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AN ESSAY

ON THE

PHYSIOLOGY OF THE EYE.

BY

SALOM HENRY SALOM.

"It is surely as little possible for us, when we open our eyes on some wide and magnificent landscape, to separate the colour, as a mere visual sensation, from the field, the mountain, the forest, the stream, the sky, as to separate it from the half-inch or inch of our retina, of the perception of which we have no consciousness in any case; and it is too much for those, who deny the immediate perception of those greater magnitudes, to urge, in proof of the necessary original perception of this inch or half-inch what, if valid in any respect, must establish no less the proposition which they deny than the proposition which they affirm."—DR. THOMAS BROWN.

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TO HIS OLD FRIEND,

SAUL ISAAC, ESQ.,

THIS ESSAY IS DEDICATED,

IN TESTIMONY OF THE AFFECTION AND ESTEEM OF

THE AUTHOR.

"*One of the most difficult problems in physiology is that relative to the respective influence of the retina and sensorium in vision. This department of the physiology of the senses may be correctly styled the metaphysical, since we are at the present time totally destitute of any empirical means of elucidating it.*"—J. MÜLLER, ELEMENTS OF PHYSIOLOGY.

"*Experimental knowledge of body and mind is the fund our reason should cultivate.* * * * *"

"*The phenomena of the human mind are few, and on these few a multitude of hypotheses has been raised, concerning mind in general and soul and spirit. So that in this part the improvement of real knowledge must be made by contraction, and not by amplification.*"

BOLINGBROKE, SECOND ESSAY ON HUMAN KNOWLEDGE.

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ON THE

PHYSIOLOGY OF THE EYE.

SECTION I.

The first of Sir William Hamilton's well-known propositions *quasi*-demonstrative of the immediacy of visual-space apprehension is, that we see colour—a truth which all will admit. His second proposition, that the power of seeing colour necessarily involves the power of perceiving differences of colour, is universally accepted by Intuitionalists, as well as by a large number of *Soi-disant* Associationalists. "A rudimentary conception must be allowed, for it is evident that without moving the eye, we are capable of having two sensations of colour at once, and that the boundary which separates the colours, must give some specific affection of sight, otherwise we should have no discriminative affections capable of afterwards becoming, by association, representatives of the cognition of lines and figures, which we owe to the tactual and muscular sense."*

We are here treading the debateable and marshy isthmus, which at once separates the Associationalist from the Intuitionalist, and unites the Psychologist with

* An Examination of Sir William Hamilton's Philosophy, by John Stuart Mill, page 24.

the Physiologist. For the eye is the hub round which metaphysics revolves; were there no eye there would be no metaphysics. Now, in undertaking to investigate the theory of visual perception, I set out with this maxim, that psychology is a science of observation, if not of experiment; that, since we can only observe the mind in connection with the body, we cannot hope to ascertain psychical laws except as connected with physical phenomena. The subsequent discussion then, is in the main, an extension of Berkeley's Theory of Vision, from the perception of large areas—phenomena observable—to small areas—phenomena not observable. Our doctrine may be briefly summarized as follows: That the eyeball is in a constant state of reflex or involuntary action; that this action is due to the dynamic force of light acting through certain elements of the retina on the entire retina itself; that the motions of the eyeball thus produced, arouse through the orbito-ocular muscles, feelings of muscularity identical in kind, although diminutive in degree, with those excited when we voluntarily determine ocular direction; that these small motions are precisely cognate with the larger ones considered by Berkeley, and similarly correspond with the other muscular exercises whereby a man born blind attains his knowledge of form and position; and that thus, without any voluntary effort on our part, are we constantly aware of visual space properties.

To such a theory, neither Sir William Hamilton's second proposition, nor Mr. Mill's critique, is fatal: for in each of these arguments lurks an *elenchus*. Physiologists inform us that the line of vision is directly in the *fovea centralis retinæ*, "the place where acute, accurately localized, distinct vision, takes place";* and although the dimensions of the retinal space-apprehending area are unknown, it has, nevertheless, been ascertained that we

* Donders. The Accommodation and Refraction of the Eye, p. 4. New Sydenham Society.

have the power of perceiving images smaller than any element known to exist at the fund of the eye. Hence the perception of a large object must be, so to say, a synthesis of many small excursions of the eye; what is seen through the *fovea* in a given moment being merely the *minimum visibile.* Now, remembering how well Father Boscovich's theory of "centres" accounts for the ultimate constitution of matter, I see no good reason why the *minimum visibile* should not correspond with such a "centre." Under this assumption then, what we at any moment would see of a particular colour, as red, would be a red "centre." Nor could at that instant, any other *minimum visibile*, as a blue "centre," be apprehended.

Sir William Hamilton's assertion, that the power of seeing colour involves the power of perceiving differences of colour, would then fall to the ground. For, in the event of our ability, simultaneously to inspect a blue and a red "centre," a *minimum visibile* would be larger than a *minimum visibile*, which is absurd. And *à fortiori* for adjacent *areas.*

Again, although true that we can see two colours without *our* moving the eye, it does not follow, that the eye *has not moved* during the period in which the two colours were seen; or, what is the same thing, that the two colours were perceived *at once.*

So far as my knowledge extends, it was Erasmus Darwin who broached the notion, that visual perception ensues from retinal motion derived through the motile force of light; visual perception being, according to him, a particular case of a general law whereby ideas follow configurations or alterations or motions of our organs of sense. "When we say, animal motion is excited by irritation, we do not mean that the motion bears any proportion to the mechanical impulse of the stimulus; nor, that it is effected by the general gravitation of the two bodies, nor by their chemical properties, but solely that certain animal fibres are excited into action by something external to the moving organ. In this sense the stimulus of the blood produces the action of the heart, and the substances we take into our stomachs and bowels irritate them to perform their ordinary necessary functions. The rays of light excite the retina into animal motion by their stimulus at the same time as those rays of light themselves are physically converged to a focus by the inactive humours of the eye. The vibrations of the air irritate the auditory nerve into animal action; while it is probable that the tympanum of the ear, at the same time, undergoes a mechanical vibration. . . . . To render this circumstance more easy to be comprehended, motion may be defined to be a variation of figure, for the whole universe may be considered as one thing possessing a certain figure; the motion of any of its parts is a variation of the figure of the whole." . . . .

"The organ of vision consists of a fibrous part as well as of the nervous medulla, like other white muscles; and hence, as it resembles the muscular parts of the body in its structure, *we may conclude that it must resemble them in possessing a power of being excited into animal motion.*" . . .

"The retina of an ox's eye was suspended in a glass of warm water, and forcibly torn in a few pieces; the edges of these parts appeared jaggy and hairy, and did not contract and become smooth, like simple mucus, when it is distended until it breaks; which evinced that it consisted of fibres. This fibrous construction became still more distinct to the light, by adding some caustic alkali to the water, as the adhering mucus was first eroded, and the hair-like fibres remained floating in the vessel. Nor does the degree of transparency of the retina invalidate this evidence of its fibrous structure, since Leuwenhoek has shown, that the crystalline humour itself consists of fibres. Hence it appears that, as the muscles consist of large fibres intermixed with a smaller quantity of nervous, the organ of vision consists of a greater quantity of nervous medulla intermixed with smaller fibres. It is probable, that the locomotive muscles of microscopic animals may have greater tenuity than those of the retina; and there is reason to conclude from analogy, that the other immediate organs of sense, as the *portii mollis* of the auditory nerve, and the *reti muscosum* of the skin, possess a similarity of structure with the retina, and a similar power of being excited into animal motion. . . . Another method of discovering that our ideas are animal motions of the organs of sense, is from considering the great analogy they bear to the motions of the larger muscles of the body . . . . They are originally excited into action by the irritation of external objects like our muscles; are associated together like our muscular motions; act in similar time with them; are fatigued with continual exertion like them; and that the organs of sense are subject to inflammation, numbness, palsy, convulsions, and the defects of old age, in the same manner as the muscular fibres.

"All our perceptions or ideas of externality are universally allowed to have been originally excited by the stimulus of these external objects . . . . it is probable that all our muscular motions, as well those which have become voluntary as those of the heart and glandular system, were originally, in like manner, excited by the stimulus of something external to the organ of motion. . . . .

"The fatigue that follows continued attention of the mind to one object, is relieved by changing the subject of our thoughts; as the continued movement of one limb is relieved by moving another in its stead . . . . Exercise of the mind and limbs improves and strengthens both . . . . As we advance in life . . . . all parts of the body become rigid . . . . less susceptible of new habits of motion . . . . and elderly people retain the ideas they had learnt early . . . . but find great difficulty in acquiring new trains of memory."*

From one proposition included in Darwin's doctrine, I cannot but dissent—namely that the motions of the organs of sense *constitute* our ideas. This error is not, however, of *the essence* of his theory, but, on the contrary, is simply superficial, being nothing more than an error of manner. What, in my opinion, is legitimately maintainable, is simply that the physical phenomenon which to us immediately precedes the *completion* (usually termed the *mental part*) of the perception, is motion of the organs of sense. It was, however, the lot of Darwin, no less than that of Hartley—who too was, not infrequently, regardless of accuracy of statement—to be appreciated rather by his external blemishes than by his intrinsic merits, to be condemned by prejudiced censors, rather than to be judged by impartial critics, to become the butt of the calumnies of men at once innocent of the faintest blush of originality, and incapable of doing justice to the original labours of others.

The tide has now changed; nor is it too much to say that a large portion of all that is regarded as most valuable in Associationalism, is directly traceable to the researches of Hartley, not less than to those of Locke, Berkeley and Hume. I hope, by turning the light of modern histological discovery on Darwin's theory of involuntary animal action, to succeed in convincing Associational Psychologists that this theory must henceforth be included in the creed of *à posteriori* thinkers.

