms is not more incongruous than the flash of light from the union of oxygen and hydrogen; but I beg to say that it is. For such incongruity as the flash possesses I now force upon your attention. The flash is an affair of consciousness, the objective counterpart of which is a vibration. It is a flash only by your interpretation."

But Tyndall might have gone a step further. As the author has pointed out elsewhere, " Matter, even considered as particles in motion, is not a thing outside or apart from consciousness, and cannot be considered as purely objective. We talk about vibrating particles, but vibrations and particles, just as much as sight and sound, are not properties of something outside our minds, but elements of most abstract conceptions. It is true that by the dualistic assumption of mind and matter we reach various conclusions of pragmatic value; but the assumption from the first is false, and must eventually prove a *reductio ad absurdum.* Consciousness is a great mystery that we cannot get behind, and all these hordes of cells and mazes of fibres and vibrating molecules are items of consciousness—of the very consciousness whose cause we think we are going to find."

The only cause that we can discover for mind and for the world in mind is Mind, and to give that causing Mind personality or self-consciousness, such as we ourselves have, is at least a working hypothesis and as good a symbol of the truth as we are likely to get.

CHAPTER VII

SOLAR RADIATION. METEOROLOGICAL AND CLIMATIC

The energy of solar radiation received by the earth is subject to certain general and local variations. The outside of the atmosphere of the earth receives less than one two-thousand-millionth of the total radiation of the sun, and this effective fraction varies only 3 per cent. according to intrinsic solar activity, as shown by sunspots, and about 6 per cent. according to the earth's position in perihelion or aphelion. These may be called variations in the general radiation affecting the whole supply of the whole planet, but are so slight that they are swamped and disguised by local variation due to other factors, which we must now briefly consider.

The total radiation energy which in calendar units of time reaches various segments of the earth's crust shows considerable fluctuations, and these do not depend on variations in the total radiation emitted by the sun and received by the atmosphere, but are due to the rotation of the earth on a tilted axis during its revolution round the sun.

This tilted rotation of the earth in its orbit produces both topical and temporal variations, for it produces at every spot on the earth's surface progressively and regularly varying hours of light and darkness, and progressively and regularly varying angles of light incidence. The day everywhere grows longer or shorter, and day by day the average angle of incidence of light grows more or less acute, and even in the course of one day the sun passes from horizon to horizon with ever-changing light incidence. Hence we get at each place the differences in radiative value between winter and summer, between night and day, between dawn and noon. Not only so, but each latitude is put into its own particular temporal relationship to solar radiation, and there is summer in New Zealand while there is winter in England, and ice at the Poles and deserts in the tropics.

Probably the most important factor qualifying the initial solar radiation is the length of the day—a factor varying with season, latitude, and altitude. Plainly there is a vast difference in radiation value between the longest and the shortest day in the Arctic regions; and plainly twenty hours' sunshine anywhere about sea level means more radiant energy than five hours' sunshine. But the average angle of incidence during the day or year is of almost equal importance.

The angle of incidence affects the value of radiation in two ways: firstly, the more slanting rays cover a wider surface than the more perpendicular rays, and are therefore less concentrated area for area; and secondly, the slanting rays have to pass across a greater mass of atmosphere, containing more or less dust and moisture, which more or less diminishes the direct radiation.

The relation of the atmosphere to radiation is not usually realised, and it will be well to deal specially with it here.

The gases—hydrogen, oxygen, nitrogen, carbon dioxide, water vapour, ozone, etc.—which constitute the atmosphere and reach at least 100 miles above the surface of the earth, mitigate and filter in all latitudes the radiation from the sun. The sun's total heating power just outside the earth's atmosphere at mean solar distance is estimated at from 1·82 to 2·02 calories per minute, according to output of radiation from the sun. Its average value, called the "solar constant of radiation," is 1·94 calories. That is to say, that if the total energy of a ray of sunlight 1 centimetre in cross-section were absorbed by 1 gram of water, the temperature of the gram of water would be raised 1·94° C., or, expressed otherwise, that the solar energy falling on the outside of our atmosphere per minute is about 1½ horse-power per square yard, or 7000 horse-power per acre.

In passing through the atmosphere, even at perpendicular incidence, to places on the earth's surface near sea-level, the sunlight loses much of its radiant energy, so that in summer, even on clear days, it may fall to 1·5 calories, and in winter to 0·77 calorie. In the central latitudes of the United States, the solar energy at perpendicular incidence has been found to vary on clear days from 1·37 calories in January to 1·5 calories in May; while in the lower latitudes it has been found to vary from 1·23 to 1·47 calories.

The loss of radiant energy in passing through the atmosphere is due not only to the gases—oxygen, nitrogen, carbon dioxide, ozone, etc.—in the atmosphere, but also, as we have already suggested, to some considerable extent to the smoke, dust, and moisture in its lower strata. Hence we find that solar radiation suffers proportionately more decimation at lower latitudes, and suffers especially in winter, when there is more moisture in the air, and that solar energy at high, dry, dustless altitudes between 2000 and 20,000 feet is not only proportionately greater than at sea-level, but also much the same at all heights and at all seasons. Thus Vallot found that on a fine summer day the perpendicular energy at the top of Mont Blanc (16,000 feet) was 1·55 calories, while Dorno found at Davos (5000 feet) 1·58 calories, on Mt. Whitney (14·500 feet) 1·64 calories, in a balloon (23,000 feet) 1·67 calories, while at Potsdam the vertical maximum of 1·44 calories was reached. Dorne also recorded 1·49 calories at Davos in May and 1·354 in December.

The figures we have given illustrate the facts we have mentioned, but they are not very impressive, and might seem to suggest that between one place and another there is little difference in radiant energy received. But they compare only the momentary value of maximum vertical radiation in summer, and do not indicate the total daily, or seasonal, or yearly radiation. When we consider the total caloric value daily, or seasonally, or yearly, received by places at various altitudes, other factors come in, and we find that differences in altitude, even in comparable latitudes, produce much greater differences in radiation than are suggested by the figures quoted.

We find that the effect of dust and moisture in the air increases with decreasing angle of incidence much more at low than at high altitudes, for when at low altitudes the sun is low in the sky, its rays, falling on places at low level, have to pass more obliquely through the very strata where the dust and moisture accumulate, and in the course of this longer passage their energy, even in clear weather, is rapidly more and more reduced, whereas even the lower atmosphere at high altitudes is free from moisture and dust. The sun at its zenith may have ten times more radiant energy than when near the horizon, and the luminosity of the sun lighting up a horizontal surface may vary with the sun's altitude from 10,000 to 50 foot-candles.

The fundamental law of absorption is given by Bouguer as follows :

" For a given coefficient of transparency, the quantities of heat transmitted decrease in geometrical progression, while the amount of atmosphere traversed increases in arithmetical proportion." (The coefficient of transparency is the quantity of heat from the sun—the proportion of the sun's initial extra-atmospheric radiant energy—which actually reaches the ground when the sun is at its zenith.)

As a corollary of this law, it follows that the maximal daily solar radiation occurs an hour before noon.

The inter-reaction of radiant obliquity and varying transparency produces *in toto*, then, much more marked calorific effects than might be supposed from the figures we have given dealing with perpendicular incidence. Because of it, we find that the average total radiation daily received from the sun at high altitudes is much greater than the average total radiation daily received at low altitudes (in comparable latitudes), simply because the rays falling at oblique incidence pass through thinner, and drier, and less air. Likewise we find that the difference between summer and winter radiation at high altitudes is less than at low altitudes (in comparable latitudes), simply because at high altitudes the air is about equally dry in winter and summer, whereas at low altitudes it is much more humid in winter. The following figures illustrate these facts.

Dorno estimates that Davos, though deprived by the mountains of three hours' sun a day, gets fully 50 per cent. more radiant energy than Potsdam. In winter it receives three times more radiant energy than Potsdam. At Davos the total radiation received in June is six times a great as in January, while at Potsdam the total radiation received in June is twenty times as great as in January.

Diminution of water in the air, even more than diminution of density and mass of air, accounts for the powerful radiation at high altitudes. A decrease of even 1 mm. in vapour pressure increases the energy of solar radiation by 0·02 calorie, and water vapour decreases in the air more rapidly as we rise, and is chiefly accountable for the increasing radiant energy. Every one with experience of high mountains must often have seen from a mountain height a radiant blue sky above his head and a sea of clouds beneath his feet, and must have realised how much obstruction can be offered to radiant energy by the water vapour in the lower strata of the air.

The transparency of the air at low levels may be altered by any local conditions which give rise to dust, moisture, or fog, such as desert dust-storms, masses of water, factory chimneys, and the alterations may greatly affect radiation. Thus the British Isles, surrounded by sea, receive much less radiant energy in winter than Manitoba, and the West of Ireland, clouded by the warm vapours of the Gulf Stream, much less than the East of England, and Newfoundland, clouded by the meeting of cold and warm ocean currents, much less than New York. Fog and smoke often seriously reduce the radiant energy received, and may even reduce the hours of daylight.

A fog contains both smoke particles and water, and a dense fog containing abundance of carbon and some 10 grammes of water per cubic metre, obviously must cut off a large percentage of normal solar radiation.

A manufacturing town may have an hour less of daylight than a neighbouring town free from factories, and Dr. Bernard quotes from the *Sanitary Engineer* that in the industrial part of Leeds the light intensity is 25 per cent. less than in the residential part, and 40 per cent. less than in a suburb 7 miles distant, while the duration of sunlight is 17 per cent. less than in a place only 4 miles distant.

Luckily a snowstorm or a fall of rain can clear the air, for a time at least, of solid impurities.

The number of hours of sun received at various places is no exact criterion of the caloric value of the solar radiation, but it has at least some general climatic meaning, and it may be interesting to state a few comparative figures. During thirty years the average hours of daily sunshine enjoyed during the whole year by Aberdeen were 3·68; by Edinburgh 3·18; by Birmingham 3·10; by Glasgow 2·98; by Newcastle 2·85; by Margate 4·34; by Falmouth 4·77; by Guernsey 5·26. During the six winter months the figures record: Aberdeen 2·27; Edinburgh 1·83; Birmingham 1·71; Glasgow 1·44; Newcastle 1·56; Margate 2·56; Falmouth 2·85; Guernsey 3·02. Between 1898 and 1902 Montana averaged 5·28 hours of sunshine in winter, and 6·05 for the whole year. In 1920 Leysin had 1768 hours of sunshine, Davos 1669, and Arosa 1724. Madrid has 2908 hours of sunshine yearly, Inverness has less than 700, and Ben Nevis, despite its height, only 726.

Latitude, of course, very much affects solar radiation, for, as latitudes approach the equator, the sun traces a higher arc in the sky and dispenses more perpendicular energy. *Ceteris paribus* 12 hours sunshine at the equator will have much more energy than 12 hours at Wick, and 12 hours sunshine at a height of 10,000 feet in Central Africa represents much more solar energy than 12 hours at the same height on Mount Elias.

In the preceding pages we have treated solar radiation as homogeneous, but solar light, as the spectrum shows, is not homogeneous, for, as we have seen in another chapter, it consists of rays of different wave-length of different refrangibility, and of different powers of penetration, varying—even after atmospheric filtration—from ultra-violet rays as small as 2900 Ångström Units to infra-red as big as 600,000 Ångström Units.

That is a very small section of the total spectrum known to us to-day, and it may be assumed that in the fiery furnace of the sun many waves outside these limits are generated, and that some of them are held up outside the earth's atmosphere, and some, especially ultra-violet, held up within it. Even those which do reach us are decimated and diminished from their total extra-atmospheric energy of about 0·2 calories. The proportional decimation and diminution of each ray depend on its wave-length. According to Rayleigh's law, rays of light meeting ultra-microscopic particles small in respect to their own wave-length are scattered by the particles in inverse proportion to the fourth power of their wave-length, and, accordingly, the bigger the wave the greater their power of penetration. Langley has calculated that 76 per cent. of the infra-red and 70 per cent. of red rays which fall on the atmosphere reach sea-level on a clear day, as compared with 42 per cent. of the violet and 39 per cent. of the ultra-violet. He gives the following table.

	Per cent. of Transmission.
Ultra-violet	39
Violet	42
Blue	48
Green-blue	54
Yellow	63
Red	70
Infra-red	76

But these proportions naturally vary with the height of the sun and other circumstances, and ultra-violet rays are more powerful and contain waves of smaller wave-length as the sun climbs in a clear sky.

We see evidence of the greater penetrating power of red rays in the rosy sky of sunset, where chiefly red rays have succeeded in penetrating the thicker atmosphere, and the power of penetration possessed by red rays is utilised in lighthouses, which burn petroleum to produce penetrating red light.

Of the total radiant energy which reaches the earth from the sun 60 per cent. is contributed by the infra-red and only 40 per cent. by the visible and ultra-violet rays, whereas, according to Napier Shaw's calculations, the solar radiation which reaches the atmosphere has 49 per cent. of its energy in visible and ultra-violet rays, and 51 per cent. in infra-red, but these figures are, of course, rough and approximate.

It is probable that many of the ultra-violet rays between 2000 and 2900 Ångström Units in wave-length are absorbed by a layer of ozone formed in the upper atmosphere over 12 miles high, and that ozone is the cause of the abrupt ending of the solar spectrum at 2900 Ångström Units, for we find no extension of the ultra-violet end of the solar spectrum even on the top of high mountains. The presence of ozone in the upper atmosphere has been shown spectroscopically by various observers. A certain amount of infra-red radiation is absorbed by carbon dioxide and oxygen. Infra-red radiations are also always absorbed to some extent by the water vapour in the atmosphere, which usually amounts to half an inch of water; and if the water vapour amount to several inches of water, practically all infra-red radiation is absorbed. A bolometer shows great cool bands in the infra-red region of the spectrum, due to absorption of heat by the water vapour, carbon dioxide, and oxygen in our atmosphere. On the other hand, water vapour is transparent to ultra-violet rays. Extreme red radiations are absorbed by oxygen. Smoke absorbs the visible and ultra-violet radiations, especially ultra-violet, violet, blue, and green radiations.

In brief, then, the sunlight which reaches us at sea-level is filtered and absorbed to various degrees, and differs in composition and in energy from the solar radiations on the outside of the atmosphere. At high altitudes, where the atmospheric filter is thinner and drier and free from dust, the energy and composition of the sunlight more nearly approximate to the energy and composition of the sunlight outside the atmosphere; but even at high altitudes the solar spectrum ceases abruptly at about 2900 Ångström Units.

So far, we have been dealing mainly with direct sunlight, but the light of common day is usually not direct sunlight, but mingled diffuse and direct sunlight, for the light from the sun is not only absorbed and weakened, but much of it, before it reaches us, is also scattered, and reflected, and diffused by the molecules of the air and by dust and other fine particles floating in the air. The intensity or energy of diffuse light is estimated by the illumination of a horizontal surface produced by the light of the sky without the addition of direct light from the sun, and, as in the case of direct light, the ultimate product depends on various selective and absorptive processes to which the diffuse light is subject *en route*. The dominating law of diffusion is the law enunciated by Rayleigh which we have already stated, *i.e.* that scattering or diffusion of any waves of light is inversely proportional to the fourth power of its wave-length. Accordingly, the smaller waves (the blue and violet and ultra-violet) are more diffused.

Between height of the sun and diffusion of light there exists a relationship which has been summed up by Dr. A. Rosselet as follows:

(1) When the sun is at its zenith the intensity of direct light is greater than that of diffuse light. As the first diminishes more rapidly than the second, there must be a time of day, when the sun is only moderately high, at which they are identical. When the sun is near the horizon, the intensity of the diffuse light is greater than that of the direct.

(2) The difference in intensity of diffused light corresponding to distances of the sun from the zenith 0° and 80° is less than that of direct light, which means that on a fine day the intensity of diffused is much more constant than that of direct light.

The relationship between altitude and diffusion is obvious, for as there are less dust and fewer air molecules at high altitudes, so the diffused must be less, even as direct radiation is more. Abbot found at sea-level 32 per cent. of the total light was diffused, and at 6000 feet above sea-level only 7·2 per cent. On the other hand, though at high altitudes the amount of diffuse light bears a smaller proportion to direct light than on the plains, it has a greater absolute brightness, because the direct light at high altitudes is much stronger. Thus Dorno finds that diffused sky-light is six times brighter in winter, and one to eight times brighter in summer at Davos than at Kiel. A clear sky of medium diffusing power has a value about 20 per cent. of the noonday sun, and is 15 per cent. richer than the direct sunlight in ultra-violet rays.

Cloudiness, represented on the ordinary meteorological scale by 5, gives 82 per cent. of the heat radiation of a clear sky, and that represented by 10, 29 per cent.

It must be noted, however, that diffused light does not come only from the sky; there is also diffused light reflected from sunlit surfaces, such as water, or snow, or ice. The whitest snow reflects 70 per cent. of the light, and " sitting surrounded with snow-fields in the Alps, a man is illuminated with diffuse light from the earth below not much less than from the sky above."

The diffusion of light is of great æsthetic value. We have said that light is scattered and diffused in inverse proportion to the fourth power of its wave-length, and that, accordingly, diffused light is rich in ultra-violet and violet and blue rays, and it is to this richness of diffused light in the blue rays that we owe the blue sky.

On the pebbles of the beach, the tiny ripples break in surf, while the larger waves roll unbroken onward. Similarly, on the ultra-microscopic pebbles of the atmospheric dust (as well as on the ultra-microscopic molecules of the air) break the tiny etherial ripples of blue light, while the larger waves of red and yellow light roll unbroken onward. By the dust, as by millions of microscopic mirrors, the scattered blue waves are reflected into our eyes, and so we see blue and project blue upon the vault of the sky. In a sort, the blue sky is the blue surf of the ocean of light where it breaks on the sand-bars of dust.

On the tops of very high mountains, and at the great heights attained by aeroplanes, where the air contains little dust and has less molecular density, the sky becomes almost black and stars may be seen at noonday. Indeed, except for diffusion of light we should have a blue sun in a sky almost black. Largely to diffusion by dust, too, we owe gorgeous sunrises and sunsets, for when the light is low it passes obliquely through thicker layers of the dust-laden air, and the coarser dust particles are big enough to scatter and reflect the larger yellow and red waves of light. Thus, after great volcanic eruptions, when the air is filled with volcanic dust, unusually magnificent sunsets are seen. The dust thrown into the sky by the eruption of Krakatoa circulated round and 'round the world, glorifying the sky.

The Hon. Rollo Russell gives a fine description of a sunset at Cannes due to Krakatoa dust: " Orange ordinary glow in S.W. near horizon; above this a greenish-blue white arc, then a beautiful yellow band; then up to the zenith a very beautiful lilac tint. All these colours were of extreme softness . . . in point of beauty they were quite unsurpassable and of superb magnificence in their further progress. The pink, purple, or lilac now retired in the most steady and regular manner towards the horizon, and were visible to the end. Thirty-five minutes after sunset the arc was formed of the inner part, which from steel-blue had gone through olive-green to yellow, the middle yellow, and the outer purple. . . . The horizon—about a quarter of a circle—was deep yellow. The purple part, being the smallest, was flooded, except at the edge, by the orange light, which shone in a grand arc for a long time with great splendour, casting shadows. In about fifty-four minutes the primary glow was gone, having sunk in a deep red band." A regular orgy of colour, and all due to dust!

Even apart from such colour effects, diffusion of light in the atmosphere has æsthetic value; for on fine diffusion of light all soft illumination depends. When a ray of white light is passed through a dustless tube, the air in the tube remains unlighted (though if the tube were long enough and big enough, molecular diffusion would produce a blue tint), and except for diffusion by dust and molecules, the atmosphere would remain unlighted by the sunlight passing through it, and it would be unillumined black: only where the sunlight actually fell would it have lighting power, and the only diffused light would be from light reflected from water and snow and large polished objects. Accordingly, there would be hardly any of the pleasant soft gradations between light and shade which now beautify the world. It would be a world of black and white. The sunlit side of a house would be radiantly white, and the shadowed side, even at noonday, black. One would require a lamp to find the door, and the lamplight would pierce the gloom without dispelling it, and would light only the patch on which it happened to fall. A world without light diffusion by dust and gaseous molecules would be a much less beautiful and less pleasant and less comfortable world to live in.

It may be interesting to note that the principle of diffusion of light has been utilised to light some of the streets of Chicago. Down a long straight street is shot a powerful beam of light, and as there is plenty of dust in the air to scatter the beam, the light is diffused, and provides a soft, pleasant illumination like the light of day. At the Hudson–Fulton celebration at New York, too, the light of arc searchlights of 1,000,000,000 candle-power was diffused and intensified by means of a fog of steam, and at the Panama–Pacific Exhibition arc searchlights of 2,600,000,000 candle-power were similarly diffused and intensified.

The relationship between solar radiation and climate is obvious; indeed, the word climate (from *κλινειν*, to incline) had reference originally to differences in the amount of sunshine received in different latitudes owing to the inclination of the earth's axis, and Claudius Ptolemy, author of the Ptolemaic System of the Universe (A.D. 120–149), divided climate into zones, "in which the length of the longest day increased successively by half an hour between the Equator and the Arctic Circle." Ptolemy's division was geographically a very irregular division; it included in the first zone 8½° of latitude and in the twenty-fourth only $\frac{1}{20}$°; also it did not satisfactorily correlate sunlight and climate, for the isothermals do not follow the parallels of latitude, and the greatest heat is north of the equator, while altitude and clearness of atmosphere, as we have seen, have almost as much to do with radiant energy as latitude.

Latitude, of course, remains an important climatic factor: we know what we mean when we say a tropical or subtropical climate; but to-day we realise that climate in its relationship to health is not merely a question of radiation, but of radiation, humidity, wind, and altitude. An average temperature of 70° F. on the plains of India and an average temperature of 70° F. on the high plateaux of the African Karroo have very different physiological meanings. Likewise a temperature of 20° F. at Peterhead or London and of 20° F. at Davos or Montana mean very different climates.

Various living forms are found to have varying solar requirements and to favour certain isothermal zones; and in some cases the animals may have selected the zones, and in other cases the zones the animals; and in yet other cases the flora or other indirect climatic concomitants may have been the selecting factor. Man himself has remarkable powers of climatic adaptation, and can flourish more or less in all zones between the equator and the Arctic circle, at any temperature from below zero to over 100° in the shade; but the white races certainly show more mental and physical vigour in the temperate zones, where they are subjected to no extremes of cold or heat or light, and all races seem to flourish best in moderate sunshine and in dry air, though many of the sturdiest and the strongest races, such as the Scotch, and Irish, and Swedes, have lived for hundreds of years in comparatively moist and sunless climates. On the whole too much warmth and light would seem more detrimental to man than too little, and if his diet be suitable, he can maintain almost full vigour with very little light indeed. Light is essential for the plant, but not for animals. We shall deal more fully with the subject in our next chapter.

CHAPTER VIII

BIOLOGICAL. LIGHT AND LIFE

A LIVING organism must be regarded as a process rather than a structure, as " a rainbow on life's weeping rain " rather than as a static rock in a stagnant pool. The machinery of living things is not like the machinery of a watch : it is not self-contained and shut up in a case. Between the living tissues and their environment there are a constant ebb and flow, give and take of matter and energy. " Viewed from the physico-chemical point of view," says Benjamin Moore, " the living cell is a peculiarly constructed energy machine or energy transformer, through which a constant flux of energy ceaselessly goes on, and the whole life of the cell is an expression of variation and alternations in the rates of flow of energy and of changes in the equilibria or balances between various types of energy." The dead contribute to the living; the living have intercourse and commerce with the dead. The intercourse is sometimes dramatic. Great mountain ranges bear witness to the lime that organisms collected from the sea, and that the sea again collected from the organisms, and every coal-seam tells how plants, with the assistance of the sun, built carbohydrates out of water and air, and how micro-organisms in turn broke down the carbohydrates.

All life consists of this interplay of structure and environment, and especially of inter-reactions between organic tissues and food, and organic tissues and air. In the case of the higher animals, the food, in contact with the cells of certain digestive glands, leads to the chemical interchanges known as digestive processes, which result in organic construction and repair; and oxygen, brought to the living tissues by the blood from the lungs, completes the reparative and constructive processes, and, oxidising the food-fuel, supplies life with motor and generative energy.

Food and air work together: both are necessary for life, and no living thing can persist unless its environment contains them. These are the two most important workers at the woof of life; but there is a third worker always at work with them, modifying all their interactions with living cells. This third worker is radiant energy—energy always derived indirectly or directly from the sun, known best in the shape of light and heat.

It works quietly and unostentatiously, but it is as essential to life as are food and air.

A hen's egg is a concatenation of atoms. Within its shell there are just exactly the right atoms in the right proportion to make a chick—feathers, and eyes, and beak, and heart and all; but without radiant heat from the hen's breast (which, like all vital heat, is transformed sunlight) to energise the atoms and make them dance into their proper places, they will never arrange themselves into a living and breathing bird. A little radiant energy makes all the difference between a rotten mass of sulphuretted hydrogen, useful only as a political missile, and a chirping chick. The breath God breathes into the nostrils of life is warm. Yet the warmth must move within narrow and precise limits, and be neither too potent nor too feeble. There are certain algæ (Confervæ) living in hot springs which are able to endure a temperature of nearly 200° F., but most living things perish at a point far below that; while, on the other hand, extreme cold arrests or destroys life, and no mammal can live if the cells of which its body is composed cool much below a temperature of 98° F.

Between absolute zero and the greatest heat the crust of the earth has known are thousands of degrees Fahrenheit, yet only within small thermal limits can living things thrive, and life has been not inaptly described as a thermal episode in the history of a cooling planet.

Yet we must not take too narrow a view of life, and regard it simply as the inevitable result of a suitable temperature acting on quite ordinary forms and groupings of molecular energy. In his fascinating volume in this series on the " Origin and Nature of Life," Benjamin Moore suggests that to-day there are ordinary colloid molecules which, under attainable thermal and other conditions, are capable of growing into living organisms and of evolving in the course of ages into all the forms of life that are in the world to-day. " It was no fortuitous combination of chances and no cosmic dust," he writes, " which brought life to the womb of our ancient mother earth in the far-distant Palæozoic ages, but a well-regulated, orderly development, which comes to every mother earth in the universe in the maturity of her creation when the conditions arrive within the suitable limits. Given the presence of matter and energy forms under the proper conditions, life must come inevitably, just as, given the proper conditions of energy and complexity of matter in the fertilised ovum, one change after another, must introduce itself and give place to another and spin along in kaleidoscopic sequence, till the mature embryo appears, and this in turn must pass through the phases of growth, maturity, reproduction, decay, and death.

"If this view be the true one, there must exist a whole world of living creatures which the microscope has never shown us, leading up to the bacteria and the protozoa. The brink of life lies not at the production of protozoa and bacteria, which are highly-developed inhabitants of our world, but away down amongst the colloids, and the beginning of life was not a fortuitous event occurring millions of years ago and never again repeated, but one which, in its primordial stages, keeps on repeating itself all the time and in our generation. So that if all intelligent creatures were by some holocaust destroyed, up out of the depth in process of millions of years intelligent beings would once more emerge."

This is well and persuasively expressed, but Mr. Moore smuggles his rabbit into his hat before he produces it, for he postulates conditions of energy and complexity of matter competent to produce living beings, and, of course, if the energy and the complexity of matter are competent to produce living beings, there is no more to be said. But the whole question is—whether there are in any colloid molecules known to-day complexities of matter and conditions of energy competent to produce the structure and function of a living being capable of reproducing and evolving. It is very difficult to believe that any known colloid molecules, under the influence of light and heat or any other factor, could make the transit in structure and function between the living and the dead. Colloids have been shown —Benjamin Moore himself has shown it—" to retain and utilise light for the further development of structure, or, in other words, synthesis of more complex colloids," but that is still an infinity from life, and we do not see life " repeating itself all the time and in our generation."

Let us see how Mr. Moore gets his " conditions of energy and complexity of matter competent to produce living beings."

By ingenious and convincing experiments, he shows that sunlight, or rather ultra-violet rays, can evoke formaldehyde in certain dilute inorganic colloidal solutions containing carbon-dioxide. The colloids act as catalysts or activators for light energy, and promote the reduction of carbon-dioxide and water through an endothermic reaction in which the light energy, converted into chemical energy, appears in the synthetic compound formaldehyde (CH_2O). Briefly, the light energy appears as chemical energy in the new compound CH_2O. This synthesis (together with a similar photosynthesis of nitrite from the nitrogen in the air) Mr. Moore believes to have been the first step in the origin of life. The process of evolution of simple organic substances having thus begun, " substances of more and more complex organic nature would, with additional uptake of energy, arise from them. Later, organic colloids would be formed possessing metastable properties, and these would begin to show the properties possessed by living matter of balanced equilibrium and up-and-down energy transformations following variations in environment. There can be little question that such energy changes as are above described occur at present, and are leading always to fresh evolutions of more complex organic substances and so towards life, and equally is it true that they must occur on any planet containing the necessary elements for the evolution of inorganic colloids and exposure to light under suitable conditions of environment."

In his interesting volume " The Making of the Earth " (Home University Library), Professor J. W. Gregory, more or less following Professor Moore, gives a brilliant exposition of the chemical creation of life, and suggests that the first living thing—the " Protobion," as he calls it—was a complex, vaseline-like jelly deposited from the carbon compounds in the primæval atmosphere, combined with various compounds of nitrogen, chloride, and phosphorus, and vitalised by catalysers.

We find it difficult to believe that any mere accretion of atoms, and any mere addition of energy according to the laws of organic chemistry—even the massive galaxies of the carbon concatenations assisted by the subtle activities of catalysers—could result in a living organism. Even when a lobster grows a new claw or a child a new tooth, there is something more than ordinary organic or inorganic accretion. Certainly no accretion will explain reproduction, nor will it even easily explain the beautiful coincidence of eggshell, egg food-supply, and egg germ. We prefer the attitude of Professor J. Arthur Thomson when ("Introduction to Science" in this series) he warns us to remember (1) that although the synthetic chemist can do wonders in building up complex things, he has not yet attained to near the artificial synthesis of proteids; (2) that we are at a loss to suggest what in Nature's Laboratory of chemical synthesis—a somewhat hypothetical witch's cauldron—could take the place of the directive chemist; (3) that there is a great gap between making organic matter and making an organism.

No addition or thermal of chemical energy suffices to explain the coming into being of living organisms, and there is much to be said for the theory of the super-addition of a new form of *directive* energy to which the name " vital " may be applied—a directive energy of the same kind as that which directs at this moment into molar channels the special molecular energies of my manual muscles. The pristine molecules of living matter were arranged not merely by chemical affinity and thermal energy, but by some energy of the same nature as the energy that arranges my fingers to write these words. Something in this unique energy not only *adds*, but arranges to fulfil purposive functions—directs to a foreseen end as well as moves. We can change thermal energy into electric energy or into locomotor energy: we can change each into the other, but never, except in living organisms, does an energy emerge of a formative or directive character. Though vital directive energy is apparently eternal and inexhaustible, it can be passed on only from living thing to living thing: *omne vivum ex vivo* is still a fact of experience—uncontroverted and without known exception. The difference between the inanimate and the animate is not a chemical difference, it is the difference between a spinning-top and a writing pen—between forms of energy incomparable and mutually inconvertible, between modes of motion infinitely different, and we know no energy in radiation to-day nor energy in inorganic molecules that seems in any way competent to bridge the prodigious gap between them. It is true that radiant energy, or molecular addition, or molecular division, or molecular re-arrangement may produce new chemical and physical properties, sometimes of an unexpected nature. Oxygen and hydrogen combined form water; carbon and oxygen combined form carbon-dioxide; carbon-dioxide and water, by a process of division and addition, form the deadly poison formaldehyde. Sugar and wood, a lily leaf and a beefsteak are molecularly cousins; a lump of black carbon and a shining diamond are constitutionally identical; the electrons hustling and bustling along the electric wire and the electrons leading a retired thorough rapid existence in the orbit of a neutral atom are all exactly alike. And it is quite true, too, as Mr. Moore so well and illuminatingly points out, that with each additional uptake of mass and energy the molecule becomes more and more unstable, and more and more approximates to the metabolic labile condition of the molecules of living organisms. All that may be admitted: all these facts are, indeed, illustrated in the molecular behaviour of a living organism; but it is not these chemical and energetic occurrences in a living organism we have to explain, but their integration and utilisation in specific structure adapted in ingenious ways to such purposive molar movements as locomotion, reproduction, circulation, digestion, speech. The chemical energies of the molecules are not changed into a new energy; they are there at work, unaltered and undiminished, but a new energy has been added which directs them all as a prescient will directs.