That the eye is in a constant state of motion, did not escape the universal ken of Goethe. "Das Auge eines Wachenden aeussert seine Lebendigkeit besonders darin, dass es durchaus in seinen Zustaenden abzuwechseln ver-

* Darwin's Zonoomia, vol. i., sections 2 & 3 *passim*. See also Plato's Theaetetus for an account of the doctrines of Empedocles and Heracleitus.

langt, die sich am einfachsten vom Dunkeln zum Hellen und umgekehrt bewegen. *Das Ange kann und mag nicht* einen Moment in einem besondern, in einem durch das Object specificirten Zustande identisch verharren. Es ist vielmehr zu einer Art von Opposition genoethigt, die, indem sie das Extrem dem Extreme, das Mittlere dem Mittleren entgegensetzt, sogleich das Entgegengesetzte verbindet, und in der Succession, sowohl als in der Gleichzeitigkeit und Gleichoertlichkeit nach einem ganzen strebt." *

Let any one fix his gaze on a particular spot, say a corner of a window on the opposite side of the street. On careful observation of the phenomenon, it will be found that the spot is seen only in company with a circum-adjacent area. This area is, moreover, not a fixed, but a fluctuating quantity; shifting now towards the right, anon towards the left, sometimes upwards, at others downwards, or in a direction which may be described as a resultant diagonal of a parallelogram, of which the adjacent sides are any two of the above directions. I was one day conducting some such experiments, with the object of determining the conditions under which we view a minute point, when it became necessary to steady the gaze with unusual vigour, and to endeavour to limit, abnormally, the field of view. The result was a violent vibratory motion of the whole eye, which called at once to my mind the following proposition: "Most reflex actions become increased in energy, if resistance be made to them. Of this we have familiar examples in the action of the expulsor muscles which operate in defecation, urination, and parturition, if, when they are strongly excited, the effect be opposed by spasmodic contraction of the sphincters, or by mechanical means." (Carpenter.) Since, in the natural condition of the eye, no vibratory effect is manifest; since the inten-

* Goëthe. Zur Farbenlehre, § 33.

sity of the vibrations increases directly with that with which the eye is fixed and with the smallness of the field of view, that is to say, with the *restraining* effort exerted on the orbital muscles of the eye, the two phenomena increase together, diminish together, disappear together. We are therefore bound to conclude, according to The Canon of Concomitant Variations, that they are related as cause and effect, that the experiment logically leads to the inference that the eye exists in a constant condition of reflex or involuntary, although imperceptible, motion. That the eye-ball, and not merely the eye-lids, is in action, is demonstrable from the apparent change of place of the luminous object. The phenomenon is very plainly perceived if we look, a few feet off, through a venetian blind of which the laths are half-opened, when the motion will be seen to be partly lateral and partly vertical. This dual character of the tremoral action I regard as partly due to the transverse direction of the light undulations, and partly to the perturbing reaction of the eyeball against the vertical pressure of the eyelids.

Hartley, with his disciple and apostle Priestley, held that our actions are all originally automatic or involuntary, then become voluntary, and are finally secondarily-automatic. " The fingers of young children bend upon almost any impression that is made upon the palm of the hand, thus performing the action of grasping in the original automatic manner. . . . . He ought, therefore, according to the doctrine of association, to perform and repeat the action of grasping, upon having such a plaything presented to the sight. But it is a known fact that children do this. By pursuing the same method of reasoning, we may see how, after a sufficient repetition of the proper associations, the sound of the words *grasp*, *take hold*, &c., the sight of the nurse's hand in a state of contraction, the idea of a hand, and particularly of the child's own hand, in that state, and innumerable other associated circumstances, *i.e.*, sensations, ideas, and motions, will put the child upon grasping, till, at last, that idea or state of mind which we may call the will to grasp, is generated, and sufficiently associated with the action to produce it instantaneously. It is, therefore, perfectly voluntary in this case; and, by the innumerable repetitions of it in the perfectly voluntary state, it comes at last to obtain a sufficient connection with so many diminutive sensations, ideas, and motions, as to follow them in the same manner as originally automatic motions do the corresponding sensations, and consequently to be automatic-secondarily. And in the same manner may all the actions performed by the hands be explained, all those that are very similar in life passing from the original automatic state through the several degrees of voluntariness, till they become perfectly voluntary, and then repassing through the same degrees in an inverted order, till they become secondarily-automatic on many occasions, though still perfectly voluntary on some, viz., whenever an express act of the will is exerted." *

" But, when it shall be as perfectly associated with this *complex set of ideas* or state of mind, as it was with a single idea, so that the one shall immediately follow the other, it is called *secondarily-automatic;* and this being as instantaneous as an originally automatic motion, the term *volition* ceases to be applied to it. This is the case when a person walks without attending to the motion of his legs, or plays on a musical instrument without thinking of the particular position of his fingers; each of which motions and positions having been dependent upon ideas, was before performed with deliberation and an express volition." †

* Hartley's Theory of the Human Mind, edited by J. Priestley, 1790, page 31.

† The Doctrine of Philosophical Necessity. Illustrated by J. Priestley. Section 4.

Hartley's theory of Association implies, that in adult life automatic action has ceased, and that we are then solely under the influence of voluntary or secondarily-automatic action. If his account of the nature of our mental faculties be exhaustive, a theory of vision depending purely, or at least principally, on automatic action must, of course, be wrecked. There is, however in my opinion, no sufficient reason for believing that we can ever free ourselves of the influence of involuntary action, what organ soever be regarded. An examination of the history of our learning to read affords a fine illustration of the co-existence of the processes, automatic, voluntary, secondarily-automatic. At birth it is evident that the eyes, though in motion, are not under the control of the will, but simply respond to what Darwin calls "irritation." Gradually they become more and more amenable to volition, it being only after this subjection has been fully accomplished that the operation of learning to read can begin. The child commences by carefully gauging the form of each letter, and, the better to impress the mind through exaggerated action of the oculo-orbital muscles, the first letters of the primer usually assume Brobdingnagian dimensions. Soon occurs the recognition of small letters; then, in succession, the power of combining letters into syllables, syllables into words, words into sentences. The two stages, the automatic and the voluntary, may now be regarded as complete. Gradual familiarity enables the pupil to dwell in ever shorter and shorter periods on the letters, syllables and words, until when in later years, the third volume of the enthralling romance has been closed, he is wholly unconscious of having seen any one letter, syllable, or word. The secondarily-automatic stage has here been successfully accomplished.

Although demonstrable, that each letter, to say nothing of words, must in the latter case, undoubtedly have been inspected, yet, in virtue of what Mr. Stuart Mill calls the Law of Obliviscence, these no longer individually engage the attention. If we desire to be aware of the fact, that purely automatic action co-exists with voluntary and secondarily-automatic action, let us fix our attention on any individual letter, when it will be observed that, exactly as, when we purposively or voluntarily engaged our gaze on the corner of the window, we saw a little more than the minute corner, so, when engaged in the voluntary and secundo-automatical acts of reading, do we also see something more than the letter which is the special subject of inspection. The reason is evident. Reflex or involuntary action is compelling the eye to start from the voluntarily viewed letter, and the "little more" is the result of reflex action. The "little more" is indistinct when compared with the voluntarily viewed letter; the comparative indistinctness and distinctness of the various parts of the field being sufficiently accounted for, 1st, by the phenomenon *having been* viewed, and viewed *involuntarily*, and 2nd, by *being presently* viewed and viewed *voluntarily*. We will afterwards return to this subject, which is of great importance to the theory of visual perception. In the meantime we lay down the doctrine that all our actions are originally automatic or involuntary, that out of these involuntary actions flow, so to speak, our voluntary actions, as a scrutiny of the history of the infant taking the breast will show. Secondarily-automatic action I regard as automatic action *plus* a rhythm acquired in the voluntary stage.

The doctrine that our organs are continually agitated by involuntary action, supplies a void which, at this time, undoubtedly exists in the Associational Psychology. Thus, to explain the phenomena, that in wakening from sleep movement precedes sensation, and that in infancy activity is greater than at any subsequent period, Professor

Bain is compelled to invent a theory of *spontaneous* activity or rush of energy; although it is difficult to see why, if the activity or rush be *spontaneous*, it should be *coerced* to reveal itself *only* at certain hours, or in certain years. Now, incessant automatic action neatly accounts for these manifestations, as indeed it does for sundry other phenomena detailed by Mr. Bain. What is signified by sleep? Simply that the system is no longer in trim to fulfil its normal functions, that a suspense of the faculties which correspond with involuntary, voluntary, secondarily-automatic action is imperative. In the morning, when sleep has terminated, the conditions are the reverse of those which obtained the evening before, when sleep began. At night, the pressure of the bed on the muscles of the sleeper's body was minimized, in the morning it is maximized; because in the first case, his condition is abnormal, and in the other normal. But not only will a bed exert a different effect on a wearied than on an unwearied man, but even the air will affect the skin, and noises affect the ear of a refreshed man with a much intenser vivacity than they can exert on a wearied one. A parallel line of argument will explain the superior activity of children. For the liveliness of fresh adult life may be regarded as on a par with the liveliness of the child when somewhat tired, the morning impressionability of the automatic centres in the adult, comparable with the afternoon impressionability of these centres in the infant; since the influence of externality on the automatic centres, although never, whilst life lasts, wearing out, is yet at its maximum in the "fresh" infant. As the voluntary faculty is sharpened, the involuntary faculty is blunted.

As the studies of a large portion of my readers will doubtless have assumed a psychical, rather than a physiological direction, I purpose offering, in this place, a few extracts from the Class Book of Botany, by Professor Balfour of Edinburgh, with the object of demonstrating—

I. The impossibility of determining a line of demarcation between the vegetable and animal kingdoms.

II. The undoubted and marvellous automatic action induced on plant life by the action of light.

The ancillary function of these extracts will be obvious. I wish, by their aid, to show that plant life and animal life are so intimately connected, run so insensibly into each other, have so many features in common, as to defy the invention or application of fiducial terminals; and that consequently, any induction which may be reached involving involuntary action of the eye by the agency of light, cannot be regarded as conflicting *primâ facie* with, but must, on the contrary, be viewed as analogically confirmed by, our knowledge of the relation of light to plants.

"Those departments of science which have reference to living bodies, and which are hence termed biological, are, in a special manner, related to each other. *No one can be considered a scientific anatomist or physiologist, who does not include in his researches a consideration of the structure and functions of animals and plants.* He must study the forms which they present, the cells and vessels which enter into the composition of both, their modes of nutrition, the circulation of their fluids, their various secretions, their reproductive functions, the movements they exhibit, the diseases to which they are liable, and the decay and death which they undergo. It is only by such means that a correct knowledge can be acquired of vital phenomena.

"While the higher classes of animals and plants are widely separated from each other, the lowest members of each kingdom approximate so closely, that it is scarcely possible to form a line of demarcation. Some bodies which Ehrenberg represents as animals, are now considered as belonging to the vegetable kingdom. . . . Movements will not constitute a diagnostic mark, for these occur in both, and some beings low in the scale, have the organic forces of plants, with the locomotion of animals. Even chemical analysis fails to aid the naturalist; for cellulose, long considered as of a vegetable nature, has now been found in the tunics of Ascideans, and a substance isomeric with starch has been detected by Gottlieb in some animal tissues."* Professor Balfour then quotes from Schmidt:—"Cannot we regard," Schmidt continues, "the *Alga* as the nurse of its more highly developed embryo? The nurse or the transitionary form of Campanularia exhibit no trace of the phenomena which we necessarily connect with the idea of animal; we have here no stomach, no internal cavity for the assimilative process, no spontaneous motion, in short, it is a perfect parent cell of an *Alga*. The embryo which, on the bursting of the so-called parent animal, begins to pass through the independent vital cycle, exactly resembles *Vaucheria*. Like the latter, when the ciliary motion has continued about two hours it becomes fixed, and thus attached, is developed into a perfect polyps. *In the first stage of this process it is a true Alga, in the latter an animal organism*. . . . . No chemical or physical difference can therefore be instituted between animals and plants. Motion is seen in *Oscillatoriæ*, and in the spores of *Algae*, as perfect as in some fixed animals."