Purposive orientation, intra-cellular, intercellular, or anatomical, can surely be best and most naturally explained as we explain our own voluntary and purposive movements—as the product of some energy other than chemical, an energy which we may call an " entelechy," if we chose, but which is really of the same mysterious nature as our own present will—" A motion, a spirit which impels all thinking things, all objects of all thought." Life, emerging from the inorganic, requires and acquires a new directive force *ab extra, a deus ex machinâ* to arrange and rearrange the molecules in space—to make big wheels within big wheels of the infinitesimal wheels within infinitesimal wheels, so that they may not only revolve in the individual organism, but evolve in the race. Life requires for its emergence from the amorphic a metamorphic, formative, causal energy, big enough and complicated and prescient enough to contain all its evolutionary consequences, even as a Sonata of Beethoven requires a Beethoven's brain. It requires not only terrific rotatory energy in the atoms, it requires spiritual energy such as our own wills in a very small measure are now privileged to exercise, to arrange and use the rotatory energy in integrated, co-ordinated, purposive processes and actions. And the great Hebraic conception of Creation is about as near to the truth as our finite intelligences can attain. The Light came first when the ether was knotted into the rotating atoms, but life was a special creation—the result of the " Logos "; of an energy of an unique nature comparable only to thought and will.

Moore himself almost admits all this, for he says: " The very building up of the machine or transformer in which the manifestations of biotic energy are subsequently to take place is, then, a cogent argument that we are dealing with a type of energy which is not met with elsewhere. For nowhere else in Nature does a similar process appear to that of the production of living structure, and by no combination or application of the forms of energy apart from life can it be repeated or simulated." That is true, for surely the " biotic " energy is not only manifested by the built-up body, but itself builds the body, as no *known* chemical and physical energies of the combining atoms and molecules could possibly build it. It is not the result of cellular complexity, but its cause (" Es ist der Geist der sich den Körper baut "). Tyndall talks of " the exquisite sense of the beautiful displayed by Nature in the formation of a common block of ice," and there is more than sense of the beautiful displayed in the moulding of an organic embryo, in which, as Huxley says, " we are forcibly reminded of a modeller in clay." Yet of clay any artist might mould a bird, or beast, or tree, but where is the artist, where is the synthetic chemist who could make the throbbing molecules and gyrating atoms dance together into a brain cell, or a blue eye, or even into a single finger-nail, or an eyelash?

Let us consider the matter more concretely in the hen's egg, which grows into a hen when subjected to gentle radiant heat. In the egg are quadrillions of molecules arranged as the white, the yolk, and the germ. A few waves of ether beat upon them, and the molecules join and divide, and divide and join, and in a few days they are rearranged and rebuilt into the tissues and organs, the heart and liver, the beak, and head, and eyes, and feathers of a bird. Had the atoms in the egg just formed chemical combinations *in situ*, like chemicals in a test-tube, there certainly would not have been a bird. The little germ of life had to collect new molecules from the white, and the yolk, and, re-orienting them, had to build them up in definite places into definite structures, and some of the structures —the bone-corpuscles or osteoblasts—had to move about and deposit lime and make the bones of the chick. Every molecule in the egg is used, and before use rightly allocated. No doubt ordinary forces are at work: it is possible even that the molecules in the egg are *from the first* so arranged and distributed that the heat of the hen's breast suffices to start an inevitable series of chemical combinations, but still, in that case, we have to explain how the atoms and molecules are assembled in exactly the right numbers and put in exactly the right places in the egg to produce this chemical automatism.

A mathematician and chemist of infinite genius might be able to collect all the millions and millions of molecules in the exact proportion required to build a chick, and he might enclose them in an eggshell; but can anyone believe that the chemical properties of the molecules plus a little heat would suffice to build them up into the living bird, unless they had been previously placed in special intricate dynamical relationship to each other —unless they had been pre-arranged and pre-oriented, or unless, as may very possibly be the case, some prescient orienting energy intervened in the actual process of development—such prescient orienting energy as a painter, or sculptor, or poet, or creator of any kind possesses and employs? Orientation in space other than that produced by radiant or molecular energy is necessary to account for life, and we believe that an orienting, arranging, prescient energy was added when life first began—an energy that to-day characterises all living things, an energy that gives specific form and purposive molar movement to living organisms, and that is of the same order as the will and the thought of a living man.

To imagine that living things can be created to-day from inanimate matter by radiation, or that the energy of the hen's historic germ-plasm begins in the egg, is like imagining that there can be a Niagara Fall without a Niagara River.

Nevertheless, ordinary radiant and chemical energy *can* start the machinery of life after the machinery has been assembled and put together by vital energy; and the heat of the hen's breast does lead to the transformation process in a hen's egg, even if only as a detonator leads to an explosion, or as the flame of the furnace works an engine, or as the flame in my muscles moves my fingers to write.

Radiant energy interacting with bio-molecular energy is directed by vital energy into certain channels which lead to the anatomical forms and the physiological functions of animals. Radiation not only, as in the case of the egg, sets life going, but it keeps life going. Yet, strictly speaking, radiation is not the main driving power: it merely augments, modifies, regulates, or liberates energy. The main energy is the molecular energy of the bio-plasm—what Moore calls the "energy-transformer"—whose marvellously co-ordinated wheels within wheels and springs within springs, started by the radiant energy and directed by the vital energy, are used and made manifest in the purposive physiological functions we call life.

In brief, radiant energy, though seemingly incompetent to make dead matter alive, and a very small thing compared with biomolecular energy, and a very blind thing compared with vital energy, does, nevertheless, play an initiating, important, regulating and reinforcing part in the structural upbuilding of living things, and to certain aspects of this matter we shall devote the next chapter.

CHAPTER IX

LIGHT AS BIOLOGICAL ENERGY

"And every star is needed for a rose."

The formaldehyde, sugar, starch, and other carbohydrates formed by the green plant, with the assistance of radiant energy, are, as suggested in the previous chapter, not merely the fundamental basis of the structural material of all living things, but the mainspring of biotic energy. Passed on like frozen solar flame from vegetable to animal, they serve not only to build up the animal tissues, but by their combustion to energise them.

Let us look, then, at the radiant energy and correlated chemical processes which lead to the production of the carbohydrates on which growth, locomotion, reproduction, and other functional manifestations of life depend, and let us try to understand how far and in what way radiant energy becomes vital energy.

The green plant is the site of the production of the carbohydrates, and in the green plant, the green leaf.

In every green leaf and in every blade of grass since the first green cell was born, the carbohydrate synthesis had been going on; but it was centuries before men of science realised the manufacturing talent of the green leaf, or the important part played by carbon-dioxide and radiant energy in its manufacture. Van Helmont, it is true, almost stumbled on the truth. He planted a willow slip weighing 5 lb. in an earthenware pot containing 200 lb. of dried soil. The slip was regularly watered. After five years he weighed the plant, and found its weight to be 169 lb. 3 oz., while the dried earth had lost only 2 oz. in weight. But though he himself invented the term " gas " and discovered the gas carbon-dioxide, and though, as he knew, his contemporary Jean Rey had proved that the increase of weight of heated tin was due to the accretion of air, nevertheless it never occurred to him that the willow was able to add to itself gases from the air, and he came to the conclusion " that water alone had been sufficient for the production of 164 lb. of wood, bark, and roots," and so the great discovery of carbon assimilation was postponed. Indeed, up till the latter half of the eighteenth century it was universally believed that the plant was nourished entirely through its roots, which absorbed nutrient materials from the black soil and from water, and that all vegetable tissues and products, such as starch and sugar, were elaborated out of the materials so supplied.

But on August 18, 1771, the famous chemist, Priestley, made a little instructive experiment. It seemed a trivial experiment, like Newton's when he bored the hole in a shutter, or Ritter's when he put a silver salt beyond the rays of the visible spectrum, but it opened up a new world to biology. Into air, under a bell-glass (set in water) where a candle had burned till, in the vitiated air, it could burn no longer, or where a mouse had died of suffocation, he introduced a little sprig of mint. Probably he expected the sprig of mint to suffer like the mouse or candle, but it neither died nor withered; it thrived and developed; and when, after a few days, a lit candle was put into the air, the candle burned brightly, and likewise a mouse introduced breathed comfortably. Plainly the mint had put something, then called "dephlogisticated air," into the air which enabled it again to support combustion and respiration.

The full significance of this experiment was not at first seen, but it at least proved that plants were able to purify the air, and Sir John Pringle, in presenting Priestley with the Copley Medal of the Royal Society, declared: "From this discovery we are assured that no vegetable grows in vain, but that, from the oak of the forest to the grass in the field, every individual plant is serviceable to mankind, if not always distinguishable by some private virtue, yet making a part of the whole which purifies and cleanses our atmosphere."

Priestley did not realise the important part played by light, even though, just through lack of light, his experiment sometimes failed, and it was left to Senebier and Ingen-Housz to make the further great discoveries that the process of purification took place only in the light, not in the darkness, and that the emission of "dephlogisticated air" (oxygen) followed the absorption of fixed air (carbon-dioxide) and the retention of carbon. In 1862 Sachs demonstrated that starch in the plant was a product of the disruption of the absorbed carbon-dioxide, and later investigation showed that sugar is formed in the leaf even before starch makes its appearance.

This absorption of carbon-dioxide, emission of oxygen, retention of carbon, and building up of starch and other carbohydrates, is now common biological knowledge, and the whole process is recognised as "the central fact of life on this planet." But even yet the precise process of the building up of carbohydrates is not known, though it has been proved that the energy of light is an essential factor, and that the potential chemical energy contained in the sugar and starch and made available on oxidation is derived from the light.

A green leaf is a most ingeniously and exquisitely constructed apparatus. If we study it through a microscope, we find on its under-surface hundreds of thousands—on some leaves there are as many as a million—of tiny apertures leading into the body of the leaf, which is spongy in structure. Through the tiny mouths—*stomata*—the air, with its three-thousandth part of carbon-dioxide, passes by diffusion into the little intercellular cavities, and thence into the little green leaf-cells, where it is dissolved in their sap, so that each cell becomes something like a microscopic green bottle of aërated water. In the green cells are little colloid bodies, called "chloroplasts," which contain the pigment, called "chlorophyll," and in the chloroplasts the radiant energy of the light is utilised, to build up sugar and starch and other carbohydrates out of carbon-dioxide and water. In the chloroplasts, indeed, may be said to meet fire, air, earth, and water to prepare provender for Life.

The pigment chlorophyll (really a complex of four pigments, two green and two yellow—the latter unimportant), which is manufactured in the chloroplast, and which makes the whole world green, suggests, by its ubiquity, its importance; and there can be no doubt that it plays an essential part in plant photosynthesis, though the exact part it plays is still debateable. It fluoresces under light and reduces light of high frequency of vibration to light of a lower frequency, which may have photosynthetic or photolytic properties, and may play a part in the later condensations and polymerisations; but it is also possible that chlorophyll and other associated pigments are only protective screens, and that the real transformer of the sun's energy is the chloroplast.

Stiles states that "the function, or one of the functions, of chlorophyll is to absorb energy which is finally utilised in the decomposition of carbon dioxide or a derivation of it such as carbonic acid or a bicarbonate." Baly, Heilbron, and Barker believe that light is absorbed by chlorophyll, and that this energy is radiated out again at infra-red frequencies, which are reabsorbed, with the result that carbon-dioxide and water are synthesised to formaldehyde or carbohydrates.

Much is still unknown and much is still obscure, but we do know that the little bodies in the green cell make life possible. Without them the sun must shine on a blind, dead world. The stomata are the lips where light kisses life, and the chloroplasts the womb where the progeny of light and life is conceived. Green is the livery of life, but under the green livery beats the crimson heart that gives all living things their energy.

The radiant energy acting in the synthesis of the carbohydrates has been found to be situated in the visible spectrum, and the red and yellow waves have been found to show most synthetic energy, the blue and violet least. This was demonstrated in two little experiments by the eminent Russian botanist, Timiriazeff: (1) He let the whole spectrum fall upon a leaf devoid of starch, and showed that there was most starch formed under the red rays and hardly any formed under the blue and violet; (2) "A series of glass tubes were filled"—to quote his own words—"with a mixture of air with a certain percentage of carbonic acid. Green leaves from the same plant and of similar size were introduced into each of them. Then the vessels were exposed to the spectrum of the sun obtained in a perfectly dark room. After a few hours it was determined by analysing the gas in which tubes the carbonic acid had decomposed and in which not—those in which it had decomposed more and those in which less." It was found that most carbon-dioxide was decomposed in the tube exposed to the red rays.

The last experiment was perhaps not quite conclusive, as red has most penetrative power, and so would pass more easily through the glass, but the two simple experiments taken together prove that the photosynthesis is prompted by the rays of the visible spectrum, and chiefly by the red rays.

That is just what we would expect from the colour of the leaf and from the examination of the spectrum of chlorophyll, for both show that the red rays are chiefly absorbed, and only absorbed rays have chemical activity. It is the red rays which make a green world; it is the red rays that make life possible; and the rosy cheek is in truth on fire with the red light hidden in the green leaf. The red rays are not the most energetic rays, they are the first rays that issue as a glowing body is heated, and yet it is their energy which makes possible all the energies known as vital.

How do these little waves act? A red wave, having crossed the 93,000,000 miles of space in the good time of about eight and a half minutes, breaks upon a chloroplast's little green flask of aërated water and, *as light*, is extinguished—the chloroplast on which it shines is not lit up, it appears black as soot—yet the extinguished light becomes part at least of the energy of life. It dies to live! What exactly happens? What exactly happens in the chemical process of photosynthesis is, as we have said, debateable and debated; but the general transformation of light-energy into life-energy can be explained.

So far as the main action of the light is concerned, the term photosynthesis is misleading, for the light's main energising action would seem to be not synthesis, but analysis, and would be better called "photoanalysis" or "photolysis," since the sun breaks to build, and tears apart to bind together. In the chloroplasts, as we saw, is dissolved carbon-dioxide —a gas in which two atoms of oxygen are firmly welded to one atom of carbon. The chemist can disrupt them only by rather violent methods. For instance, he can pass carbon-dioxide through red-hot tubes. There the radiant energy, absorbed in the form of heat by the carbon-dioxide molecules, will—changing into mechanical or locomotive energy—so agitate them that they will fling each other off. In the separated partners the mechanical energy acquired will still persist as intrinsic motor (hidden, not really latent) energy of the electrons—an energy capable of being made manifest in the phenomena of chemical combination, hence often called chemical energy or the energy of chemical affinity.