"In plants, there are two modes in which new individuals are produced; one, by the agency of stamens and pistils, or of certain reproductive cells giving rise to seeds or spores containing the embryo plant; the other, by the production of leaf-bud, or by the fissiparous division of cells. Animals in these respects exhibit resemblances to plants.

* Balfour's Class Book of Botany, page 3.

"The most common mode of reproduction in animals is by eggs, equivalent to seeds, dependent on the presence of sexes, but the production of buds is by no means rare among some of the lower tribes. Thus certain *Medusae* have eggs produced by the agency of testes and ovaries, and at the same time have buds which reproduce the individual. . . . .

"Analogies may be still further traced, when we consider the transformation which plants undergo in their various stages of growth, and compare this with the alternations of generation which occur in animals. The seed of a plant, when placed in favourable circumstances, sprouts; a stalk or skin is formed which gives origin to leaf-buds; in due time changes take place, by which flower-buds are formed, and these in their turn form seeds. So it is in the Animal Kingdom. Polyps and medusae are in some instances, different states of the same species . . . The medusaé produce eggs which pass through the infusorial state, fix themselves, and become polyps . . . . and these polyps produce a kind of bud, which finally drops off and becomes a medusa. This alternation of generation is similar to the stages of plant-growth, commencing at the seed and going through the leaf-bud to the flower-bud. Each leaf-bud is an individual as distinct as the polyps in a compound zoophyte. The flower-bud is composed of the same elements as the leaf-bud; but they differ as much as the medusa does from the polyp. The flower-individual arises as a bud from the leaf-individual or the group of leaf-individuals."*

We thus perceive the intimate connection which allies plant-life with animal-life; how much these have in common; how fine the shades of gradation which define their coalescence; how impossible to establish a border

* Balfour's Class Book of Botany, pages 2 to 6.

line between the two worlds. We proceed with our extracts, selecting those which irrefragably demonstrate the motile force of light on plants, with the avowed object of determining the reader's acquiescence in the proposition that, since Plants and Animals have so many common properties, they may reasonably be assumed to possess additionally in common, the quality of having parts excitable into action by light, and thus serve to illustrate and explain the experiment which directly demonstrates the reflex action of the eye.

"The effects of light and darkness are frequently very marked in causing the elevation and depression of leaf stalk, and the expansion and folding of leaves. The changes which take place in leaves during darkness were included by Linnæus under, what he called, the sleep of plants. During darkness leaves often hang down, and in the case of compound leaves, there is also a folding of the leaflets, either in an upward direction, as in the sensitive *Mimosa*, or downwards, as in *Tephrosia Caribea* . . .

"In *Mimosa pudica* and *sensitiva*, the motions of the leaves are very conspicuous. They are influenced by light and darkness, and they are exhibited on the slightest touch. In these plants, the leaf . . . is a compound bipinnate one, having four partial leaf stalks proceeding from a common petiole. The small pinnates or leaflets are expanded horizontally, when the plant is in the light and in its natural state, but when it is in darkness, as well as when the leaves are touched or irritated, the pinnates fold upwards so as to bring the upper surfaces into contact, and at length the petiole is depressed, so that the entire leaf folds down. . . .

"The stem itself seems *not* to be directly concerned in the motions. . . . Artificial light, according to Candolle, *caused the expansion of the leaves.* He exposed sensitive plants for several days to the influence of light during the night, and of darkness during the day. In these circumstances, the plants at first opened and shut their leaves irregularly, but at the end of some days they became accustomed to their new position, *opening their leaves in the evening* (their time of night), and closing *them in the morning* (their time of light). . . .

"In the case of *Hedysarum gyrans*, a native of the East Indies, the phenomena of leaf motions are very remarkable. The leaf . . . is unequally pinnate, having a large leaflet or pinna at the extremity of the stalk, and two pairs of small pinnæ placed laterally. The large leaflet exhibits oscillatory lateral movements, as well as the ordinary sleep movements, in an upward and downward direction. During the day it rises and appears to have slow motion from one side to the other, so that it often is seen in an oblique position as regards the stalk; during the night it is depressed and motionless. The little pinnæ, on the other hand, constantly exhibit a jerking motion, by which they first approach to each other and then retire, the length of time required to complete their movements being about three minutes *when the plant is vigorous and exposed to a bright light.*"*

Before addressing ourselves to as rigorous a demonstration as the nature of physiology permits, of the eye's adaptation to the maintenance of automatic action, and of the origin of this action to light, I will exhibit some of the most important results that we have already ascertained. These are,—

I. THAT THE EYE EXISTS IN A STATE OF AUTOMATIC OR REFLEX ACTION.

II. THAT THE TRUTH OF THIS LAW IS STRONGLY CORROBORATED BY OUR KNOWLEDGE (A) OF THE ACTION OF LIGHT ON PLANTS, AND (B) BY THE NUMEROUS PROPERTIES WHICH PLANT-LIFE AND ANIMAL-LIFE HAVE IN

* Balfour's Class Book of Botany, pages 492 to 497.

COMMON: THESE LAWS SUGGESTING THE PROBABILITY THAT CERTAIN PORTIONS OF THE TISSUES OF PLANTS AND ANIMALS HAVE A COMMON SUSCEPTIBILITY TO THE MOBILE FORCE OF THE WAVES OF LIGHT.

A critical examination of the various parts of the eye constitutes our next occupation.

Of the many elegant adaptations of means to ends, offered by the eye to our wonder and admiration, none is more extraordinary nor more exquisitely delicate than the apparatus by which that organ is balanced. Set between six muscles, to which a quantity of highly delicate nerves is supplied, the eye-ball can, with great ease, be turned rapidly and accurately in all directions. The manner in which change of ocular direction is effected, is not, however, arbitrary; the *modus operandi* being highly confirmatory of the doctrine that the eye is under the influence of the mechanical force of light-undulations. "Observations on our own eyes and on those of others, show that the visual axis may be directed in many different directions, but it is only very rarely that the angle can be changed directly, that is, immediately. *This change of direction is nearly always effected by zigzag or wave lines.* The eye is doubtless always carried directly to the object, *but this is the result of practice and habit.* . . . The numerous ways in which the zigzag and undulatory movement of the visual axis is performed during the change of direction of the eye, may be demonstrated by looking in the evening, at a well-lighted lantern, and observing the directions of the images which follow the motion of the eyes. It will be plainly evident after looking repeatedly, first at the lantern then at an object, that the eyes seldom move in a straight line but that, when we do not strive against it, they move in zigzag or undulating lines." * The result is of great importance to our theory. For, from the hypothesis that the eye is in a constant state of oscillation in respondence to undulations whose planes of action are transverse to the direction of the light, it would appear naturally to follow that the eye's traverse must also be effected in a wavy or zigzag manner. THAT THE EYE IS IN A STATE OF MOTION THROUGH THE ACTION OF LIGHT IS STRONGLY CONFIRMED BY THE CIRCUMSTANCE THAT WHEN THE EYE SEEKS TO CHANGE ITS POSITION IT NATURALLY DOES SO AS IF UNDER THE INFLUENCE OF WAVE ACTION.

The sclerotic coat, to whose outer surface the six orbital muscles are attached, is the external and toughest of the tunics of the eye, and imparts to that organ all its rigidity. The sclerotica nearly surrounds the eye, a small space being left in front for the reception of the watch-glass-like cornea, and a smaller space behind for the occupation of the optic nerve. Under the cornea, the aqueous humour is found in its special membrane. In this fluid, suspended from the anterior margin of the ciliary ligament, near the place where the cornea joins the sclerotica, is placed the iris. This membrane constitutes a curtain pierced in the centre by a circular hole forming the pupil, whose office is to contract and expand with the greater or less intensity of light. These expansions and contractions are effected by means of nerves and muscular fibre, freely distributed throughout the membrane, and are involuntary acts. If a small pencil of rays be allowed to pass through a small cone of paper, and thus impinge the iris, the size of the pupil is not affected; whilst, if the pencil be allowed to pass through the pupil, the latter is contracted. This is due to the well known physiological law that, sensor and

* Ein Neues Ophthalmotrop: zur Erlaeuterung der Functionen der Muskeln und brechenden Medien des Menschlichen Anges. Von Dr. C. G. Theodor Ruete, Leipzig, page 44.

motor nerves never act directly on each other, but through a *tertium quid* involved in the grey matter of the ganglia or of the cerebro-spinal axis. The nerves supplied to the iris are therefore motor, and its muscular fibre of the involuntary kind. The character of the involuntary fibre of the iris, differs markedly from that of involuntary muscular fibre in general, a circumstance which, as will be subsequently seen, has a highly important bearing on this discussion. " The fibres which make up the proper substance of the iris, are of a peculiar kind, very nearly allied to the ordinary unstriped muscle, *but not by any means identical with it* . . . . The fibres which we see on the front of the iris, with the ring of knotty elevations on which they join each other near the margin of the pupil, all consist of fibres loaded with nuclei, and must be regarded as of a contractile nature, *although they are not in all respects the same as fibres which we know to be muscular in other parts.*" * Nor, is this divergence of the muscular tissue of the iris from the unstriped character of involuntary muscle, solitary. " The fibres of the heart differ remarkably from those of involuntary muscular organs in general, in as much as they present transverse striæ. . . . . It must be remembered that whilst the organic substance on which vital contractility depends, is probably uniformly the same in composition, it does not everywhere assume the same form and texture. The anatomical character of human voluntary muscle differs widely from those of most involuntary muscular structures, and still more from the contractile tissues of some of the lowest invertebrate animals, although the movements must in all these cases be referred to the same principle. *The heart of the embryo beats whilst yet but a mass of cells, united to all appearance by amorphous matter, in which no fibres are seen,* yet no

* Lectures on the parts concerned in the operations of the Eye, by W. Bowman, page 49.

one would doubt that its motions depend then, on the same property as at a later period, when its structure is fully developed" (Quain). Thus the form of involuntary muscle admits of variety. Whilst the character of the muscular elements of the iris differs widely from the type of involuntary muscular fibre, whilst, in the adult heart involuntary muscular fibre is seen bearing the actual diagnostic of voluntary fibre, in the heart of the embryo we see muscular action conducted through an apparatus in which no trace of muscular fibre, voluntary or involuntary, is discoverable. INVOLUNTARY MUSCLE IS NOT ALWAYS PLAIN, BUT IS SOMETIMES FOUND ASSUMING THE STRIPED APPEARANCE OF VOLUNTARY FIBRE, WHILST AT OTHERS THE MUSCULAR FUNCTION IS EXERCISED IN THE ABSENCE OF VISIBLE FIBRES, STRIPED OR UNSTRIPED.