The transformation of heat radiation into mechanical work which at bottom is the transformation—described in our chapter on Radiation—of ether wave energy, into the energy of electronic revolution, is a well-known phenomenon, seen on a large scale when heated water molecules move as steam with sufficient force to drive a piston. And the amount of work to be got out of heat and the amount of heat to be got out of work—the so-called "mechanical equivalent of heat"—were determined long ago. We know that the amount of heat required to raise the temperature of one kilogramme of water one degree Centigrade can be transformed into work equal to raising 426 kilogrammes to the height of one metre. There is nothing unusual or anomalous, then, in the chemist's method of separating the carbon from the oxygen by means of heat; he is simply making a special application of this principle of the transformation of heat into mechanical work, and there is an exact relationship between the heat he puts into the carbon-dioxide and the mechanical or chemical energy supplied to it. Now, the red rays contain heat or its energy equivalent, and when they are absorbed by the carbon-dioxide in the leaf, the energy is changed in exactly the same way into energy of pace and position: the electrons in the atoms change their orbit or accelerate their pace, and acquire energy of motion or position exactly equivalent to the energy of the radiation they absorb, and it is their radiation, ultimately transformed into the form of energy of motion or of chemical combination, which compounds and animates living matter.

An extraordinary thing is, that the red radiations do their work so easily and quietly. The bond between the carbon and oxygen is strong: the chemist requires to use great thermal violence to break it, and yet a sunbeam breaks it quite coolly and calmly. More subtle is Nature than the most skilled chemist.

How the quiet, gentle red radiations of the sun manage to break the strong chemical bond, we do not know. Probably the molecular energy of the chloroplast assists, for only in the chloroplast is the disruption effected.

In the sun-energised atoms the extra energy is hidden and useless. A lump of black carbon seems about as lethargic a substance as it is possible to find, and a molecule of oxygen does not seem much more energetic than a molecule of nitrogen or argon; but, nevertheless, the energy of the solar radiation is working in the electrons of the carbon and oxygen, and can be transformed again into exactly the same amount of radiant energy as was absorbed prior to disruption by the carbon of the carbon-dioxide molecules, simply by allowing the separated carbon and oxygen to combine again. The carbon and oxygen collide, and clash, and combine; the embracing electrons lose part of their energy of motion—just exactly the same amount of extra energy as was imparted to them by the radiation—and the energy of motion and mass which they thus lose reappears as etherial radiations of exactly the same energy as the disruptive radiant energy originally absorbed from the light. From sunlight through matter to sunlight again. From radiation through motion to radiation again. And from the last radiation a transformation perhaps into motion in the electrons in the brain-cell of a man!

Except as fuel for machinery, carbon in pure form does not provide animals with energy: it is only when carbon is built up into so-called food substance that it becomes a direct source of animal energy. Nevertheless, the principle is the same, whether the carbon be contained in fuel or food. It is white flour we eat, not black coke-carbon, but when the carbon of the wheat is brought into contact with the oxygen of the blood it burns in us and gives out heat, in the same way as coke burns in a furnace blast and heats a boiler, and in both cases the carbon came originally from the carbon-dioxide of the atmosphere and was separated and energised by the red rays. We get from food 3000 or 4000 calories daily, and all the energy we get from our food is primarily put into carbohydrates by red sunlight. Like Nebuchadnezzar, we are all grass-eaters, and, in more than one sense, our flesh is like grass. And good energy-creating diet it is, for a pound of wheat bread contains enough explosive energy to pitch itself about 14 miles, and every ear of grain hanging in a field of oats is an explosive bomb, and as full of potential energy as a can of petrol.

The pen writing these words is moved by sun-energy stored in green vegetation, and when Gimbernat drank soup made from a mastodon's tooth, he was really putting into his muscles sunbeams collected from green Miocene vegetation by the same herbivorous molar tooth hundreds of thousands of years before: he was releasing from the tooth sunbeams that had been imprisoned in the carbon of its gelatine for perhaps a million years. What a chequered career the carbon in Gimbernat's soup may have had—volcano, green leaf, mastodon's tooth, soup, blood, brain-cell!

Of all the wonderful illustrations of the theories of modern science with respect to the conservation and transformation of energy, this transformation and conservation of the radiant energy of red light in the chloroplast of the green cell is surely the most luminous and beautiful. The imagination is overwhelmed by the marvel of it—by the radiant testimony of the invisible to the accuracy of men's audacious theories about its working.

Let us look at it once again. Let us say the same thing in other words, for such a picture cannot be painted too often.

An electron whirling in the hydrogen atom of a fiery solar cloud drops from orbit three to orbit two (we are dealing with incredibly or at least inconceivably infinitesimal masses and radii), and lo, part of the electro-magnetic mass-of-motion of the electron is changed by the fall into the radiant etherial energy of electro-magnetic waves; and waves, red, green, and blue (all precisely proportioned in their particular wave-length) emitted from the atom run abreast across 93,000,000 miles of space, and in about eight and a half minutes beat upon an oak leaf. The green and blue waves refused by the leaf are reflected into the eye of a man, and, extinguished there as radiation, are reborn as extra electronic motions in his brain-cell, which extra motions, in some mysterious way, give rise in his consciousness to light and green colour and the subject-object leaf. (Be it noted that the *immediate* cause of vision is not radiation, which is merely a mediate cause, but the motion of electrons.) The red waves, on the other hand, absorbed by the carbon dioxide in the green chloroplast, are transformed into such extra and excessive motion of the electrons of the carbon-dioxide molecule that it disrupts, and its carbon and oxygen components go their separate ways, each still endowed with the red waves' radiant energy in the form of extra electronic motion. The red waves so transformed in the carbon are built up by the chloroplast, probably with the aid of other radiant energy, into big molecules of sugar and starch, but the energy of the carbon so built up into the sugar and starch can—as we have already explained—be made manifest again as radiant energy (of various wave-lengths) by oxidation, and such oxidation in animal and vegetable tissues is the sole source of all the characteristic exhibitions of vital energy—such as heat and motion.

Only in the plant is such a storage of sun-energy in easily available form achieved: animals cannot form it for themselves, and without photosynthesis of sugar and starch in the plant animal, existence would be impossible. The luciferous ether is also the fructiferous ether.

" Nature," said Mayer, who was perhaps the first to establish the relationship between light and vital energy, " seems to have set itself to capture the light that falls upon our planet, to transform the most mobile of all forces into an immobile form and to conserve it as such. With this end in view, it has covered the crust of the earth with organisms, which, during their lifetime, absorb the sunlight, and form, at the expense of this energy, the stores of latent vegetable energy incessantly accumulated. These organisms are *plants.* The vegetable world is a kind of store-house, where the sun's rays are arrested and stored for further use. The physical existence of mankind depends on this economical solicitude of Nature, and a single glance at our luxuriant vegetation involuntarily provokes the sensation of prosperity."

Marvellous, indeed, are the permutations, combinations, transformations, transubstantiations of energy which we have just tried to describe. Most marvellous of all, perhaps, is the precise quantitative relationship between the sun and the leaf—between light and life. An electron drops in its tiny orbit in blazing solar hydrogen 93,000,000 miles away, and eight and a half minutes later an electron in a gaseous molecule leaps up just as high as the solar electron has leaped down. Verily "we cannot touch a star without troubling of a flower."

Seen as great magazines and factories of energy, forests, and meadows, and prairies acquire more imaginative worth; every green leaf has a crimson heart, every green blade is a tongue of fire.

The chemist cannot compete with the sun in analytic and synthetic chemistry; but within recent years the biochemists have had successes that have awakened the hope that they may be able to supply us with carbohydrates without assistance of the leaf and even without assistance of the sun.

Some years ago Benjamin Moore showed that light produced formaldehyde from carbon-dioxide in colloidal solutions of inorganic iron salts, or iron, or aluminium hydrate, and suggested that the iron in the chloroplast might play an important part in photosynthesis. And quite recently, Baly, Heilbron, and Barker succeeded in producing formaldehyde—which has been supposed by many biochemists to be the first product in photosynthesis—by the action of ultra-violet light of short wave-length (2000 Ångström Units) on carbon-dioxide in water without the aid of iron or any other catalyst, and even succeeded, by means of longer ultra-violet rays, in polymerising the formaldehyde into carbohydrate.

These certainly were great experimental successes, but still rather of theoretical than of practical value, and the leaf and sun are likely to remain for many years undisputed starch and sugar manufacturers of the world.

The sunlight is a motive power of tremendous energy and the leaf a working organism of matchless efficiency. The solar energy reaching the ground at midday, as we have seen, is equivalent to 5000 or 6000 horse-power per acre per minute, and Mouchot calculated that in Paris on a bright day the sunlight falling during eight or ten hours in each square metre is equivalent in mechanical energy to one horse-power. Such motive power we can find nowhere else : it is the mightiest and cheapest motor power in the world. Nor can we hope to invent any absorbing and transforming machine so efficient as the green vegetation. Machines, it is true, have been invented by Mouchot, Eneas, Shuman-Boys, Ericsson, and others which transform the heat of the sun into mechanical energy which can be used for boiling water, baking bread, irrigating fields, etc., but how much energy can they absorb and transform as compared with a meadow? Think of the enormous surface the blades of grass in a meadow offer to the sun ! Timiriazeff states that " the total surface of the leaves of a clover plant exceeds twenty-six times the area of land occupied by the plant," so that an acre of clover is " equal to twenty-six acres of green surface absorbing the rays of the sun." Other plants offer even larger surfaces. " The sainfoin has a leaf surface thirty-eight and lucerne eighty-five times larger than the areas they occupy. Mixed grasses would probably give still higher numbers." And think of all the thousands of greedy little green hands held out to the sun by a spreading chestnut tree! We can find out how much sun energy the plant has absorbed by burning it, for the oxidation, as we have said, transforms into radiant energy (*i.e.* heat) the energy absorbed and hidden in the plant. On burning a single pound of wheat, 890 units of heat are produced—enough heat, that is to say, if changed into mechanical energy, to lift over 70,000 lb. 1 foot, or to throw 1 lb. more than 70,000 feet high. How much heat, then, with what mechanical equivalent, must be contained in a Wellingtonia pine or in a thick tropical forest, or in a great Canadian wheatfield! What absorber, what transformer could be made capable of storing so much energy, and capable, like a tree, of increasing its storage capacity year by year!

Nevertheless, it must be confessed that the green leaf as a storer of solar energy has its defects. As its colour tells, it does not absorb much green and blue light, and careful investigations have shown that it absorbs only about 25 per cent. of the whole radiant energy it receives, and that it uses a considerable part of this 25 per cent. in evaporation, and in respiration, and other unproductive work, so that in the end the total stored never exceeds an average of one hundredth of the energy received. Even *intensive* cultivation cannot recover from plants more than one-thirtieth of the solar energy they receive. Accordingly, even making allowance for the large leaf area offered to the sun, there is room for improvement, and it is not quite impossible that in the far future the ingenuity of man may succeed in inventing more efficient energy-absorbers and energy-transformers, though meantime he cannot compete with the great field and forest factories. But let us hope he never will succeed, for if, in the far future, he does succeed in beating sun and leaf at starch-making, it will be a sad day for the beauty of the earth, since then, as Timiriazeff mournfully prophesies, " instead of the emerald green of our meadows and woods, our planet will be covered with the mournful black surface of artificial light-absorbers," and the earth will be transformed into a universal factory, and will be all " black country " together.

The chemist and engineer, then, so far, cannot compete with sun and green leaf, nor must it be forgotten, when considering the energy stored in carbohydrates, that the energy would be unavailable for life were there not oxygen in the air to liberate it. Sun and leaf work up carbon-dioxide and water into the chemical (or electronic) energy of carbohydrates, but if it were not for oxygen the carbohydrates would be of as little value as are the miser's coins locked up in his coffers, and the oxygen in the air is mainly a photolytic by-product of the process of photosynthesis. Light and the leaf not only supply carbohydrate to sustain life, but take measures to make the energy utilisable. The oxygen emitted by the leaf when the red light falls on it is the main source of the oxygen on which both animal and plant life depend.

It may be, indeed, that all the oxygen in the atmosphere is the product of photosynthesis in the green plant, for the enormous amount of carbon-dioxide occurring as carbonate of lime in the seas and mountains—about seven times the volume of the present atmosphere—tells us that at one time there must have been vast amounts of carbon-dioxide gas, and that possibly the original atmosphere consisted entirely of it and nitrogen. And if all the original atmosphere consisted entirely of carbon-dioxide and nitrogen, there would seem to be no other source of the oxygen in the air than the photosynthetic activity of green cells.

On this supposition we find an interesting possible sidelight on some facts of evolution, for it may be that the heavy, sluggish reptilian animals and the rich vegetation of some of the early epochs of the world flourished then because the heavy proportions of carbon-dioxide in the air suited the growth of inactive animals and green carbon-feeding plants; and it may be that, as plants threw ever more oxygen into the air, the atmospheric condition grew suitable for the smaller, quicker, more active animals that arrived later.

At present, atmospheric obligation between green plants and animals is natural, for the plants as they feed give oxygen to the air for animals to breathe, and animals as they breathe give carbon-dioxide to the air for plants to feed upon.

We have dealt, so far, only with the relation of solar radiation to the energy supplied in the form of carbohydrate food to living things, but solar radiation, working in and through vegetation, has supplied man with other sources of energy, namely the fuels—wood, and coal, and oil. Like carbohydrate foods, these fuels have been manufactured from carbon-dioxide by light, and, as in the case of carbohydrate foods, their energy of position is converted into energy of action by oxidation. Oil and coal, moreover, contain—though it does not seem to have been pointed out—not only the photolytic energy of sunlight, but also the analytic energy of the organisms of decay, which, by decreasing the oxygen content of the decaying vegetation, increase its combustibility or radiant energy.

A great part of the extra-organic energy of man comes from these sources, especially from coal. In primæval times, in damp warm epochs, vegetation was exceedingly rank and luxuriant. Horse tails grew to 50 feet high and ferns grew higher still. And the jungles and forests of the warm Carboniferous periods were enormous factories where sunbeams were conserved for after use. For millions of years, sun and leaf worked together there, breaking up the carbon of volcanoes and storing up energised cellulose (the carbohydrate of wood) for unborn men. To-day, when we warm our toes at a coal fire, we may be said to be warming them with the red rays of sunlight that shone on the great mosses and ferns of prehistoric forests. And in burning the coal and liberating the sunbeams, we are perhaps using the very oxygen that the mosses and ferns we burn in the coal emitted ages ago into the sunny air.

What an inheritance of sun-power these shady jungles and forests bequeathed to modern man! The energy a man gets from his daily food amounts, as we have said, to 3000 or 4000 calories, and of these only about 300 or

400 calories are available for his voluntary muscles; whereas there is enough coal produced to-day—notwithstanding lock-outs—to supply every inhabitant of the globe with a ton of coal a year, which represents about 8,000,000 calories, or about eight times the total energy supplied by his food. How much sunlight energy is used to make gas-light, to propel the many millions of motor-cars and the many steamers now burning oil, would be difficult to calculate, but it must be immense. And it must be remembered that most of the electrical power in use to-day is derived from coal, and therefore from the sun. Even the energy of a zinc electric battery comes originally from the sun, for the coal is used to deoxidise the zinc and produce energy of tension, which is converted into electrical energy.