Continuing our regress towards the optic-nerve pole of the eye, we pass the posterior portion of the ciliary ligament and the inner termination of the choroid coat. The choroid coat is, externally, covered by the sclerotic, and inwardly, nearly throughout its whole extent, is lined by the retina. The choroid, like the sclerotic, is pierced for the passage of the optic nerve. "The inner surface of the choroid is smooth, and *is connected with the retina very firmly* at the *ora serrata*,* but is only *loosely adherent in the rest of its extent:* on the other hand, in front of the *ora serrata*, on the ciliary processes particularly, it is very intimately united with the *pars ciliaris retinæ*" (Kölliker).†

Now, since the attachment of the retina to the choroid throughout its whole extent, save at the edge of the retina, is loose, whilst the inner surface of the choroid is smooth, it follows that the retina can have a certain amount of easy vibratory "play" over the inner surface

* The outer extremity of the retina.

† The whole of this theory of perception may be said to hinge upon this sentence, and I beg therefore to urge it on the reader's careful attention.

of the choroid. Since the junction of the choroid and *pars ciliaris retinae* is, however, so intimate, that they never can be completely detached, it follows that, when this vibratory action of the retina on the choroid takes place, the whole eye-ball must in turn, take a movement of oscillation from the reaction of the retina on the choroid, and thus, through the orbital muscles, give rise to sensations of muscularity identical in kind with, although much smaller than, those implied in Berkeley's Theory of Vision.

The inner surface of the choroid is, however, not only smooth, but includes an apparatus calculated to reduce friction to a minimum. "The most remarkable development of pigment-cells in the higher animals, is on the inner surface of the choroid coat of the eye, *where they have a very regular arrangement*, and form several layers known as the *pigmentum nigrum*. When examined separately, these cells are found to have a polygonal form, and *to have a distinct nucleus in their interior*. The black colour is given by the accumulation within the cell, of a number of flat rounded, or oval granules of extreme minuteness, which exhibit an active movement when set free from the cell, and *even when enclosed within it.*"* Now, since it was on the dead subject that the activity of these choroidal granules was observed, the conclusion that this activity would be infinitely more lively in the granules of the living eye, appears inevitable; whilst, from the persistence of the activity after death, the further inference ensues, that this action is congenital, and not a condition of *intra-uterine* life. For, movements which, so to speak, are of the essence of vitality, are seen, in studying the genesis of life, to animate the organs to which they pertain in the intra-uterine stage as well as after birth., *e. g.*, the beating of the heart and the

* Carpenter on the Microscope, 3rd edition, page 722.

motion of the limbs,* and to cease directly with life, or directly after the severance of the organ from the cerebro-spinal axis. But, as the movements of the choroidal granules do not end with their separation from the cerebro-spinal axis; as, moreover, we have no evidence of their existence in the fœtal retina, they cannot be regarded as of the essence of vitality, and must consequently be described as mechanical movements acquired subsequently to birth; the impetus imparted and followed up during life having been strong enough to enable the elements to retain a *post-mortem* potency of action. A dissection of the choroid of the eye of a human fœtus, in view of this discussion, appears to be a *desideratum*.

We must now anticipate. It will presently be shown that the outer surface of the retina—the surface in contact with the choroid—is made up of the ends of a practically innumerable quantity of long rods, *very regularly arranged*. But the choroidal cells, which contain the minute granules, have also "a very regular arrangement." Now, the rods abutting on these cells are abruptly truncated, are rectangular when seen in profile, and cylindrical when viewed in plan. Hence the inference, which I opine to be a good one in Physiology (which must ever be, to a large extent, a science of Possible Relations, since neither the application of the *experimentum crucis*, nor of The Method of Concomitant Variations, is there very frequently practicable), that the choroidal granule-containing cells correspond, and are related functionally, to the ends of the rods. From this conclusion it appears to me logically to follow that, each choroidal cell has its respective abutting rod, or congeries of rods; and *vice versâ*.

To anticipate still further our future investigation, it may be stated that each rod is, to a great extent, inde-

* The motions of the limbs and fingers of the *fœtus in utero* may be regarded as the germs of our knowledge of Extension.

pendent of its fellows, and may be regarded as, in all probability, an oscillating beam receiving an impulse of motion from within; the outer end of such rod oscillating over its own set of choroidal granules. But these choroidal granules are in violent activity. The function, then, of the choroidal granules comes to be regarded as that of rollers, which, in addition to the natural smoothness of the inner choroidal surface, tend to reduce the friction of the retina, as it moves against the choroid, to a minimum.

That the eye is in a state of involuntary action through the motile force of light is a probable conclusion from a consideration of the constitution of the outer surface of the retina, the inner surface of the choroid, and the connection of the choroid and pars ciliaris retinæ.

Still pursuing our enquiries towards the optic nerve, we find the ciliary muscle and crystalline lens, the latter situated between the aqueous humour—in front—and the vitreous humour—behind. These structures being mainly important to the accommodation of the eye for distance, may, for the present, be dismissed. The posterior surface of the membrane (hyaloid) enclosing the vitreous humour, is in contact with the internal limiting membrane (*membrana limitans interna*) of the retina.

"Nervous tunic of the Eye-Ball. — The retina (*tunica nervea*) is a delicate, almost pulpy membrane, which is continuous with the optic nerve, and is situate within the vascular choroidal coat.

"In general shape it resembles the other tunics, only it does not reach so far forward in the eye-ball; and it has little strength and thickness, requiring support from the central part of the ball for the maintenance of its form. It extends from the bottom of the eye to one-eighth of an inch behind the cornea, or nearly to the outer edge of the ciliary processes of the choroid, where it ends in a finely jagged border (*ora serrata*) (*margo un-*

dulato serratus). From its ending there is continued onwards, a thin layer of transparent nucleated cells (not nerve elements), of an elongated or cylindrical form, which reaches as far as the tips of the ciliary processes, then subsiding gradually, and is sometimes named *pars ciliaris retinæ.* Its thickness diminishes from behind forwards. In the fresh eye it is transparent, and of rather a pink-grey colour; but after death it soon becomes opaque white. . . . The outer surface is flocculent when the choroid is detached, and is in contact with the pigmentary layers of the choroid. . . . *The inner surface is smooth and is merely applied* to the vitreous body within it; on it the following objects may be seen, when it is viewed in an eye cut circularly near the cornea. In the axis of the ball is a yellow spot—*macula lutea*—(*limbus luteus*—Soemmering) which is somewhat elliptical in shape, and about one-twelfth of an inch in diameter; in its centre is a slight hollow, *fovea centralis*, and as the retina is thinner here than elsewhere, the pigmentary layer of the choroid is visible through it, giving rise to the appearance of a hole through the tunic. About one-tenth of an inch inside the yellow spot is the point (*porus opticus*)* where the optic nerve expands, and the vessels of the retina branch" (Quain).

Since, then, the internal surface of the retina is only "applied" to the hyaloid, it follows that, just as the outer surface of the retina may vibrate on the choroid, the inner surface of the retina may vibrate over the hyaloid. Thus there is no hindrance whatever to the free vibration of the entire retina.

"As respects the course of the nerve fibres of the retina, this much is certain, that they radiate on all sides from the *colliculus nervi optici*, and constitute a continuous membraneous expansion, which extends as far as the *ora serrata retinæ*, and presents any considerable

* *Colliculus nervi optici.—S.*

interruption, only in the situation of the *macula lutea*. In this true nervous membrane, the fibres are associated into larger and smaller compressed bundles . . . which mutually anastomose at very acute angles, or run for considerable distances parallel with each other. Notwithstanding all that has been stated by various authors, *it may be boldly asserted* that the terminations of these nerves are as yet unknown."*

"The axis of the dioptric system is called the *optic axis*, the interior extremity of which corresponds to the centre or apex of the cornea, and the posterior extremity to a point situated between the yellow spot and the entrance of the optic nerve. By the term *visual line* is meant the line of direction drawn straight from the object . . . to its image formed at the yellow spot. It was formerly supposed that the optic axis and visual line were identical, but this is not so; for, according to Helmholtz, the visual line outside the eye, lies somewhat above, and to the inner side of the optic axis, and its posterior extremity on the retina consequently lies a little to the outer and lower side of the axis."† This important phenomenon plays, on more than one occasion, a principal *rôle* in our discussion. Suppose that the optic and visual axes were coincident, that those elements of the retina whose functions are locomotive were arranged symmetrically round the axis of the eye-ball, and that, under these circumstances, the eye were exposed to the motile force of light. It might, possibly, now ‡ remain *in equilibrio*, since the *momenta* on each side of its principal vertical plane would certainly be equal, and perhaps so opposed that, like the ass between the two bundles of

* Kölliker, Human Histology, vol. ii., page 375.

† Soelberg Wells on Long, Short and Weak Sight. 3rd edition, page 15.

‡ I find it impossible to deduce *exactly* its behaviour under these circumstances, although I am inclined to believe that the eye would not move.—S.

hay, it might have no motive to turn preferentially to one side.

If, however, whilst the optic axis remains constant, the visual axis, or what is equivalent, the yellow spot with all the retinal system of which it is the centre, be shifted outwards and downwards, as actually is the case, the locomotive elements will be arranged excentrically instead of concentrically, with the optic axis. An excess of locomotory element is now to be found on the one side of the *quondam* axis of symmetry, so that when light is "let on," this excess of motory elements will represent so much motory force, acting on one side of the system, and unbalanced by a corresponding force on the other. This excess will therefore *necessitate* the motile force of light to enter into mechanical action.

THE NON-COINCIDENCE OF THE AXIS OF THE RETINAL SYSTEM WITH THAT OF THE OPTIC AXIS, PERMITS OR FACILITATES THE OSCILLATORY ACTION OF THE EYE-BALL NECESSARY TO VISUAL PERCEPTION.

The *fovea centralis* is part of the visual axis and is, as we have stated, "the place where acute, accurately localized, direct vision, takes place" (Donders). I view it as the *locale* through which *colour* is apprehended; the idea of visual space being given through the oscillations of the eye-ball; the simultaneous excitation of the foveal nerves and eye-ball making up the idea of coloured space. It is of primary importance to his successful pursuit of the argument which ensues, that the reader should fully accept this proposition in its full force: that he should clearly understand that the *fovea* "travels," in perception, over the infinitesimally small particles of the large image refracted on the retina: that this "travelling" is due partly to Reflex Action and partly to the Will.

I before remarked that the comparative distinctness or indistinctness of the various parts of a field of view, is referable respectively, to the influences of the Will and of Reflex Action; to what on the one hand, *is voluntarily*, *most* constantly and *presently* brought before the place of inspection, and to what, on the other hand, *was involuntarily*, *least* constantly, and in the *past* before that place. The distinct part of the field is that seen by means of the Will overcoming Reflex Action: the indistinct part, that due to Reflex Action itself. The central part of the field being that seen through the incessant persistence of the Will subduing the eyes' involuntary movements, is most distinct: the peripheral portion seen fugaciously and accidentally, through Reflex Action, the least distinct. The different states of the mind whilst engaged in inspection are to one another as the contrasted set of relations of present and voluntary (distinct perception of the central portion of the field) on the one hand, past and involuntary (indistinct perception of the lateral portions of the field), on the other.

The endeavours of Associational Philosophers to assign a dual origin to our knowledge of visual extension, to regard it as partly referrible to the mediate action of the ocular muscles, and partly to the immediacy of the retinal expansion, so as to be enabled to explain the relative distinctness and indistinctness of the constituent elements of the field of view, appear to me highly unphilosophic, to be at once irreconcilable with the uniform course of nature, and inconsistent with the tendency of scientific investigation. The history of science is, largely, that of the successive subordination of phenomena, previously regarded as independent, under old laws, not of the invention of new laws for the explanation of cognate phenomena. A stage in the development of the Theory of Gravitation exactly resembles the present phase of the Associational Theory of Visual Perception. We know that Newton, setting out on his memorable discovery, reasoned in this way. Since matter attracts matter on every part of the earth, on the highest hills as in the deepest mines, it is reasonable to frame the hypothesis that the earth attracts the moon. But, in entering on the investigation, he unfortunately accepted an erroneous measurement of the earth's semi-diameter, and, unable to reconcile his calculations with the phenomena, regarded for a time, the force which maintains the planets in their orbits as twofold, as partly explicable by the vortices of Descartes and partly by gravitation ; and it was only on becoming acquainted with more accurate geodesical measurements, that he resumed his researches to reduce the force which governs the fall of an apple, and that which restrains the motions of the planets, under an unique law. "Natural effects of the same kind," says the immortal author of the Principia, "are to be referred to the same cause, as far as can be done. We are not to admit other causes of natural things than such as are both true and suffice for explaining the phenomena." I propose to reason in this spirit, to set out with the belief that the *vera causa* revealed by the Berkelian Theory of Vision, ought equally to account for the perception of small as of large spaces, as well for phenomena which we cannot, as for those that we can, directly observe, and which analogy naturally suggests as akin.

"There is no branch of physical science," says Sir David Brewster, "upon which such unsound views have prevailed as in that which relates to the optical functions of the eye ; and, in studying the speculations of modern metaphysicians and physiologists, we feel as if we were grasping with the chimeras of Aristotle and Descartes."* The following extraordinary *pseudo*-demonstration of the duality of the process of visual perception, is extracted from a book written, not by an Intuitionalist, but by an Associationalist of the Associationalists, and aptly illus-

* Brewster's Life of Sir Isaac Newton, 2nd edition, vol. i., page 200.

trates Sir David's proposition. "If a small piece of red paper be held before the eye, and then moved on one side without the eye following it, so that the impression is made just on the yellow spot and then on the lateral parts of the retina, the colour is variously seen. *To the yellow spot the colour is red;* as it moves sideways it becomes darker; gradually it assumes a bluish tint; and at last it appears perfectly black. Similar variations occur with any other colour, simple or mixed, and also with white, which unites all the colours. The last in the series is, in all cases, black. Whence it appears that different parts of the retina are differently sensitive to impressions of colour. The variation occurs in the same order in every direction, but with unequal rapidity. The series is passed through quicker when the object is moved outwards than when it is moved inwards, and also quicker for the upward than for the downward movement. It does not follow that in looking at a wide expanse of one colour we see the gradations of tint in consecutive rings. *This is a case where the mind overbears the sense.* We have contracted our notion of each surface from the way that its parts affect us when brought successively before the yellow spot—the place of minute examination—and what we seem to see is the habitual effect, rather than the effect at the instant." *

Now it is not too much to say that, had Professor Bain lived in the Middle Ages, he would, by parity of reasoning, have discovered equally specious arguments to prove that, Nature abhors a vacuum, A thing cannot act where it is not, When the Sun and Mars are in opposition a violent death may be expected, That the Elixir of Life, the Philosopher's Stone, Perpetual Motion, and the Squaring of the Circle, are objects worthy of earnest thought. For the arguments offered in support of these

* Bain, The Senses and the Intellect, 2nd edition, page 237.

phantasms were identical in quality with Professor Bain's, and were equally untruthful anticipations of Nature.

If it is true, as the learned and generally sagacious philosopher admits, that "we have contracted our notion of each surface from the way that its parts affect us when brought successively before the yellow spot," why stultify this good explanation by the bad one, that we *also* perceive, *otherwise than through the yellow spot*, the particoloured annular series of pictures, and, that these may not conflict with our perception of the central image, the mind is busily and constantly occupied, in addition to its other multitudinous employments, in *overbearing the sense?* "Rémarquez bien," says Dr. Pangloss, "que les nez ont été faits pour porter des lunettes. *Aussi* avons-nous des lunettes." With the phenomenon of visual perception taking place in the *fovea*, reasons Professor Bain, exists the phenomenon of the picture on the retina; and these phenomena, having to be brought into consilience with a foregone conclusion, he tortures—by the aid of a piece of sophistry, which bears as much on Physiology, as the arguments of Molina bear on Morals—events connected simply coincidently, into a relation of cause and effect.

Let us turn from this unhappy morsel of mystic argumentation to the too frequently despised common sense of Darwin. "If our recollection or imagination be not a repetition of animal movements, what is it? You tell me it consists of pictures or images of things. Where is this extensive canvas hung up? Where are the numerous receptacles in which they are deposited? Or, to what else in the animal system have they any similitude?

"That pleasing picture of objects represented in miniature on the retina of the eye, seems to have given rise to this illusive oratory! *It was forgot that the representation belongs rather to the laws of light than to those of life;*

and may with equal elegance be seen in the camera obscura as in the eye; and, that the picture vanishes for ever when the object is withdrawn."*

There is another phenomenon involved in the production of an image of externality on the retinal surface, which it has been the fashion to explain away by the agency of that intellectual legerdemain, "the mind over-bearing the sense." I refer to the inversion and cross-handedness of the image. If, however, the fact that perception takes place *only* in the fovea, be accepted as the law of nature, how simple the explanation! Thus, during inspection, the fovea "travels" over the inverted and cross-handed image; the picture finally apprehended at the optic centre being a synthesis of the separate foveal impressions. Now, the two poles of the visual axis of the eye-ball are related similarly to the extremities of a plank poised on a log. When one end of the plank is up, the other end is down. When one end veers eastwardly, the other veers westwardly. So, the eye being balanced round the crystalline lens, will assume corresponding polar relations. When the corneal apex rises, the *fovea* falls; when the former turns eastwardly, the latter turns westwardly. Now, it is evident that a rise and an eastward turn of the corneal apex against the erect external scene, is exactly tantamount to a fall and westward turn of the *fovea* over an inverted and cross-handed image; whilst our notions of visual form and position being derived through the sensibility of the orbital muscles attached to the *anterior* half of the eye-ball, the mind will, in visual perception, interpret a series of motions precisely corresponding, in direction, with those movements of our limbs and fingers whereby we apprehend tacto-muscular space.

"The mere sequence of one event after another event," says Dr. Thomas Brown, "is too easily conceived, and has too little in it of that complication, which at once

* Zoonomia, vol. i., page 29.

busies and delights us, to allow the mind to rest in it long. It must for ever have something to disentangle, and therefore, something which is perplexed; for such is the strange nature of man, that the simplicity of truth, which might seem to be its essential charm, and which renders it doubly valuable in relation to the weakness of his faculties, is the very circumstance that renders it least attractive to him, and though in his analysis of everything that is compound in matter, or involved in thought, he constantly flatters himself that it is this very simplicity that he loves and seeks, he yet, *when he arrives at absolute simplicity, feels an equal tendency to turn away from it, and gladly prefers to it any thing that is more mysterious, merely because it is mysterious.*" "'I am persuaded,' says one who knew our nature well, 'that if the majority of mankind could be made to see the order of the universe, such as it is, as they would not remark in it any virtues attached to certain numbers, nor any properties inherent in certain planets, nor fatalities in certain times and revolutions of these, they would not be able to restrain themselves on the sight of this admirable regularity and beauty, from crying out with astonishment, What! is this all?'"*

Faust—Mich duenkt, die Alte spricht im Fieber.
Mephis.—Das ist noch lange nicht vorueber.
Ich kenn es wohl, so klingt das ganze Buch;
Ich habe manche Zeit damit verloren,
Denn ein volkommner Widerspruch
Bleibt gleich geheimnissvoll fuer Kluge wie fuer Thoren.
Mein Freund, die Kunst ist alt und neu.
Es war die Art zu allen Zeiten
Durch Drei und Eins, und Eins und Drei
Irrthum statt Wahrheit zu verbreiten.
So schwaetzt und lehrt man ungestoert;
Wer will sich mit dem Narr'n befassen?
Gewoehnlich glaubt der Mensch, wenn er nur Worte hört,
Es müsse sich dabei doch auch was denken lassen.

* Lectures on the Philosophy of the Human Mind, by Thomas Brown, M.D. Lecture VIII.

The following description of the minute anatomy of the retina, is chiefly derived from *Die Membrana Fenestrata der Retina*, by Professor W. Krause, of Göttingen. Whenever I may have occasion to cite facts other than those due to Professor Krause's work, such will be placed between inverted commas. But by far the greater portion of my *matériel* will not be so placed, for henceforth I will be endeavouring to play, on a diminutive scale, the part of Kepler to M. Krause's Tycho Brahé. The difficulty of the investigations, either originated or verified by M. Krause, may be imagined from the circumstance that the *maximum* thickness of the retina is but the sixtieth part of an inch, and that, from this small volume have been mapped no less than sixteen distinct strata, many being compound. I greatly regret that there is no English translation of Die Membrana Fenestrata, since it is at once a valuable contribution to histological literature, a model for the prosecution of researches amidst circumstances of the greatest difficulty, and since no condensation of an original work, how carefully soever conducted, can include those fine lines which serve to set its principal features into due relief.