Nor have we even yet exhausted the sum of the energies exerted by the sun on behalf of living beings. We must consider, too, the enormous energy it exerts through water and air. Vast as are the amounts of the sun's energy which are expended in manufacturing carbohydrates, they are small in comparison with those it expends in lifting and moving water. The amount of heat required to evaporate water sufficient to cover 1000 square miles to the depth of an inch has been calculated as equal to heat produced by the combustion of 500,000 tons of coal; and the heat expended in evaporation during October over the Bay of Bengal has been estimated as equal to 800,000 steam engines of 1000 horse-power working incessantly. Even in evaporating water from trees, the sun expends much more energy than in making carbohydrates. It plays only a subsidiary part to the moon in lifting the tides of the sea, and we might perhaps dispense with its work in that respect; but to solar radiation we owe clouds, and rain, and rivers, without which land life would be almost, if not quite impossible. The weight of water lifted as vapour from the sea and land by the sun must be prodigious, for all the rain that falls and all the rivers that flow, solar heat has lifted. The clouds that may cover a whole continent are raised and held by the sun; all running water (save perhaps the condensed steam of volcanoes) is lifted before it can run. To keep the Niagara Falls and the Victoria Falls flowing, the sun must lift an equal volume of water as fast as the mighty torrents fall, and that is less than a drop in a bucket compared with the millions of rivers, large and small, that it supplies with water—the Amazon, the Mississippi, the Nile, the Ganges. Without rain, without flowing water, how could the land vegetation survive and make carbohydrates for man? The "white coal" which is already at work in the service of man, lighting his homes, driving his turbines, pounding his pistons, works as truly with energy imparted to it by the sun as Pouchot's sun-machine, or a railway engine, or a writer's fingers. We use to-day only a small fraction of the white coal lifted for us by the sun; but perhaps the day will come when it will do more work for man than ever the black coal of rotten primæval vegetations. But some of the energy of the sun's white coal we use willy-nilly. Life uses not only the heat of the sun reflected from the cloud, but also the heat of the sun absorbed by the cloud and given off again as heat of longer wave-length, and we have the benefit of the latent heat of its lifted water-vapour when it condenses. It is the sun-energy in the water-vapour which accompanies the Gulf Stream and which is given forth when energy of position is converted into energy of radiation—it is the sun-energy in the water vapour given forth on condensation that gives Britain not only a mild, but also a fertile climate.

And the sun lifts more than warm water vapour, it lifts warm air, and all our winds and tempests are due almost entirely to the energy absorbed from the sun's heat by the air and turned into energy of motion. The earth's rotation and the difference between the inherent temperature of the crust of the earth and of the ice at its Pole augment the motion, and the former plays a particular part in the Trade Winds, but the chief motive power is the sun. It is the sun that drives the clouds along the sky; it is the sun that turns the windmills and the water-mills; it is the sun that blew Columbus across the Atlantic; it is the sun that makes such cyclones and tornadoes as destroyed Miami.

Practically all the energy in the world that living things can use—the energy of carbohydrates, the chemical energy of photography, the electrical energy of dynamos, the energy of falling and flowing water, the energy of wind—except the lunar energy of the tides and the crustal heat of the earth, are directly or indirectly derived from solar radiation, and even the lunar tug and the crustal heat can be shown to be originally of solar derivation. Within the last few months, too, M. Georges Claude and M. Paul Boucheret, two famous men of science, have exhibited at the Academy of Sciences a mechanical apparatus of their own invention, whereby the sun-warmed waters of the tropical seas can be used to provide an inexhaustible supply of mechanical energy.

The surface water of tropical seas has a temperature some 20° C. above the temperature of the water 1000 metres down, which is kept cool by polar currents; and by means of cold water drawn from the ocean depths, the inventors propose to create a vacuum in a turbine and draw through it the natural steam of the surface water; and this steam, as they have shown, will have sufficient power, though at low pressure, to turn the turbine.

The main difficulty will be to pump up the cold water from the depth of the sea; but competent engineers believe that that difficulty can be overcome, and that it is possible that the warm water of the tropical seas will become a source of inexhaustible energy. In which case solar energy will have yet greater significance for living things.

CHAPTER X

ANIMAL PHOTO-PHYSIOLOGY

We have already discussed the relation of radiation to the life of the plant, and the relation of vegetable photosynthesis to the life of animals. We have described how the carbohydrates energised by light in the chloroplasts release, when oxidised, their intrinsic atomic energy, and how their assimilation and oxidation in the animal body are the mainspring of animal energy. But animals are themselves exposed to direct radiation; and direct radiation, as we have seen in the case of the hen's egg, serves at least to start the wound-up machinery of the germ plasm, and doubtless, in some form or other, plays a part, or rather many parts, in all animal activity, so that an investigation of the whole effects of direct radiant energy on animal life is plainly desirable.

The investigation is complicated, for radiation not only works subtly and intricately, it also works in collaboration with other even greater environmental forces, such as food and air, which mask its working and render it difficult to apportion its precise physiological value.

Lately there has been a tendency to exaggerate its vital importance and to make certain extravagant claims for it as a vitalising therapeutical force. Writers have claimed that most of the diseases and weaknesses from which civilised man suffers are due simply to lack of insolation (sunlight), and can be cured simply by radiation. These writers apparently fail to realise that though radiation may affect health and strength, it does not and cannot, except under very exceptional conditions, play such dominant parts in the maintenance of health and vigour as do food and air and the general routine of life. A man must die in a few minutes from lack of air, and in a few days from lack of food, while he can live all through the Arctic winter without any sunlight; and if—as is widely advertised—children enjoying sun-baths can gain an extra pound or two in weight, so also can children provided with an extra ration of food. Doubtless certain diseases and disabilities are due, or partly due, to deficient radiation of various kinds, just as certain diseases and disabilities are due, or partly due, to excessive radiation of various kinds, and doubtless the health of the community may be improved by providing more radiation where sunlight does not even reach the small minimum required for health; but radiation is only one of many environmental factors that affect vitality, and a factor of such comparatively small therapeutic importance that its value can hardly be statistically shown. Statistically speaking, indeed, we should be inclined to say that—a few diseases apart—so far as radiation seems correlated with health and strength there is more correlation between ill health and excessive insolation than between ill health and deficient insolation. We find no difference in the mental and physical energy of Scandinavians, Spaniards, Arabs, Red Indians, Hawaiians, Zulus, Cingalese, Goorkhas, Japs, Patagonians, all with very differing solar environment, which can be particularly closely correlated with the varying amounts of insolation they receive. We find that the Scotch, though with less sunlight, are quite as healthy and strong as the English, and the English, with less sunlight, quite as strong and healthy as the Mediterranean peoples. We find, too, no increase in sickness rate and in death-rate during sunless weather, unless the cold be sufficiently intense to depress vitality, or unless the sunlessness be due to irritating vapours like black fog.

Carozzi examined forty women workers who had worked in darkness in a photographic factory for periods varying from one to thirty-three years, and found them in good health and no more anæmic than workers working in the light. Miners and sewer-men who live a great part of their life underground are quite as healthy and long-lived as field-workers, and cave-dwellers in Tenerife and many other parts of the world are vigorous and normal human beings. Many of the healthiest and most energetic races, such as the Scotch and the Esquimaux, have been bred in dark huts and hovels. The Irish peasants lived for centuries in ill-lit, cave-like hovels, and yet, as Woodruff points out, " in spite of this lack of light in his home and out of it too—for the average cloudiness is very high—is a type of great physical vigour." It were strange indeed if insolation played a direct and dominant part in the vigour and health of animals when we consider man's uterine beginning, his hairy skin and his arboreal and antral history, when we remember also that a vast number of land and sea animals are night-prowlers and night-hunters.

Light is of paramount importance to vegetable organisms, but of only secondary importance to animal organisms. Even as one of the climatic factors of environment, sunlight has no more importance for animals than humidity, or pure air, or altitude, or wind. The interesting and important facts that ultra-violet rays can make anti-rachitic substances in the skin when they are lacking in the diet, and that sunlight and exposure to the air promote the healing of certain tubercular lesions, etc., do not imply that everyone is suffering from lack of light.

But, nevertheless, in spite of exaggerations and extravagant claims, radiant solar energy does play an interesting part in animal physiology, and can, in some cases, be used as a remedial agent. Let us glance briefly at some of its biological properties and functions.

The optical properties of light and the possible physiological effects of colour-rays received through the eye on the nervous system we have already mentioned in the chapter on the Eye. And it is probable that all the molecular changes due to light in the optical nerve tracts have not only visual and psychical significance, but also a specific influence on the functions and metabolism of the body. Exposure to sunlight in some cases causes sneezing, showing some reflex action through the eye on the respiratory centre, and it has been proved that light received through the eye increases the elimination of carbon-dioxide and the intake of oxygen. It is difficult to believe that a receptor specially adapted to receive and transform light rays should not have a physiological as well as a psychical function.

The eye, however, is only modified skin, and the whole skin surface has a sensory and receptual relation to radiant energy. Light, with its sensory product, sight, and correlated molecular changes, is not the only form in which radiant energy is received by the nervous system. The eye has its receptor with a special faculty for transforming solar radiation through molecular movements into sight, but the skin has millions of little nerve receptors which transform the radiation into warmth as a sensation and also into warmth as molecular movements. Under the transparent epidermis the nerves end in peculiar bulbous enlargements known as Pacinian Corpuscles, and some of these at least, though irresponsive to waves shorter than 5500 Ångström Units, are receptive to infra-red, red, and yellow rays, and both provoke in the brain the sensation of warmth, and reflexly arrange for certain thermal adjustments of the physiological functions. Each of these little bodies may be considered a little eye blind to light but sensitive to warmth, and each of them is a centre whence molecular disturbances are propagated far and wide through nervous channels. As Luckiesh and Pacini well express it, "it is as if these sensitive spots were miniature radio-receiving sets tuned-in on certain wave-lengths to catch the constant flow of radiations which are broadcasted by the sun. Now a remarkable, though not generally realised fact is that when radiation strikes the receptors with which the skin is so abundantly supplied, the influence is conveyed internally to millions of cells situated in different tissues." If the radiant energy so carried suit the cells, the cells profit, but if it be excessive, it sets automatically in action the legs or the sweat glands of the organism, in an endeavour to mitigate the harmful influx of energy. If measures to mitigate the radiant energy fail, then the whole organism suffers. So we may consider the nerve endings in the skin as at once receptors, transformers, and sentinels.

But the skin has other receptors and transformers in its dermis. Even as chlorophyll is formed as a light screen and filter in the plant, so a brown pigment called melanin is deposited under the action of sunlight as granules in the deeper cells of the epidermis. This pigment absorbs the radiations of the visible and ultra-violet light which happen to penetrate so far, and, converting some of them into radiations of less energy, longer wavelength, and greater power of penetration, passes them on to the thermal nerve endings in the skin (which, as we have above described, send impulses to brain centres which thereupon moderate the heat through the sweat glands and vaso-dilator nerves.

If melanin powder obtained from ox-eyes be mixed with water to form a brown-black suspension, and a few drops of the suspension are placed on the palm and exposed to light concentrated by a burning-glass, the radiation absorbed by the pigment and converted again into heat will evaporate the water, yet the hand will not be overheated. This is probably an illustration of how pigment acts in protecting the deeper layers from too much heat. By conversion of radiation into heat, the sweat glands of the skin are stimulated, water is evaporated, and the part exposed is kept cool. The pigment also radiates away heat more quickly than unpigmented skin, and thus a negro's skin exposed to strong sun is cooler than a blond's skin. It also probably prevents the penetration of excessive doses of ultra-violet rays. Its prime function, therefore, as says Dr. Leonard Hill, is "undoubtedly that of a screen against the lethal effects of excessive light and the conversion of light into heat which is sweated off when excessive."

Dr. Rollier believes that the pigment acts as a kind of dynamic accumulator. "Experience," he writes, "at least confirms this by showing that the resistance of the patient is nearly always in proportion to the degree of pigmentation: it acts not only in protecting the skin against the too violent irritation of the ultra-violet rays, but in regularising the thermic contribution of the sun. Finally it is probable that the pigment receives, furnishes, and activates the elements essential to the metabolism of the hormones. Pigmentation is the expression of an increase in the deep biological process of a fermentative and hormonal nature, as demonstrated by Bloch in the skin, by Pinkussen in the blood, and by Bickel and Ischido in the marrow of the bones." Jesionek, on the other hand, believes that the pigment passes into solution in the blood and is changed there into substances that act favourably in pathological processes, such as tuberculosis. Logically, therefore, light treatment should be intermittent and the patient allowed alternately to form pigment and to depigment again.

Under the action of light, pigment is quickly formed in all human beings except albinos and some red-blonds. It is found most plentifully in black races, not so plentifully in brunets as in blacks, and least plentifully in red-blonds; it can in each type be increased to a maximum by exposure to strong light.

Formerly it was believed that only ultra-violet light led to pigment formation, and that pigmentation was in some causal relation with a precedent erythema or photodermatitis (sunburn), but recent experiments give us ground for believing that some dark heat rays by themselves can cause pigmentation, that the deepest pigmentation is caused by a combination of infra-red rays with ultra-violet rays, and that pigmentation can occur without any precedent erythema. Wittek, after ten years' experience of insolation, writes: "The optimum for pigmentation by light rays apparently consists in a definite combination of chemical and heat rays." It is certain that the deep dark pigmentation caused by the mixed ultra-violet and infra-red rays of sunlight to some extent fade away when a patient is subjected to the cool ultra-violet rays of a mercury lamp, and Dr. Rollier and Dr. Bernhardt have both proved that pigmentation may be produced by gradual insolation without any appreciable sunburn.

The pigment is formed *in situ* in the skin and seems to have some connection with the adrenal glands (which, as is well known, are related to the pigmentation seen in Addison's disease). It is believed that the adrenal supplies to the skin two substances, an oxidase and an amino-acid like adrenalin, called "phenylalanine," whose combination under the action of light produces the pigment. Even excised skin forms pigment when exposed to light. "Whatever," say Luckiesh and Pacini, "pigmentation may or may not signify, it certainly furnishes an index of the internal chemical affairs of the body." But it is also to some extent an index of the condition of the sympathetic system, for the chemical process is in some way regulated by the sympathetic system. Luckiesh and Pacini found that ergo-toxin which, taken by the mouth or by injection, deadens the sympathetic nerve endings in the skin, also prevents pigmentation, and that drugs which activate the sympathetic system promote pigmentation.

Radiant energy of the sun, then, is absorbed and transformed mostly into dark heat in the skin by its nerves and by its pigment, and in both cases, as we have seen, one result of the absorption and transformation is a stimulation of the vasomotor nerves and sweat-glands. In fact, up to a point, the sunlight acts almost entirely as heat energy, and all its physiological results, save the formation of pigment, could be produced by a poultice, or fomentation, or Turkish bath. To a great extent, the heat simply provides the body with invisible heat in addition to the heat generated in the body itself by oxidation, and in weak and old people, who have little autogenic heat, the gift of additional calories is an advantage. In certain cases also the solar warmth is good, where it is desirable to increase the flow of blood in the skin or the secretion of sweat, and so remove waste products and stimulate local and constitutional chemical processes, or where it is desirable to reduce arterial pressure, by cutaneous hyperæmia. In fact a sunbath, so far as those thermal results go, is good for just the same class of cases as benefit from hot fomentations, hot baths, and Turkish baths, and the normal healthy man does not, in these respects, require much sunlight at all. His own body, protected by its clothing, will make all the heat he requires and sometimes more than he requires, will probably work much better in the shade than in the sun, and will probably benefit much more from a *cold* air- or water-bath given as a stimulant than from a *warm* air- or water-bath given as a diaphoretic or rubefacient.

It must be realised that the heat production of the body is very small compared with the heat energy of the radiant energy of the sun. Rubner found that sunlight gave heat thirteen times as fast to an animal as the animal itself radiated heat. Moreover, the skin is twice as tolerant of sun-heat as of pure infra-red rays, so that there is more risk of overheating. Sonne showed that the skin of the arm could endure 3·11 calories per square centimetre per second in the case of visible light and only 1·79 calories in the case of shorter infra-red rays. In each case 35 per cent. of the rays were reflected by the skin.

So far, then, as the sun is a giver of heat it is not of great biological importance for man outside polar latitudes, and sun-baths for miners and healthy people, in so far as they simply increase the heat of a healthy body, are quite unnecessary, and may be enervating. It is certain that much illness—neurasthenia, anæmia, etc.—in sunny and hot climates is due to excessive insolation, and it is probable that the greater average mental and physical vigour of natives of temperate zones is due to freedom from the thermal and photochemical irritation of excessive sunlight.