It is a circumstance of great importance in confirming our theory, that Professor Krause regards the pigment epithelium of the choroid as, anatomically and functionally, an integral part of the retina. His reasons are morphological, the pigment layer of the choroid being developed from the outer layer of the primitive eye-vesicle, whilst the *membrana limitans externa*, a membrane acknowledged on all sides as part of the retina, proceeds from the inner layer of the vesicle. THE CHOROID EPITHELIUM IS MORPHOLOGICALLY AND FUNCTIONALLY A CONSTITUENT ELEMENT OF THE RETINAL SYSTEM.

With these explanatory remarks we proceed to give Professor Krause's enumeration of the retinal elements :

EXTERNAL LAMINA.	Pigment Layer.		
INTERNAL LAMINA. Rod Layer.	Rods. Cones. Needles.	Outer Segment. Inner Segment.	Ellipsoïds. Axis fibre.
Membrana limitans externa.			
EXTERNAL GRANULE LAYER.	Rod granules. Cone granules.		
CONE FIBRE LAYER.	Cone fibres. Rod fibres.	Cone spheroids. Rod spheroids.	
Membrana fenestrata.			
INTERNAL GRANULE LAYER.	Membrana perforata in fishes. External Layer. Middle Layer. Internal Layer. Nuclei of the radial fibres.	Radial fibres.	
GRANULATED LAYER.	Radial fibres. Processes of the Ganglion Cells.		
GANGLIONIC CELL LAYER.	Radial fibres.		
OPTIC FIBRE LAYER.	Radial fibres.		
Membrana limitans interna.			
Membrana hyaloidea (of the vitreous).			

EXTERNAL LAMINA. Pigment Layer. This has, for our purpose, been already sufficiently described.

INTERNAL LAMINA. Rod Layer. This "consists of innumerable thin rods, placed vertically side by side like palisades, and of other large bodies named cones. These structures are soft, glistening, easily destroyed, and lose their character in fluids. *The rods are abruptly truncated externally* . . . . *Towards the margin, they become more numerous;* near the centre, the cones *predominate;* and in the *macula lutea*, the cones *alone* are seen" (Quain). "The more numerous rods are directed with their extremities outwards, while exactly the reverse is the case with the cones; and it is on this account that the latter on imperfect investigation, appear to constitute an inner, special, narrower layer, situated between the inner extremities of the rods. . . . . The rods in man are long, narrow, cylindrical bodies which possess the same breadth throughout the whole thickness of the bacillar (rod) layer. . . . . The substance of the rods is clear, homogeneous, with a slight fatty lustre, very soft and pliant, but at the same time very brittle. . . . . The cones are somewhat shorter rods, provided at their inner extremity with a conical or pyriform body, whose length is equal to half the thickness of the bacillar layer. . . . . Each of these cones . . . has a slight lustre resembling that which forms the rods, *except that it is clearer*. . . . . The rods and cones are situated close to one another, and are arranged perpendicularly on the retina" (Kölliker). The points of this description, which it is of special importance to remember, are that, THE RODS ARE MORE AND MORE NUMEROUS AS WE ADVANCE FROM THE FOVEA TO THE PERIPHERY; THE CONES ON THE CONTRARY MORE AND MORE NUMEROUS AS WE APPROACH THE CENTRE; THE SUBSTANCE OF THE RODS ALTHOUGH LARGELY COGNATE WITH THAT OF THE CONES IS NOT BY ANY MEANS IDENTICAL WITH IT, THE LATTER BEING CLEARER; THE RODS ARE ABRUPTLY TRUNCATED IN THE PLACE WHERE THEY ABUT ON THE CHOROIDAL EPITHELIUM.

"*The bacillary layer in the fovea, contains cones only;* and rods first appear midway between the centre of the *fovea* and the outer border of the *macula*. The foveal cones are longer and more slender than those distant from the *macula*, and there is a similar difference in the length and stoutness of the rods. *In both rods and cones an outer and an inner* segment are observable; the outer in profile is a slender rectangle; the inner is flask-shaped, and is, in the cones, much stouter than the outer segment, while in the rods, it only slightly exceeds the outer segment. . . . . The division of the rods and cones into an inner and outer segment *is natural*. The facts in support of this are, the presence of the division in perfectly fresh specimens; its sharpness and constant recurrence at a definite place; the constantly rectilinear figure of the outer, and the curvilinear figure of the inner, segment; the *different* refractive powers of the segments, and their different behaviour towards staining and chemical solutions. From these structural differences it is a fair inference, that *the segments have different physiological meanings.*" *

"At the line of junction of the outer and inner segments, the slightest violence snaps them asunder." † The junction of the inner and outer segments of the rods and cones is variously shown in figs. 1, 2, 3, and 8. A rod resting on its pigment cell is shown in fig. 1 (*p*).

The information obtained from these extracts will be highly useful in the sequel. We have been taught that, THERE ARE NO RODS IN THE FOVEA, BUT THAT CONES ONLY, ARE THERE FOUND; THE RODS AND CONES ARE NOT HOMOGENEOUS; THE RODS AND CONES ARE DIVIDED INTO TWO SEGMENTS, EACH OF WHICH HAS A SPECIFIC PHYSIOLOGICAL MEANING.

The inner segments of the rods and cones of many animals include, at their outer ends, little ellipsoïdal bodies (*e*, fig. 7).

When the microscopic specimen is treated in acetic, chromic, or osmic acid, there is seen running along the whole length of the inner segment, in the axial direction, a slender thread, which has been termed axis-fibre (see fig. 7, *e* to *gre*). Since this phenomenon has not, as yet, been seen in specimens prepared in their own vitreous, Professor Krause does not pronounce *decidedly* for the existence of axis-fibres, although he does not hesitate to declare that their existence in the living subject is not only possible but, in many cases, probable.

In nocturnal mammals, the outer segments of the rods are so enormously developed (see fig. 2), as to render the cones invisible by the usual mode of treatment; and it

* Hulke on the Anatomy of the Fovea Centralis of the Human Retina. *Phil. Trans.*, 1867.

† Hulke's Lectures on the Histology of the Eye. *British Medical Journal* for 1869, vol. ii., page 234.

was through pursuing the ordinary method of treating specimens, that Shultze was led to promulgate the notion that in these animals the cones are wanting. The employment, however, by Professor Krause, of a solution of tungstic acid in preparing the retina of a rabbit for microscopic observation, caused it to dilate, and thus separate the rods and thereby expose the cones.

In birds and amphibia oil-drops are found at the outer end of the inner segments of the cones, occupying the whole breadth of the segment (see figs. 3 and 7, *o e*).

We are thus put in possession of two special laws of animal life.

In nocturnal mammals the outer segments of the rods are enormously developed. Oil-drops are found at the outer end of the inner cone-segments in birds and amphibia, occupying the entire breadth of the segments.

Between each pair of rods and each pair of rods and cones, are seen little pointed bodies (figs. 4 and 6, *n*), termed needles, which anatomically fill up the spaces left between the inner ends of the inner cone segments and those of the inner rod segments.

The cones are much more delicate in their organisation than the rods; and the cone connections generally throughout the retina are much more delicately organised than the corresponding connections of the rods.

There are two different and independent ways of demonstrating the rods, cones, and needles to be not nervous but, cuticular formations. By studying the history of the development of these elements, they are seen to be solid offshoots from the *membrana limitans externa*, with which they are in continuous connection. But the *membrana limitans externa* is cuticular, therefore the rods, cones, and needles are cuticular likewise, and are consequently not nervous.

This has been arrived at by what Mr. Mill would call The Method of Agreement. We can show the same result by The Method of Difference. A knife having been constructed so as to divide peripherally the optic nerve without injuring the remainder of the eye, a series of peripheral optic-nerve sections was instituted on various animals. Now, it is an ascertained physiological law that after peripheral nerve section the following phenomenon ensues. The nerve, with all its ramifications as well as all nervous elements which are in anatomical continuity with those ramifications, undergoes fatty degeneration. The various optic-nerve sections were conducted by M. Krause, under precisely equal conditions, and with exactly uniform results. Three weeks after the operation the animal was killed and the eye examined, when numerous bodies, including the nerve and its ramifications, were found to have undergone fatty degeneration: whilst the condition of the rods, cones, needles, ellipsoïdal bodies, oil-drops, axis-fibre, *membrana limitans externa* and other structures remained perfectly normal. Hence, observation and experiment agree in determining the rods, cones and needles to be other than nervous elements.

There is, moreover, a special reason why the inner segments of the cones of birds and amphibia, with their axial fibres, cannot be nervous, which, in view of the probability that the various ways in which perception is effected in different animals are simply varieties of degree, I will here state. We have already noticed that the inner segments of the cones of birds and amphibia contain oil-drops occupying the whole breadth of the segment. Now so far as is known, a nervous process cannot be led though fatty matter, therefore the inner cone-segments of birds and amphibia are not nervous. Yet the inner segments of the cones are generally regarded as the physical *loci* of space apprehension!

Remembering the intricate and difficult nature of physiological research, and the consequent desirability of manipulating simultaneously, the smallest possible number of facts; seeing how completely the elements included between the choroidal epithelium and the *membrana limitans externa* suggest themselves the constituents of a complete system, an *imperium in imperio*, independent whilst dependent, we are reminded that it is now an appropriate time to endeavour to subduce the phenomenal laws already exposed, under a law or laws of still greater simplicity and generality.

Before entering on a discussion so complicated and difficult as that involved in the investigation of the functions of the bacillar elements, we propose to recur to those broad and fundamental principles which are always the best, whilst sometimes indeed our sole, luminaries in circumstances of intricacy.

"The object being supposed to be," says Mr. Stuart Mill, "the investigation of the laws of animal life; the first step, after forming the most distinct conception of the phenomenon itself, possible in the existing state of our knowledge, is to erect into a great class (that of animals), all the known kinds of beings where the phenomenon presents itself; in however various combinations with other properties, and in however different degrees. . .

"This is merely saying that we should put the instances from which the law is to be inductively collected, into the order which is implied in one of the four methods of Experimental Inquiry discussed in the preceding Book, the fourth method, that of Concomitant Variations. As formerly remarked, this is often the only method to which recourse can be had, with assurance of a true conclusion, in cases in which we have but limited means of effecting, by artificial experiments, a separation of circumstances usually conjoined. The principle of the method is that, *facts which increase or diminish together and disappear together, are either cause and effect, or effects of a common cause.* When it has been ascertained that this relation really subsists between the variations, a connection between the facts themselves may be confidently laid down, either as a law of nature, or only as an empirical law, according to circumstances.