We have not yet, however, nearly finished with the physiological relations between sunlight and the skin.

The hyperæmia or blushing of the skin produced by solar as by other heat fills the reticular network of capillaries in the skin, so that it is interposed like a red parasol over the deeper tissues, and this red parasol has its own special relations to heat and light. It absorbs infra-red, ultra-violet, and practically all of the visible spectrum except red. The red of the hæmoglobin, as compared with the green of chlorophyll, quite possibly indicates another complementary relation between plants and animals. The stroma of the red blood-corpuscles and its red pigment may represent in animals the stroma of the chloroplast and the green pigment in plants, and the blue and green rays absorbed by the red blood corpuscles (after transformation by the red pigment) may be physiologically as important for the animal as the red rays absorbed by the chloroplast (after transformation by the chlorophyll) are important for the plant, and seem to suggest, too, a physiological advantage for animals in the green colours of vegetation. But, in any case, the red parasol at once physiologically differentiates between the mixed heat of the sun and the heat of infra-red or ultra-violet rays. For near infra-red, and green, and blue, and ultra-violet rays are all caught by the red parasol, whereas, as we have said, the red rays, which are the most energetic heat rays of the solar spectrum, pass through. The red rays are able, accordingly, to penetrate vascular tissues better than any other solar ray, as can well be seen when one looks at the sun through closed eyelids. The red rays, in fact, penetrate as far as the muscles and the joints.

One important result of this thermal filtration of solar rays with penetration of red rays probably accounts for an interesting and important fact noted by Sonne. Sonne showed that on radiation of the skin with infra-red rays as strong as could be borne, the temperature of the surface rose to 45·5° C. and that the temperature gradually fell with increasing depth to a steady temperature of 37° at a depth of $\frac{2}{8}$th inch; whereas on radiating the skin with visible rays as hot as could be borne, the temperature rose at the surface to 43·8° C., but reached a maximum of 47·5° at the depth of $\frac{1}{8}$th inch. In some relation, too, to the transparency of blood to red rays, may be Oerum's observation that red light causes a diminution in the number of red corpuscles and the hæmoglobin content, as well as a reduction of the quantity of blood, while blue light produces a considerable increase in the quantity of blood along with an absolute increase of the total hæmoglobin.

It may be noticed, too, that the transparency of the blood to red rays is advantageous to the body in other ways. The dilatation of the capillaries on exposure to light and heat is not primarily for the purpose of offering a larger surface for the absorption of heat, but in order to provide a larger radiator surface from which heat may be radiated away, and it is plain that if the blood in the capillaries absorbed the hot red light, the radiator would have little or no cooling value.

We see, accordingly, that the sun rays have certain specific relations to the skin and to the skin capillaries; we find that red light penetrates more deeply than the other visible rays and than infra-red and ultra-violet; we find that the red is not absorbed by the capillary blood, and that cooling by distending the capillaries is thus facilitated. The very fact, indeed, that the surface is cooler than the underlying tissues, which gradually increase in heat from without inwards, ensures good radiator action.

Radiant sun-heat, therefore, has a particular distribution in the cutaneous and subcutaneous tissue; it heats the surface capillaries less and the deeper tissues more than the same radiant energy imparted in the form of infra-red; and its distribution favours its outward radiation.

So far, we have been dealing simply with sun-blush or transitory hyperæmia, which dwindles away as soon as the heat is removed, but when the unaccustomed skin is exposed to sunlight, it usually undergoes further changes, which are not found after warm baths of infra-red heat, or after either air- or water-baths. We find that some time after exposure to the sun there is a secondary persistent reddening of the skin, which has been called "erythema." This secondary reddening, of the nature of a dermatitis or skin inflammation, is photochemical, not thermal, and occurs even when the sunlight has little caloric value, though it is increased if the skin be warmed either from within or without. It is the result of ionisation and irritation of the deep cells and nerve endings of the epidermis by ultra-violet rays, and, like other irritative skin inflammations, it causes a flow of more blood and lymph and lymphocytes to the part and alters the immunising properties of the tissues. It is a chemical burn, not a thermal burn, and differs in many respects from thermal burns. It appears, not at once, as in thermal burns, but two to eight hours after radiation, and the dilatation of the arterioles and capillaries is followed by stasis,* thrombosis, and diapedesis, and persists to some extent for months after radiation. Attached to it, therefore, are all the direct and indirect vascular consequences we have mentioned when discussing hyperæmia, but to a greater degree; and any ailment that benefits by derivation of blood to the superficial vessels will be therefore benefited by erythema solaris. On recovery from the erythema, the skin will not again for a long time show erythematous reaction to the same dose of ultra-violet light, and it can be gradually educated to tolerate very long and strong radiation without reaction. Its immediate immunity is due to coagulation of the more superficial layer of living cells, and in such a tolerant and immune condition it probably acquires, like pigment, some protective function.

Ultra-violet erythema is almost always followed by some desquamation, depending on the dose, and an overdose will cause blistering and sometimes even necrosis. The erythema, as we have mentioned before, is

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* Stasis = arrest of the blood flow. Thrombosis = formation of blood clot in the vessel. Diapedesis = emigration of the white blood-corpuscles through the walls of the capillaries.

accompanied by pigmentation, due to action of the same rays, but the two phenomena are not causally connected: there may be pigmentation without erythema, and erythema without pigmentation, and the skin can acquire some immunity to erythema photogenica even in the absence of pigmentation. Apart, however, from the immunisation following erythema, those who are naturally well-pigmented show more resistance to the inflammatory effects of ultra-violet rays than do blonds and red-blonds.

The ultra-violet rays which cause the dermatitis have been shown to be chiefly those of wave-lengths between 3200 and 2800 Ångström Units, and the most effective rays seem to be those of round about 3000 Ångström Units. Ordinary sunlight, accordingly, which stretches as far as ultra-violet rays of a wave-length of 2900 Ångström Units, just includes these most potent rays. Rays shorter than 2900 Ångström Units have less and less photochemical potency; and rays as short as 1200 Ångström Units (which can be produced by artificial light) do not penetrate the skin at all. Shorter than 2000 they do not penetrate even the air. The active ultra-violet rays of the sun lie between 3300 and 2950 Ångström Units; but even these rays have little penetration : they cannot penetrate ordinary glass or a thin film of skin from a blister, and are easily absorbed by fog and cloud. Accordingly, in smoky cities most of the ultra-violet light of the sun never reaches the soil, and it is only at high altitudes in clean air that we get the solar ultra-violet rays in their full potency.

When the sun is low in the clear heavens, diffused light of the blue sky contains thirty times more ultra-violet light than the direct sunlight, and even when the sun is at its zenith, the blue sky radiates 15 per cent. more ultra-violet light than the sun itself, so that it is possible to get sunburned without actually being in direct sunlight.

The most obvious effects of ultra-violet rays on the human skin are pigmentation and erythema due to photochemical irritation.

The ultra-violet rays act by giving extra energy to the electrons of atoms which absorb them, thus effecting the release of the electrons and producing ionisation. " As the living cell dies," says Leonard Hill, " a fine granulation appears in the cellular substance, an aggregation, probably produced by the rays, putting an end to the mutual repulsion of positively and negatively charged particles."[1]

Thus they can coagulate protoplasm and destroy hormones, pro-enzymes, and enzymes.

But the most obvious effects of the short rays are not the most important physiologically. Though the rays have very small power of penetration—and they certainly cannot penetrate further than the superficial capillaries—yet it has been proved, as we shall see in the next chapter, that they produce in the body vitamins which prevent rickets and that they increase the bactericidal power of the blood. We shall also see that these important rays can be conveniently produced by artificial light almost unmixed with other rays.

Here we may say a few words on sensitisation. Sensitisers are substances in the blood that alter the physiological value of radiations which happen to reach them. The pigment of the skin is usually regarded as a sensitiser: it converts visible heat waves into invisible heat waves which excite the sensory nerves. Hæmatoporphyrin (a substance obtained from hæmoglobin), if injected into the tissues, changes harmless sun-rays into dangerous rays, or at least renders an animal pathologically sensitive to light. Mice sensitised by eosin exhibit swelling and necrosis of the ears on exposure to light. Cattle with unpigmented skin, fed on buckwheat, develop sores when exposed to the sun. Pigs can also be sensitised by eating a root called Lachnanthes. A diet deficient in protein sensitises some people, so that parts exposed to the light become swollen and dropsical. And many other instances of sensitisation might be quoted. They all suggest constitutional differences resulting in different responses to insolation.

Before leaving the subject of insolation, we wish to return to the proposition we advanced at the beginning of the chapter that the normal man requires little sunlight in order to enjoy good health, and that the chief physiological result of sunlight is the production of dark heat in the tissues.

As we pointed out, it is extremely difficult to apportion the physiological value of sunlight, and still more difficult to lay down general rules as to minimum, maximum, and optimum quantities of light. It is certain that man may suffer in general health, in vigour, and physique from complete lack of light, that deficiency of light short of complete darkness is physiologically deleterious, and that excess of light can be dangerous and deadly; but to mark the points where deficiency and excess begin is almost impossible.

That depends on race, custom, costume, colouring, habit of life, food, vasomotor activity, and sometimes even on personal idiosyncrasy, consequent, as we have suggested, on sensitisers in the blood. Nor in the great majority of cases is it desirable or necessary to give sun-baths to make up any deficiency in solar radiation, for all that is required can be supplied through the eyes, and the skin of the face, and hands, even by the diffused light of an ordinary bright day. In the course of one bright summer day the face and neck and hands may receive as much light as is given during some weeks of artificial insolation. There are few summer days without a considerable amount of sunlight, and few places which in summer lack ultra-violet light. The sun at noon on a summer day in England may have as much radiant energy as in the tropics, but whereas people in the tropics who have learned wisdom hide from the hot sun, people in England are encouraged to sun-bathe naked for hours. Wiser surely it would be to advise people to beware of too much insolation in summer, and in winter, if necessary, to supplement deficient radiation by means of lamps. Because sunlight is a psychical excitant, or because a little ultra-violet light cures rickets, or because the sun by irritative processes throws stimulating substances into the blood, or because it decreases loss of calcium or phosphorus, or because vasomotor dilatation produced by sunlight improves skin nutrition and increases the growth of hair, it by no means follows that sun-baths are necessary or even physiologically desirable for most healthy people, or that they are more valuable than a sea-bath or a brisk walk. It is quite easy to understand that a heating of the subcutaneous tissue such as Sonne has demonstrated, or an irritant katabolism of cells, may have a temporary stimulating effect on vital chemistry and the vital functions, but the question remains whether such stimulation beyond the degree to which civilised clothed men are accustomed is, in the long run, good for the organism. Quite apart from sunstroke, which seems mainly due to overheating of the blood in the brain, and to heat-stroke, which is mainly due to overheating of the whole body, and to actual skin necrosis due to ultra-violet rays, there are certainly many other cases of obscure ill-health due to excessive exposure to the sun—especially in those hypersensitive to the sun—cases which should be treated by darkness. It is well known that the long summer day in low latitudes causes nervous irritability and nervous exhaustion; and in the tropics exhaustion following temporary stimulation is usual. Major Woodruff, who made a special study of tropical light, wrote: "During the first few months of a tropical residence, before the light stimulation has caused exhaustion, there is a marked increase of the feeling of well-being. Mental processes are more active, muscular vigour is marked, and there is a universal opinion in all newcomers that the climate is not bad, after all; nevertheless, it is only a question of time in most cases till exhaustion supervenes." Statistics proved that nearly half of the troops—not only blonds, but brunets—who spent three years in the Philippines deteriorated in health.

But, of course, it must be recognised that other factors besides tropical light and heat may have had deleterious effects on the health of the troops.

According to evolutionary theory, man began life as a hairy animal living in the leafy shade of a forest, and when he lost his own hair he annexed the hair of sheep and other animals, and under this borrowed hair he has spent hundreds of thousands of years. The radiant heat of the sun, as we have mentioned, can sometimes radiate the skin with seventeen times the radiant heat which the body irradiates; but the sun is a capricious and variable source of heat, and civilised man in all cool climates depends chiefly for his bodily heat not on the sun without him, but on the sun-energised fuel within him, whose heat—some 3000 or 4000 calories in value—he collects and conserves by means of the borrowed hair. An Eskimo after a big meal of fat and protein can sleep in his furs in the open, even in the Arctic zone. By means of his clothes, in fact, civilised man surrounds himself with a covering of equable moist warm air, and lives, except for his hands, face, and neck, in a subtropical climate. Further, by exercise, even in his clothes, he can increase his thermal output to as much as 10,000 or more calories, and bring all his sweat glands into action. Likewise, on exposure to cold his body can make more heat and can conserve it. Man, therefore, under ordinary circumstances has no need of thermal contributions from the sun, and even when the sun is shining, prefers to heat himself by his own fuel. When the weather is warm, indeed, the clothes he wears serve rather to keep out the sun's extra heat than to conserve his own radiations.

Such use of borrowed hair seems perfectly sensible and physiological, and man certainly cannot do himself much harm either by dispensing with the sun's heat—unless he be old and debilitated and unable to make heat—nor much good in availing himself of it. But if this be so, how are we to explain the wonderful results reported by such eminent helio-therapeutists as Bernhardt, Rollier, and Rosselet, who declare that exposure to direct sunlight has a remarkable effect on the health and vigour of man? Nothing we have mentioned so far in the chemico-physics or thermo-physics of the sun—neither the sun's heat, nor solar dermatitis, nor increase of calcium—would seem capable of explaining the improvements they record, or of explaining why half an hour's direct insolation on the body should be so much more effective than the day-long exposure to which many people's hands and faces are subjected. The explanation probably is that other important factors besides sunlight play a big part in the physiological result. Sunlight works in collaboration with other environmental forces stronger than itself, and probably much of the constitutional benefit ascribed to sunlight ought really to be ascribed to these.

Civilised men live, as we have said, in a subtropical, damp climate, under a borrowed skin, and when they shed their skin and lie unclothed in the sun—especially in an Alpine sun—they completely alter the climatic conditions under which they have been living. The air, instead of being damp and hot, is dry and cold; the air, instead of being stagnant, is in movement, and the atmospheric pressure is reduced. The physiological effects of such complete climatic change are, and must be, very great. The following table by Lefèvre will show the effect of cool, moving air and the difference of metabolism in a clothed and unclothed man.

HEAT LOST BY A HARDY MAN OF 65 KG. RESTING

(Rate calculated per diem in calories.)

Temperature of air.	Velocity of air movement.		
	3·5 m. per sec.		1 m. per sec.
	Naked.	Clothed.	Clothed.
– 1°	10,698	6,654	5,406
+ 5°	7,834	4,704	4,000
10°	5,718	3,690	3,060
15°	4,158	2,754	2,317
20°	3,144	2,130	1,896

In Alpine health resorts especially, where insolation is carried out, the air, owing to its high physiological saturation deficit, is drying and cooling all the year round, and Dr. Leonard Hill states that " the cooling power which the Alpine air exerts out of doors, as measured by the dry Kata-thermometer, is some three times greater than in ordinary conditions indoors. The heat production of the resting subject, stimulated by this cooling power, is put up, above that taken indoors in London, some 40 to 50 per cent. in the case of clothed adults, and 60 to 90 per cent. in the case of children exposed more or less nude to the sunny, calm, Alpine, windy atmosphere." Dr. Leonard Hill has shown, too, that " a high cooling power not only increases the heat production of the body during exposure, but it raises the basal metabolism to a higher level. The fire of life is made to burn faster," and a careful examination, with Sir Henry Gauvain, of children at the Treloar Hospital, Alton, and Hayling Island, led him to conclude that the high metabolism produced equally in pigmented and unpigmented children was due to the cooling power of the air, and not to radiation. This conclusion was confirmed by observations made on children exposed to the arc light at the London Hospital in a warm room, for children under such conditions, where the air was not cooling, showed either slight or no increase in their metabolism and little improvement in their general condition.

Halstead, who introduced the open-air treatment in the Johns Hopkins Hospital and who, with Trudeau, carried out the same treatment at the Sarawak Sanatorium in the Adironacks, made his patients live night and day in the open air, and attributed his remarkable results in affections of the bones and glands solely to the fresh air; S. Bangs, with much experience of both, believes that the air-bath is more beneficial than the sun-bath, while Professor J. Dollinger of Budapest says it is impossible to decide whether open air or sunlight plays the more important part in the healing processes.

Every specialist with knowledge of open-air treatment has seen how a little more exposure to fresh, moving, cooling air will lower a patient's temperature and check his night-sweats—big constitutional effects which radiation alone cannot achieve. In cases in the High Alps it has been noted that the febrile temperature drops even before insolation.

We are safe, therefore, we think, in affirming that though cautious insolation may have some of the physiological advantages we have noted—reduction of blood-pressure, relief of congestion, retention of phosphorus and calcium—yet it plays, and can play, only a subordinate part in the metabolism and vigour of normal men, who with a very little of it can yet live an energetic and healthy life, and who are just as likely, in summer-time at least, to suffer from excess of it as from deficiency.

CHAPTER XI

PHOTOTHERAPY

In previous chapters dealing with the physiological relations of sunlight to health, we have more than once incidentally referred to some of its relations to disease. We have suggested, for instance, that sunlight as thermal energy acting on and in the skin produces much the same vascular changes as are produced by fomentations, mustard-leaves, and other forms of heat, and that, therefore, it might be used in the same way in the treatment of rheumatism, high blood pressure, and other diseases. We have suggested, also, that credit has sometimes been given to light which was really due to air. But now we must come to closer quarters with the question of light and disease, and especially with that modern department of phototherapy which is known as ultra-violet radiation or actinotherapy.

Phototherapy, or at least heliotherapy, as empiric treatment of disease, has had a long past. There seems some reason to believe that the ancients took sun-baths not merely as pleasure baths or health baths to promote their health, but as treatment for definite diseases; and in the early centuries of the Christian era red light was used in the treatment of smallpox, and sunlight was used to disinfect contagious garments. But the first glimmerings of phototherapy as a science appeared only in the last decades of the eighteenth and the first decades of the nineteenth centuries, when Faure, Hufeland, Dobereiner, Rosenbaum, Rikli, and others wrote treatises on the subject, and used light more or less systematically and scientifically in the treatment of rickets, scrofula, etc., and not till Downes' and Blunt's discovery in 1876 of the bactericidal power of violet light could the foundations of scientific light treatment be said to be well and truly laid.

" The researches of Downes and Blunt," says Dr. Rosselet, " occupy the same position in the study of bactericidal action of light as do those of Newton in the study of radiant energy : they form a foundation and a base." Their experiments were undertaken to combat Spallanzani's view that light killed microorganisms merely through its thermal energy, and they succeeded in proving that violet light—the light weakest in thermal energy—and diffused light were more bactericidal than the hotter light of the spectrum, and that they acted directly on the microbes in the culture medium, and not through changes in the culture medium.

That was a great advance in scientific theory, and within a few years Finsen utilised it in practical phototherapy. Finsen, who already had carried out researches on the action of red light and violet light in smallpox, conceived the idea of using the violet rays of sunlight to kill the tubercle bacilli which destroy the tissues in cases of skin tuberculosis known as "lupus." He quickly realised that it would be necessary to concentrate the light and to filter most of the heat rays out of it in order to effect sufficient penetration with the bactericidal rays and yet not burn the tissues; and after many experiments he succeeded in constructing a suitable apparatus. It consisted essentially of a hollow plano-convex lens 4 or 5 inches in diameter. This hollow lens was filled with a blue solution of sulphate of copper and ammonia, which cooled and allowed the passage of blue and violet rays, but absorbed almost all the red, the greater part of the yellow, and a part of the green. This lens was mounted in such a way that it could be raised and lowered, and placed with its plane surface at right angles to the sunlight in whatever direction the sunlight might come.

Thus the sunlight could be readily focused on any lupus patch. But the Danish sun is as capricious as the English, and finding that electric light contained abundance of violet rays, Finsen determined to use it instead of the sun, and made suitable modifications in his concentration apparatus so as to refract, filter, and cool the electric light sufficiently. That did not finish his labours, however, for, after he had made this change, he became cognisant of the strong bactericidal properties of ultra-violet rays, and had to make still further adaptations. His difficulties in utilising the ultra-violet light were two-fold. Firstly, ultra-violet rays would not pass through glass, and secondly, they would not pass through vascular tissues. He surmounted these two difficulties: the first, by using quartz lenses, which are transparent to ultra-violet rays; the second, by rendering the skin bloodless by pressure. We cannot here describe his final apparatus in detail, but it was ingeniously adapted for the work it had to do, *i.e.* to concentrate ultra-violet rays on anæmic lupus patches, and in practically the same form it is in use to-day all over the world.

In its science and its art Finsen's achievement was brilliant and in its results magnificent. "He made few and simple experiments," say Luckiesh and Pacini, " but they were devised, performed, and interpreted with an unerring instinct rightly termed genius." Up till then the terrible disease lupus had been almost impossible to cure, and the tubercle bacilli had gnawed pitilessly away at the features of its victims, but this ingenious young Dane routed and slew the bacilli, and saved thousands from the martyrdom of a loathsome disease. The tiny invisible rays discovered by Ritter nearly a hundred years before conquered the tiny invisible foe.

How the tiny invisible rays act is another question. Finsen worked on the fact, proved by Downes and Blunt, that the violet rays were bactericidal, and assumed that the violet and ultra-violet rays directly slew the tubercle bacilli in their lairs in the skin. But later investigations have thrown doubt on Finsen's assumption. So feeble is the penetration of the short wave-lengths of ultra-violet rays that one bacterium protects another, and it is almost impossible that many of the well-entrenched bacilli can be killed *in situ.* It is more likely that the bacilli are killed by bactericidal substances which, as Dr. Leonard Hill and Dr. Eidinow have shown, are produced more plentifully (even if only transitorily) under the stimulation or irritation of ultra-violet rays. Dr. Eidinow has found that a dose of ultra-violet rays sufficient to cause erythema will increase the bactericidal power of the blood, and it has lately been shown that treatment of lupus by the Finsen lamp is more effective if it is supplemented by general ultra-violet radiation. At the Finsen Medical Institute at Copenhagen, Dr. Axel-Reyn adds general to local treatment by the Finsen and Reyn lamp (a modification of Finsen's lamp), and Dr. Sequeira at the London Hospital finds that cases of lupus which do not heal under local Finsen lamp treatment can be cured by exposing the nude body to the carbon-arc light for from fifteen minutes to two hours daily—the time of exposure being gradually increased.

However the rays may act, their action is healing, and their use in lupus is one of the triumphs of radiotherapy.

Even as lupus can be healed by the ultra-violet rays, so also can tubercular joints and glands, and many ulcerations and wounds can be hastened in their healing. In 1902 Dr. O. Bernhard of St. Moritz, who had been treating surgical tuberculosis for many years by open-air methods, was moved by Finsen's work and results to expose all wounds to the pure, dry mountain air and to direct bactericidal powers of the ultra-violet rays, which, as we have already noted, are particularly potent and plentiful in high Alpine stations. He at once obtained encouraging and remarkable results, and has since treated a great number of cases. In the same year, Dr. F. de Quervain started similar heliotherapy at Chaux de Fonds. Following their lead, Dr. Rollier founded a large number of sanatoria and sun-schools at Leysin, where he has treated, with sensational success, thousands of cases. And more recently, Sir Henry Gauvain instituted the same treatment at Alton and Hayling Island.

" Since 1902," writes Bernhard (in his book on " Sunlight Treatment," published 1925), " I have carried out sun treatment uninterruptedly, and have become more and more a disciple of this method. . . . When I compare the results obtained in the 302 cases treated with fresh air only, with the 1163 cases treated by open-air and direct sunlight, the comparison is very clearly in favour of the great therapeutic value of direct insolation, inasmuch as by it not only is the duration of the healing process shortened, but, what is the main advantage, the operative interference is still more reduced, even in apparently hopeless cases."

Surgical tuberculosis has been successfully treated not only by sunlight, but also by the light of lamps containing abundance of ultraviolet rays; and Ernst of the Finsen Institute of Copenhagen, who has practised this treatment for several years, declares that "observations at the Finsen Light Institute are almost like an experiment which points to the importance of the high sun, outweighing every other factor." With this statement of Ernst's, however, Dr. Bernhard does not quite agree: he maintains that "neither the sun nor artificial light alone will achieve results equal to those due to a combination of light therapy and dietetics with climatic treatment, especially in the high mountains. Take it all in all, the final goal is a raising of the body resistance, and to this end a combination of favourable factors of course works more effectually than any single one.

"High sun and high climate combined are the best means at our disposal at present for combating our greatest plague, tuberculosis, whether it be of the lungs or of the surgical form. Both factors are a great stimulant and remedy for the human organism, and in their effect, compared with the sun and air of the plains, especially in winter, are as champagne unto wine."

Again: "The ideal solution would be if all cases of surgical tuberculosis could be treated in the high mountains. Under the influence of the sun and climate there, most of the patients would recover spontaneously, and where there were indications for surgical treatment, better results could be obtained than elsewhere."

Dr. Rollier holds that heliotherapy, combined with the open-air cure at high altitudes, heals external tuberculosis in all forms, in all stages, at all ages, provided it is used long enough. In the case of children, he believes that it exercises a remarkable action in the muscular system. "By dilating," he writes, "the capillaries, the sun draws the blood from the depths to the surface through the muscular layers, thus acting as the most perfect system of massage. This rebuilding of the muscular system must also be attributed, it would appear, to a constant tonic action of cold air on the skin, and so on the muscular fibres (an action following upon the vibratory shock which the solar radiations cause upon the close network of the sensorial terminals of the skin). By restoring to the muscles and ligaments, those levers of the frame, their original tonicity, the sun-cure favours, by a strictly physiological process, the return of the functions of the joints. Thus heliotherapy may restore to young bodies, even those most atrophied and warped by disease, their natural beauty of form. Little rickety bodies after a few months' cure are possessed of firm muscles, full and harmonious forms, and sometimes lines as pure as those of the young athletes of ancient Greece. A mere glance at a sun-cure balcony will suffice to show that this comparison is not exaggerated. The sun-cure, especially at high altitudes, causes in children an increased activity of the lungs, and, in consequence, increased heart action and general circulation. Under its influence the number of corpuscles is augmented as well as the content of the blood in hæmoglobin, the blood formula improves, and nutritive exchanges are more active. The tonifying power of the sun also acts upon the abdominal organs; the sun-bath, strictly rationed, sharpens the appetite, stimulates the digestive functions, and restores strength."

These are enthusiastic statements, and while one might dispute their formulation, about the facts themselves fortunately there can be no doubt at all. Thousands of cases which otherwise would have required surgical operation, with consequent maiming or laming, recover completely and regain general health *pari passu* with the healing of the local lesion. That the sun, and especially the ultra-violet rays, in such cases plays a part in the therapy is also indubitable. The only question is how the rays act and to what extent, and both these questions are still unsettled.

The local action of the light in open wounds must, of course, differ from its action in closed, deep-seated lesions. In open wounds it is plain that the light may have a germicidal action on any tubercle bacilli or other germs within reach, and doubtless the local hyperæmia caused by heat rays and ultra-violet rays stimulates the formation of bactericidal substances and supplies nourishment to the growing cells.

In closed and deep lesions the subcutaneous bactericidal substances formed after radiation with ultra-violet rays may act at a distance, or special substances may be thrown into the blood (or light energy may be transmitted by the blood). The question is still to be settled; and though many attribute the healing entirely to ultra-violet rays, it may be mentioned that Dr. Bernhard, after twenty-four years' experience, is of the opinion that all the rays of the solar spectrum are effective, while, as already mentioned, Bangs and Halstead believe that exposure to the air, with increased skin heat-loss and consequent increased metabolism, plays a bigger part than the sun in the therapeutic result. It is certainly safer at present to regard the sun, not as a specific in surgical tuberculosis and open wounds, but rather as one of the many factors, great and small, that to different degrees in different cases and circumstances promote health and healing; it is also safer at present to use, where possible, not only ultra-violet rays, but all the rays of the solar spectrum produced either by the real or artificial sun.

On a much firmer scientific basis is the treatment of rickets by ultra-violet light.

The building-up of bone is one of the most beautiful and mysterious of physiological processes. In the embryo there are no bones at all, merely membrane prefiguring most of the bones of the skull and cartilage prefiguring the other bones of the adult skeleton. In the fifth week of fœtal life, lime appears in the collar bones, and by the seventh week almost every bone has some lime in it. The complete building of the bones is a very prolonged and elaborate process, and is carried out by free amœboid cells, cousins germane of the white blood corpuscles. These little cells—myriads of them—are hodmen and plasterers and lime-layers, and though there is no architect nor foreman nor master builder to direct them, yet, under normal conditions, they do their work with exquisite art and skill. A well-made bone is twice as strong for its bulk as oak, and three times as strong as elm or ash, and it is built with arches and piers and girders to resist the various strains and stresses to which in life it is specially subject. But at times the chemistry of the body, especially its calcium and phosphorus chemistry, seems to go wrong: the bones do not harden as they should, and become bent and misshapen and knobby, and there results disease called rickets—sometimes, alas, abroad called the "English disease"—with such direct consequences as curved spine, bandy legs, pigeon-breast, and such indirect consequences as contracted pelvis, broncho-pneumonia, etc.

For long the cause of the disease was in doubt. Some attributed it entirely to dietic errors, pointing out that it could be cured by cod-liver oil, and Mellanby showed that it could be experimentally induced in various animals by depriving them of a dietary constituent very like vitamin A, and proved, too, that excess of cereals favoured the development of the disease. But others considered it in some way due to lack of light, and pointed out that it did not occur in the tropics or where sunlight was plentiful, and was rife in dark slums. As long ago as 1835, Rosenbaum recommended sun-baths for rickety infants, and Dr. Palm, writing in *The Practitioner* in 1890, advised "the systematic use of sun-baths as a preventive and therapeutic measure in rickets and other diseases."

Both theories had truth in them, but no one succeeded in putting the ætiology and treatment of rickets on a really scientific basis till Huldschinsky, in 1919, definitely proved that sunlight could prevent and cure rickets, and that for its prevention and cure ultra-violet rays were even more efficacious. "Cod-liver oil as well as sunlight were found to be decidedly slow in their action, the exposure to ultra-violet light yielding incomparably better results." Huldschinsky's work was confirmed by Hess, Chick, and others, and soon not only this fact, but the whole causology of the disease, was established by careful, convincing, and dramatic experiments on rats, rabbits, chickens, dogs, and other animals.

The causology was found to be complex. The disease was proved to be due to a considerable deficiency of both calcium and phosphorus in the blood, which deficiency, again, was due to lack in the food of a substance like vitamin A. This lack, again, was found to be remediable either by the addition of the lacking substance (*e.g.* by giving cod-liver oil) or by exposing the rickety animal to artificial or solar ultra-violet rays. It was found that the rays particularly effective were rays of a wave-length of about 2900 to 3100 Angström Units, and that any light capable of providing these rays increased the calcium and phosphorus contents in the blood, and prevented or cured rickets, even if the food itself, minus the light, were rickets-producing. It was not sufficient to give plenty of calcium and phosphorus, and no matter how full and nourishing a dietary might otherwise be, deficiency in some substance was followed by rickets unless ultra-violet rays or cod-liver oil were provided to make up for the deficiency. Light lacking the special bundle of ultra-violet rays was not remedial in rickets and did not increase the calcium and phosphorus of the blood. Light, for instance, which had passed through window-glass, which absorbs the bundle in question, did not cure rickets. Dr. Harriette Chick, studying the cases of rickets which were so common after the War among the badly-fed Austrian children, noted that children fed on deficient diet escaped rickets if they were exposed to the sun out of doors. Of those kept in a ward which received the sunlight through the ordinary glass windows, all showed rickety bones except one, who lay in a cot near an open door and was illumined by the direct sunshine.