"That the application of this method must be preceded by the formation of such a series as we have described, is too obvious to need being pointed out; *and the mere arrangement of a set of objects in a series according to the degrees in which they exhibit some fact of which we are seeking the law, is too naturally suggested by the necessities of our inductive operations*, to require any lengthened discussion here. But, there are cases in which the arrangement required for any special purpose, becomes the determining principle of the classification of the same objects for general purposes. This will naturally and properly happen, when those laws of the objects which are sought in the special inquiry, enact so principal a part in the general character and history of these objects—exercise so much influence in determining all the phenomena of which they are either the agent or the theatre—*that all other differences existing among the objects, are fittingly regarded as mere modifications of the one phenomenon sought;* effects determined by the co-operation of some incidental circumstances with the laws of that phenomenon. Thus in the case of animated beings, the difference between one class of animals and another may reasonably be considered as mere modifications of the general phenomenon, animal life; *modifications arising either from the different degrees in which that phenomenon is manifested in different animals, or from the intermixture of the effects of incidental causes peculiar to the nature of each, with the effects produced by the general laws of life: those laws still exercising a predominant influence over the* *result.* Such being the case, no other inductive inquiry respecting animals can be successfully carried on, except in subordination to the great inquiry into the universal laws of human life. . . . .

"To establish a classification of this sort, or even to apprehend it when established, *requires the power of recognizing the essential similarity of a phenomenon, in its minuter degrees and obscurer forms, with what is called the same phenomenon in the greatest perfection of its development;* that of identifying with each other all phenomena which differ only in degree, and in properties which we supposed to be caused by difference of degree. In order to recognize this identity or, in other words, this exact similarity of quality, the assumption of a type-species is indispensable. We must consider as the type of the class, that amongst the kinds included in it, which exhibits the properties constitutive of the class in the highest degree; *considering the other varieties as instances of degeneracy*, as it were, from that type: deviations from it by inferior intensity of the characteristic property or properties. *For every phenomenon is best studied where it exists in the greatest intensity.* It is there that the effects which either depend upon it, or depend on the same causes with it, will also exist in the greatest degree. It is there consequently, and only there, that those effects of it, or joint effects with it, can become fully known to us, SO THAT WE MAY LEARN TO RECOGNIZE THEIR SMALLER DEGREES, OR EVEN THEIR MERE RUDIMENTS, IN CASES IN WHICH THE DIRECT STUDY WOULD HAVE BEEN DIFFICULT, OR EVEN IMPOSSIBLE. Not to mention that the phenomenon in its higher degrees may be attended by effects or collateral circumstances, which, in its smaller degrees do not occur at all, requiring for their production in any sensible amount, a greater degree of intensity of the cause than is there met with. In man for example, (the species in which both the phenomenon of animal, and that of organic, life exist in the highest degree), many subordinate phenomena develop themselves in the course of his animated existence, which the inferior variety of animals do not show; the knowledge of these properties may nevertheless be of great avail towards the discovery of the conditions and laws of the general phenomenon of life, which is common to man with those inferior animals. And they are even, rightly considered as properties of animated nature itself; because they may evidently be affiliated to the general laws of animated nature; BECAUSE WE MAY FAIRLY ASSUME THAT SOME RUDIMENTS OR FEEBLE DEGREES OF THOSE PROPERTIES WOULD BE RECOGNIZED IN ALL ANIMALS BY MORE PERFECT ORGANS, OR EVEN BY MORE PERFECT INSTRUMENTS THAN OURS; and because these may be correctly termed properties of a class, which a thing exhibits exactly in proportion as it belongs to the class, that is in proportion as it possesses the main attributes constitutive of the class."*

These pregnant words, in every way worthy of the ample yet subtle intellect of one of the greatest thinkers of our age, should be written in letters of refined gold by all who aspire to succeed in physiological discovery; and I desire to impress my readers with the necessity for completely digesting these remarks, if they wish fully to enter into the spirit of the following discussion.

The problem being in general terms as follow: Given the rods and cones, each a solid, homogeneous, cuticular formation composed of an outer and an inner segment having different anatomical and functional characters; the segmental junction being frequently marked by an ellipsoïd; the outward extremity of each outer rod-segment in probable juxtaposition with the actively excited contents of a cell in the choroidal epithelium; an enormous development of the rods in nocturnal mammals; the

* Mill's Logic, 6th edition, vol. ii., page 283.

addition of oil-drops, intensely developed, to the ellipsoïds at the segmental cone-junctions in Birds and Amphibia: Required the prognosis of the phenomenon effected through the intermediacy of the rods and cones.

Our first business is the discovery of a type-species which will exhibit the segmental phenomenon most intensely developed. Now, although Professor Krause favours us with a retinal type-species, or rather type-scheme, this is scarcely of the kind prescribed by Mr. Mill, since it represents the *average*, instead of the *intense*, phase of the development. The extensive plan, however, of that histologist's researches, fortunately enables us to erect for ourselves a variety of models, so that we are enabled to view the conditions of the segmental junction, in their intense, average and feeble forms. Thus the retina of the fowl (fig. 7) evidently exhibits the intense, the Krausean type-scheme (fig. 1), the average development of the segmental connection; and, although the *locus* of the segmental apparatus is, in the human retina (fig. 8), occupied simply by a line, we nevertheless must conclude, in compliance with the canon exposed by Mr. Mill, the existence here of that apparatus in a degenerated form; since "we may fairly assume, that some rudiments or feeble degrees of those properties would be recognized in all animals by more perfect organs or even by more perfect instruments than ours." We therefore infer, that the ellipsoïdal body is of the essence of bacillo-segmental junction, and exists accordingly, in various degrees of development, in all animals at the places of junction of the inner and outer segments of the rods and cones; that in short, the representation of the bacillar segmental junction shown in figure 1 holds, in various degrees, for the whole class of Vertebrates.

For precisely similar reasons, must we judge that in all animals oil-drops, more or less developed, exist in juxtaposition with the ellipsoïds at the junction of the bacillar segments. For, where the ellipsoïd is most amply developed, namely in the segmental cone-junction of the fowl (fig. 7), the oil-drop alone is found. We must therefore conclude that, in those cone-segment junctions which are less intensely developed than those of the fowl, oil-drops are found on a degenerated or rudimentary scale. Moreover, since we have seen cause to conclude that the ellipsoïds exist throughout the Vertebrata, at the place of junction of the rod-segments, as well as that of the cone-segments; since in the type-scheme (fig. 1), the ellipsoïd of the cone declares itself identical in quality, and superior only in the scale of development, with the rod ellipsoïd; it appears to me that, the conclusion just arrived at namely, that the oil-drop is of the essence of the cone-segment connection, must logically be extended to the rod: that we must infer the oil-drops to be of the essence of the junction of the rod-segments. Hence we lay down the proposition, ELLIPSOIDS AND OIL-DROPS PROBABLY EXIST GENERALLY AT THE PLACES OF JUNCTION OF THE ROD AND CONE-SEGMENTS.

But as the oil-drops and intensely-developed ellipsoïds are only *seen* in Birds and Amphibia, we are placed in possession of two contrasted sets of relations. Birds, Amphibia, Intensely-developed Ellipsoïds, Oil Drops; Not Birds, Not Amphibia, Feebly-developed Ellipsoïds, No Oil Drops; and, although in the absence of a *catalogue raisonné* of the bacillar layers of various animals, we cannot *demonstrate* the development of the ellipsoïds and oil-drops to proceed *pari passu* with the development of some grand salient diagnostic of bird-life and amphibia-life, yet, since we know that these two sets of phenomena disappear together, it is still a legitimate inference that the two sets of relations are *with probability* at least, related as "cause and effect, or as effects of a common cause."

Before examining the habits of life of Birds and Amphibia with the view of ascertaining—according to our lights—the probable function of the intensely-developed ellipsoïds and oil-drops, it will be convenient to glance at the circumstances in which the outer segments of rods are, in general, placed. At its outer extremity the outer rod-segment abuts upon a quantity of elements in active excitation. At its inner end, as we have just concluded, is an oil-drop. What is to be inferred from these circumstances? One consequence, and so far as I can perceive, *only* one consequence; THAT THE OUTER ROD-SEGMENT IS IN MOTION. For, we should be stretching our conceptive faculty vastly beyond the limits warranted by experience or by analogy, were we to hold that a solid rod poised between a quantity of actively mobile elements at one end and oil at the other, is preferably in a state of rest. The form of the outer end of the inner cone-segment (fig. 1), strongly favours this conclusion, since it presents the appearance of being hollowed to form the female part of a socket joint for the reception and play of the inner end of the outer segment. A similar form and function may be legitimately extended to the outer end of the inner rod-segment (fig. 1). The validity of this explanation is confirmed by the appearance of the delicate fibre running, in an axial direction, throughout the inner cone-segment (fig. 7): for the function of this axis-fibre may reasonably be assigned as that of hindering the severance of the segments, whilst permitting the play of the outer on the inner segment. We thus arrive at the proposition that THE OUTER SEGMENTS OF THE RODS AND CONES PROBABLY OSCILLATE IN SOCKETS HOLLOWED OUT OF THE OUTER ENDS OF THE INNER SEGMENTS.

We must make one anticipation more, prior to considering the cases of Birds and Amphibia. It is a part of our theory, that nerve elements exist at the inner surface of the retina, and are "irritated" into motion by the mechanical force of light: that this motion is conveyed by means subsequently to be described, so as to pull inwardly the internal surface of the *membrana limitans externa*, and thus to cause jerks of inner rod segments. Now the jerk of an inner rod segment would necessarily be followed by the jerk of its outward segment. From this point of view then, the function of the degenerate rod oil-drop will be apparent. Its duty is lubricative; its object akin to that of the choroidal cell-granules, namely to minimize friction. The question now naturally arises, Why should the oil elements and sockets of the cones be so enormously developed as compared with the development of these elements in the rods?

Were there only a single rod, and nothing else, on the outer surface of the *membrana limitans externa*, it appears to me highly probable, in view of the immense dimensions of the outer compared with those of the inner segment, and of the extreme readiness of the segments to part company, that a jerk of the inner segment would result in—the presence of the axis-fibre notwithstanding—the severance of the segments. Under the actual arrangement of the bacillar structure, the following events would however, appear to follow a jerk of an inner rod-segment (fig. 1). The rod would strike against a cone, and thus the rod force would be *deadened* by, *and thrown into*, *the cone*, whose reaction against the rod, *would convert the jerk of the outer rod segment into an oscillation.* The brunt of the rod force comes in this way, to be ultimately borne by the cone, which must thus be regarded as a cushion, having a "braking" or "buffing" function. This view of the duty of cones is confirmed by their situation, shape, division into segments (one of which has the power of motion on the other), by a superior lightness of colour testifying to a superior fatty nature and therefore to a superiority of power to yield, and by the circumstance that the cones have only half the length of the rods (see fig. 1), a proportion which permits the exercise of the buffing function of the cones, but so as not to prevent rod oscillation. Thus, whilst the inner and comparatively stolid segment of the rod strikes against the inner and comparatively stolid part of the cone, the outer segment of the rod destined for oscillation, moves against the buffing, yet highly yielding (because capable of rotation in a well oiled socket) short outer cone-segment.