But what was the anti-rachitic substance and how did it act in the matter? At first it was believed that the substance, evidently very plentiful in cod-liver oil (which even in small doses had great anti-rachitic power), was identical with the fat-soluble vitamin A of that oil; but experiments afterwards proved it to be another specific substance with its own specific properties, for if the vitamin A in cod-liver oil was destroyed by oxidation, *e.g.* by blowing air through the oil, the oil nevertheless retained its anti-rachitic properties. The nature of the specific substance and the relationship of ultra-violet light to it and to rickets remained for some time a riddle, but Hume and other workers at the Lister Institute had shown that rats which, on a certain rationed diet, had ceased to grow, could be made to grow again either by radiating them with ultra-violet rays or by feeding them on tissues of irradiated rats; and Steenbock, taking a hint from the observation, irradiated tissue after it had been excised, and found that it, too, stimulated growth and increased the mineral content of bone in rats which were fed on it. Plainly, then, the ultra-violet rays acted on some constituent in the tissue, and altered it in such a way as to give it anti-rachitic characters, and it would therefore seem that radiation of children by ultra-violet rays also altered some constituent of their tissues and rendered it anti-rachitic. In fact, under the influence of ultra-violet rays children seemed to form in their skin their own anti-rachitic substance, and its absorption into the blood cured or prevented rickets.

It was a striking discovery, for, as Steenbock says, " physiology and chemistry offered no parallel instance where therapeutical activity had been induced in a compound by exposing it to light." Naturally, too, it opened up new fields for experimentation and led to many more illuminating discoveries, and soon it was found that any fresh vegetable or animal oil could be rendered anti-rachitic by ultra-violet radiation, and that some could be radiated even as active as cod-liver oil.

In some of Steenbock's earliest experiments he found that rats fed on deficient diet, including *non-radiated* olive oil, contained only 48·9 per cent. of mineral oil in their bones, while rats given radiated oil had 56·5 per cent. of ash.

With grains he obtained exactly the same results. " When we gave," he writes (" Physical Therapeutics "), " our rats a ration consisting among other things of 30 per cent. wheat or flour, cream of wheat, shredded wheat biscuits, corn meal, corn flakes, hominy, or rolled oats in place of wheat, analysis of their bones showed that they contained from 22 to 31 per cent. of ash. In contrast with these values, when the grain or their products were fed after irradiation, in no case were any values less than 43 per cent. obtained, and in one case we obtained a value as high as 55 per cent. Furthermore, histological examination showed that when rats which had been kept on a rickets-producing ration for some time were changed to the same ration irradiated, in the course of a few days calcium was observed to make its appearance in the calcium-free rachitic metaphyses. In about two weeks the rachitic bones were found to be completely healed."

Kramer fed eight rickety infants with milk irradiated by ultra-violet light and found healing in all cases. Other food substances which can be rendered anti-rachitic by ultra-violet radiation are dried milk, lard, hay, liver, mussels, lettuce, but different sugars, glycerine, gelatin, alcohol, and petroleum cannot be activated.

These were remarkably illuminating discoveries, and they soon led to a detection of the particular substance—the vitamin D—concerned in the photochemical reaction. By analytic methods it was shown that the substance activated by light was always in the oil or fat of the animal or plant, and further analysis proved that it resided in a small unsaponifiable fraction of the fat. Finally Steenbock, Hess, Webster, and Rosenheim hunted it down, and identified " cholesterol " or " phytosterol " as the usual parent substance of the anti-rachitic vitamin. (More recently Webster and Rosenheim have come to the conclusion that the substance activated by light is not cholesterol, but another sterol which clings closely to cholesterol.)

The relations between cholesterol, ultra-violet light, and anti-rachitic vitamin were ingeniously demonstrated by Rosenheim and Webster. They exposed one sample of cholesterol spread in a thin layer under a quartz disc to the sun, and another sample they exposed in the same way but under glass. Exposure continued for thirty days in a sunny July, and then the samples were tested for the anti-rachitic power, and it was found that " two rats which received 5 mg. each per day of cholesterol exposed to sunlight through quartz were completely protected from rickets, whilst those fed on the specimens exposed through glass as well as the control animals developed typical rickets." It may be interesting to point out that Wacker and Beck as long ago as 1921 had pointed out that cholesterol seemed to play an important part in the anti-rachitic action of cod-liver oil.

Phytosterol is found in all vegetable oils, but not mineral oils; and cholesterol occurs in all animal cells, but especially in the skin, brain, and nerve tissues. It is also found frequently in gallstones.

The occurrence of cholesterol in the skin offers a very obvious explanation of the cure of rickets in infants by exposure of their skin to artificial ultra-violet rays or to the ultra-violet rays of sunlight—simply that the cholesterol activated in the skin and converted into anti-rachitic vitamin D is thrown into the circulation through the lymphatics; and the anti-rachitic action of the irradiated skin given by Steenbock to his rats is also capable of the same explanation. Exactly how the vitamin D acts it is difficult to say. Webster suggests that either radiation or cod-liver oil increases the absorption of calcium and phosphorus from the bowel, probably by lessening microbic infection; but it may also act on the physiological or chemical activities of the osteoblasts which build the bone.

The morals to be drawn from the discovery of the ætiology of rickets are numerous; and the question is, Which of the morals is of most therapeutic value? What we know now teaches us that a diet deficient in vitamin D will lead to rickets, but that either the addition of the activated sterols in any form, or exposure to ultra-violet light, will prevent or cure the disease. The question remains, Which is the better treatment: the provision of vitamin D in the food or the manufacture of vitamins in the skin? Nothing is easier, save in exceptional cases, than to prevent rickets by providing a diet containing vitamin D, or by adding a little to the diet in the form of cod-liver oil. And that is probably the best treatment, though there is no reason at all why assurance should not be made doubly sure by keeping the child so far as possible in a well-lit environment. In winter, when the child, even apart from rickets, may suffer from light starvation, a little ultra-violet ray treatment may be desirable, but it will be difficult for poor mothers—and rickets is particularly a disease of the poor—to spare time to convey their infants to and from lamps, and they will often find it easier to administer a little cod-liver oil.

The idea that all infants and children must be directly dosed with ultra-violet rays in order to escape rickets and acquire good health is contrary to experience. We can get vitamin D, as we get vitamins A, B, C, from our foods, and under ordinary dietetic conditions there is no more need to get rickets from lack of vitamin D than to get scurvy from lack of vitamin C. The money spent in equipping and staffing light-treatment cliniques for children might possibly—so far at least as rickets is concerned—be better spent on the children's food.

The fact that rays of ultra-violet light shorter than 3300 Ångström Units cannot penetrate glass has led to the production of various kinds of glass, such as "Vita-glass," which are permeable to the short anti-rachitic rays, and it has been urged that all school-rooms and dwelling-rooms should be provided with such glass. That seems in more senses than one an extravagant idea. Children can get enough ultra-violet light in summer without such expedients, and if in winter they cannot, as in some city slums is the case, then the safest and best thing is to provide plenty of vitamin D in their food. The Eskimo children born at certain seasons of the year have to spend many months with no other light than oil lamps, and yet they do not seem to be specially subject to rickets. Most wild animals breed in the dark, and even if they were to breed and live in the sunlight, little or no ultra-violet light could penetrate their hair or fur. It is true that monkeys and iguanos and other animals at the Zoo which have been provided with lamps have improved in health, but it is difficult to understand the rationale of such actinotherapy.

Moreover, it must not be forgotten that though ultra-violet light has the power of activating cholesterol, and thus preventing rickets, it cannot take the place of open air. Rats fed on deficient diet exposed to sun and open-air for four hours a day will live much longer than rats radiated with ultra-violet rays thirty minutes a day.

The interesting and sensational discovery that ultra-violet light can prevent and cure rickets by activating some sterol in the skin and forming an anti-rachitic vitamin, does not prove that it is a panacea, or that it cures consumption, or that it is necessary for healthy people. Its action is limited. Rays 3000 Ångström Units penetrate hardly at all into the skin, and probably do not reach the blood in the capillaries. Its physiological effects are few. (1) It forms vitamin D, which has an effect on the calcium and phosphorus metabolism, and, according to some, increases the iron and iodine in the blood. (2) It stimulates the nerves in the epidermis and produces more or less erythema with its consequences. (3) It causes pigmentation. (4) It causes changes in the superficial cells of the skin. (5) It causes a temporary increase in the number of white corpuscles and in the bactericidal properties of the blood. (6) It is an anodyne. Some of these effects may (as we have before pointed out when treating of insolation) be beneficial in rickets, high blood pressure, and other pathological conditions, but it is difficult to see why they should be desirable, not to say necessary, in normal men and women; and it is certain that overdoses of ultra-violet rays decrease the bactericidal power of the blood and have other bad consequences.

The natural source of all our vitamins is food, and the remarkable discovery that foods containing certain sterols can be activated by light and rendered anti-rachitic, naturally makes it possible to extend an anti-rachitic menu by treating various foods containing phytosterol and cholesterol with ultra-violet rays, and furthermore suggests that phytosterol and cholesterol activated by ultra-violet rays would themselves be the best anti-rachitic food. Already, in fact, activated cholesterol is used as an anti-rachitic. The anti-rachitic properties acquired by irradiated food persist for some months at least; but, on the other hand, too much ultra-violet light seems to destroy vitamin D, and attempts to increase the anti-rachitic value of cod-liver oil may destroy the value altogether. Steenbock believes that the cholesterol in the cod is activated and rendered anti-rachitic by ultra-violet rays which penetrate the water and reach the cod's skin, but it is evident that there is a limit to its activation outside the cod. The cod also gets sterols from food and ultimately from plankton.

Professor Drummond has lately pointed out that there are serious drawbacks to the irradiation of milk with ultra-violet rays. " Milk," he says, " which has been exposed to the radiations of a mercury-vapour lamp for as short a time as five minutes, not only becomes unpalatable in that it acquires an unpleasant tallowy odour, but actually suffers chemical changes which are highly undesirable from the standpoint of nutrition. Of these, one is the destruction of vitamin A by oxidation."

Children therefore, according to Professor Drummond, fed on irradiated milk would be likely to show the retarded growth and diminished resistance which appear when there is insufficiency of vitamin A in the dietary, but Dr. Walsh and some other authorities do not agree with Professor Drummond's findings.

In view of the fact that cholesterol and phytosterol are activated by sunlight, there would seem to be a seasonal ebb and flow of D vitamins in food products, and it might be possible to increase the vitamin D in plants and animals themselves and in the foods obtained from them by prescription of ultra-violet rays. This has already been done. Steenbock, for instance, irradiated with ultra-violet rays from a quartz-mercury lamp a badly-fed milch goat, whose milk was so low in anti-rachitic value that it took twelve cubic centimetres of it given daily to a rickety rat to produce even a trace of calcification. After irradiation it took only two to four cubic centimetres to produce the same result. The goat was irradiated only for two hours in the course of four days; and Steenbock says: " The promptness with which the change was produced impressed us as scarcely believable."

With Professor Halpin, Steenbock made similar and even more interesting experiments on hens. They divided forty-eight pullets into two groups of twenty-four each. One of these was irradiated with an Alpine sun lamp for ten minutes a day. The other was kept unirradiated for purposes of comparison. " Month after month," he writes, " we obtained records of egg production where the irradiated group produced from three to four times as many eggs as the non-irradiated; and what is most important from the standpoint of human medicine—as egg yolk is being used as an anti-rachitic adjuvant to cows' milk—is the fact that here, just as in the case of the goat's milk, the egg yolks were increased in anti-rachitic potency at least ten times."

Steenbock has himself proved that short ultra-violet radiations do not penetrate the skin, and it would be interesting to know how they penetrate through hair and feathers. Probably in the case of all hairy and feathered animals the rays act not through the skin, but through the eye—the organ specially constructed to receive light, though it is possible that photo-chemical substances may be formed in hair and feathers and pass thence into the blood.

It might be imagined that it would be possible to prevent rickets by ensuring that the mother had the right food and plenty of light previous to child-birth and during lactation; but it has been proved that the infant cannot be protected in this way, even though light treatment during lactation may, as Dr. Humphris suggests, increase the calcium in the maternal milk.

The remarkable results obtained by use of ultra-violet light in rickets have, as we have suggested, led to a rather ill-grounded belief in their utility in health; but have also led to their legitimate and fruitful application in many diseased or abnormal conditions besides those already mentioned, and their value in such conditions has been amply proved. In this little volume on light we can only briefly indicate a few of these conditions.

The bactericidal property of ultra-violet light, especially of its rays shorter than 3000 Angström Units, together with its property of causing erythema or hyperæmia, can be utilised in many bacterial and parasitic skin diseases. Lupus we have already mentioned, but a long list of other skin diseases which can be benefited by ultra-violet treatment might be added. Many successful results in acne, eczema, fununculus, sycosis impetigo, herpes, have been obtained.

Constitutional ailments and diseases which benefit by ultra-violet treatment are rheumatism in all its forms, tetany, some kinds of neurasthenia, high blood pressure, alopecia.

BIBLIOGRAPHY

Historical.

J. C. Poggendorff : "Geschichte der Physik."
E. Gerland : "Geschichte der physikalischen Experimentierkunst."

Astronomical.

C. G. Abbot : "The Sun." "The Earth and the Stars."
Sir Robert Ball : "The Story of the Sun." "The Earth's Beginnings," 1909.
G. Forbes : "The Wonder and Glory of the Sun."

General Science and Physics.

M. A. Cleaves : "Light Energy."
Professor J. W. Gregory : "The Making of the Earth" (Home University Library).
R. A. Houston : "Light and Colour," 1923.
Sir Oliver Lodge : "Atoms and Rays," 1924. "Ether and Reality," 1925.
M. Luckiesh : "Artificial Light," 1920.
Th. Lyman : "L'Ultra Violet," 1924.
Benjamin Moore : "The Origin and Nature of Life" (Home University Library). "Biochemistry," 1921.
Bertrand Russell : "The A.B.C. of Atoms," 1923.
F. Soddy : "Matter and Energy" (Home University Library).
Stiles : "Photosynthesis," 1925.
J. Arthur Thomson : "Introduction to Science" (Home University Library).
Sir J. J. Thomson : "Structure of Light," 1925.
Silvanus P. Thompson : "Light, Visible and Invisible." 1910.
C. A. Timiriazeff : "The Life of the Plant." 1912.
Philosophical Transactions of various years.

Medical.

O. Bernard : "Light Treatment in Surgery," 1926.
J. B. Ferguson : "The Quartz Vapour Mercury Lamp," 1926.
P. Hall : "Ultra-violet Rays in the Treatment of Disease," 1926.
Hausmann : "Grundzüge der Lichtbiologie und Lichtpathologie," 1923.
F. H. Humphris : "Artificial Sunlight," 1926.
L. Hill : "Sunshine and Open Air," 1925.
M. Luckiesh : "Ultra-violet Radiation," 1922.
M. Luckiesh and Pacini : "Light and Health," 1925.
R. C. Macfie : "Air and Health," 1909.
Mackenzie and King : "Practical Ultra-violet Light." "Therapy," 1926.
Molten : "Die Licht Therapie," 1926.
Rollier : "Heliotherapy," 1927.
C. M. Sampson : "Physiotherapy Technique," 1923.
C. E. Woodruff : "Tropical Light," 1905.
Various numbers of the *Lancet, British Medical Journal, Practitioner* and *Journal of Biochemistry.*

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190.	Electricity *(Illustrated)*	Dr. T. F. WA

Complete List up to August 1939. New titles will be added yearl