We now revert to Birds and Amphibia, with the object of inquiring why the development of the apparatus at the cone-segmental junction, should here proceed on such a comparatively large scale. Now, in examining those habits of life of birds and amphibia which involve the exercise of sight, we find these animals exceptionally subject to violent and extraordinary vicissitudes of vision, through their natural liability to frequent and sudden changes of exposure to intense and feeble lights. The nervous nature of birds is notorious; and their consequent liability to sudden alternation of place, and therefore to rapid and extreme alternations of light, must necessarily involve the accompaniment of a corresponding means of overcoming that staggering, "dazzling" of the eyes which puts these, in man as in many other animals, utterly out of gear on the sudden succession of intense to weak rays, since in birds, no such staggering or dazzling effect is perceptible on their sudden start from a weakly to a strongly illuminated place. Amphibious animals again, must be presumed equally capable of pursuing or eluding their prey as well amidst the recesses of watery caves as under the sudden glare of a tropical sun, and therefore to possess, equally with birds, some means for preventing any derangement or suspension of the visual powers. It may be said, that the iris exists in the eyes of birds and amphibia, as well as in other animals. But we must not presume too much on the iris. The action of that membrane is notoriously sluggish; nor will sluggish action answer to the exceptionally sudden and violent changes of light, which, in the case of birds and amphibia, have to be responded to.

Under our view of the nature of rod-action, it is evident, that were the rods and cones of birds and amphibia constructed and circumstanced identically with those of man, they would be totally incompetent to encounter, as they do, sudden extremes of light: in other words, the dazzling shock experienced by human beings on the sudden advent of strong light, is accounted for by reason of the rods being set into a state of action, for which they are entirely unsuited by nature. If we imagine a pendulum put in motion by a percussion, instead of by a gentle motion of the finger, a railway locomotive striking at "speed" a carriage which is stationary, instead of "slowing" before setting the latter in motion, we will have an idea of the condition of the human rods when exposed to those sudden and extreme changes of light, to which birds and amphibia must be naturally exposed. Now, as the brunt of the rod-shock is ultimately borne by the cones (corresponding to the buffers of a railway carriage), it is evident that in the cases of birds and amphibia, the cones must have a "readiness" of "braking" power unnecessary in the case of cones of human beings. The extra scale of development of the socket joint and lubricator of the cones in the bird and amphibian retinæ would, then, seem exactly to "jump with" the extra momentum suddenly exerted in these instances, firstly on the rods, and secondly on the cones. Thus, the inquiry into the habits of birds and amphibia confirms the conclusion that the outer rod-segment is in a state of oscillation between the granules of the choroidal cells at one end and a lubricated recess at the other.

The circumstance of the rod-impulse being, in the course of its progress from within, interrupted by the *membrana limitans externa*, instead of being received directly, will additionally aid in securing smoothness of action to the outer rod-segments; for, by this means the little independent inner direct "pulls" on each rod, are combined into a large, elastic, swinging and, so to speak, smooth "dance" of an interdependent system.

It will be remembered that, we found the rods of nocturnal mammals developed in an exceptionally enormous degree; that, in all retinæ, the number of cones increases, and that of rods decreases, as we approach the *fovea*, and *vice versâ*. These phenomena are highly corroborative. The light which acts through the inner nerve-elements on the rods is, in the case of nocturnal mammals, very weak. The weak light and the "colossal"—to use Schultze's phrase—development of the rods of nocturnal mammals being regarded as related in cause and effect, we infer that the superior length of the rods, in this case, makes up for the abnormally feeble motive force of the light destined to act on them,—on the principle that, the product of a given weight applied at the end of a given lever is equal to the product of a lighter weight applied at the end of a longer lever.

Again, with a dilated pupil, that is, under weak light, many inner nerves (communicating with the rods) are exposed, whilst, under intense light (the pupil being then contracted) few of these nerve-communications are exposed. But, from the exposure of few or many rod nerves under intense and feeble lights respectively, follow the oscillation of few or many rods. On the principle that the effective force of a few levers, each actuated by a given weight, is equivalent to the effective force of a larger quantity of levers each actuated by a lighter weight, the resultant action of intense light on a few rods is equal to that of weaker light on a greater number of rods. Nor, seeing that the act of perception is effected only through the *fovea*; seeing, moreover, that

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the retinal picture, even under the most constricted pupil, is *always* vastly larger than the *fovea*, is the dilatation of the pupil under feeble light otherwise explicable.

The study of these phenomena reveals the fact that the retina vibrates under fixed conditions of rate. Now, since the breadth of light-waves, and therefore their rate of motion, is constant for each colour and completely independent of the degree of intensity of the light (for intensity is referrible, not to the amplitude, but to the *height* of the waves, *cœteris paribus*), it would follow, firstly, that the inner-nerve vibrations are isochronous with the undulations of the impinging waves; secondly, that the vibrations of the whole retina are isochronous with those of these inner-nerve fibres; thirdly, that the whole eye should vibrate or oscillate at the same rate as, that is with, the retina. The rate of vibration of the whole eye would then be that of the undulations of the incident light, and would vary with the incident colour. This result tallies with a conclusion which, in the second section of this essay, we are led to notice, namely, that perception under a beam of white light is more distinct than under any constituent ray of that beam.

The elements included between the external surface of the *membrana limitans externa* and choroidal epithelium I term THE MECHANICAL SYSTEM OF THE RETINA.

OUTER GRANULE LAYER.
CONE FIBRE LAYER.
Membrana fenestrata.

The OUTER GRANULE LAYER is composed of "a great quantity of elliptic corpuscles, which, when perfectly fresh, exhibit striation similar to muscular fibre" (Quain). See fig. 5 and *gre*, in figs. 2, 6, 7, 8, 9, and 13. Each corpuscle, or granule, is made up of discs which lie in planes perpendicular to the lines of direction of the rods and cones, and are composed of two substances, one of which has a high, the other a low refracting power; discs of high and low refractive powers being placed alternately, so that, whatever the number of discs, the middle one is composed of the higher refractive substance and is always bi-concave, whilst the outer discs are convexo-concave.

That the outer-granules are not of a nervous nature we know from dividing the optic nerve, when they remain normal. If a quantity of these granules attached to their connecting fibre be soaked in dilute chromic acid, whose strength is gradually being increased, THE ROD-GRANULES SPRING FROM THEIR FIBRES, and swim about the fluid in thousands. From this phenomenon I believe THE ROD-GRANULES to be what they plainly declare themselves to the eye, namely, INTENSELY DEVELOPED, INVOLUNTARY,* MUSCULAR ORGANISMS, which have been in a constant state of excitation from birth. Nor, does it demand any violent stretch of the imagination to conceive the continuance, after death, of pulsations due to propulsions imparted to a specially constituted, highly sensitive, muscular organ at the rate of hundreds of millions of millions during every second of a lifetime that the eye was exposed to light; for we know that a pendulum can be so circumstanced as to oscillate for sixteen hours after only *one* propulsion. The acquired activity of the choroidal granules—an activity continuing after death—has, then, its exact counterpart in the acquired activity of the external granules, and the conclusion is that the former are probably muscular.

This *post-mortem* activity of the external and choroidal pigment-cell granules appears to lead logically to the conclusion that the entire retina may be, or probably is, in a state of (gradually diminishing) vibration—1° after

* It has been already shown that the presence of stripes is quite compatible with the general characteristics of involuntary fibre. See *supra*, page 21.

death, and 2°, *à fortiori*, in sleep and in darkness. Were the latter not the case, it seems difficult to imagine that the eye could be aroused in a few seconds from a state of complete inertia (which it would otherwise have assumed in the moment immediately preceding the act of awaking) to vibrate in response, say, to the undulations of violet light, that is, to vibrate 699,000,000,000,000 times in a second. The degree of "dazzling" experienced on awaking to the glare of a strongly lighted atmosphere would, therefore, probably represent the difference between the force of the eye's action in the successive moments during which the patient was asleep and awake.

An illustration of the power of light to induce action on the eye may be derived from an observation of Professor J. Müller. He found that, when at sea, if he looked for a considerable time at the waves, and then suddenly directed his gaze on the deck, the latter appeared to move in the same manner as the water. Now, this phenomenon evidently arises from the fact of the eye being so strongly influenced by an "induced" motion corresponding with that of the water, as to defy the action of the Will and of the *natural* automatic force of light.

The scope of this essay does not justify the introduction of any psychological discussion other than points immediately involved in the Theory of Vision. But I can scarcely refrain from indicating to Associationalists the direct bearing which the probable persistence of retinal motion during darkness and sleep—after the exciting cause has ceased to exert itself—has upon the Associational Theory of Ideas by means of Revived Sensations.* For, if the retina persist in vibrating after

* See The Senses and the Intellect, by Professor Bain, 2nd edition, page 343.

the withdrawal of light, we may justifiably presume that parts of other organs of sense have the same capacity. And the Theory of Revived Sensations postulates the activity, in a subdued form, of those very organs of sense by whose active energy we cognize The External World.

The muscular outer-granules are attached (see *gre*, figs. 2, 8, and 9), directly or indirectly, to the inner surface of the *membrana limitans externa* (*mle*, in figs. 2 and 9). The direct attachment need not be described. The indirect connection is effected by means of two sets of fibres, which constitute the

CONE FIBRE LAYER, and are named rod-fibres and cone-fibres, the latter giving its name to the layer, as being more numerous than the rod-fibres. The cone-fibres compose the web, or tissue, which, *inter alia*, supports that part of the retina included between the *membranæ limitans externa* and *fenestrata*.

For each rod and each cone there is an external granule, and *vice versâ*. Hence the division of the external granules into two orders or classes, namely, rod-granules and cone-granules. For each rod-granule and each cone-granule there is a fibre, and *vice versâ*. We are thus enabled to form the following proposition:— EACH ROD AND EACH CONE HAS ITS OWN ROD-GRANULE AND ROD-FIBRE, AND CONE-GRANULE AND CONE-FIBRE RESPECTIVELY.

The distinction before referred to as obtaining throughout the retina between the rod-connections and cone-connections, is found to hold here, namely, that the striation of the rod-granule is much coarser than that of the cone-granule.

"Owing to the peripheral situation of the outer granules belonging to the central cones, this (the outer granule) layer is absent from the centre of the *fovea*. It begins at a short distance from the latter, attains its maximum thickness at the foveal edge, then decreases gradually, and again increases towards the border of the *macula.* This variation is due to the presence, at the margin of the *fovea*, of the granules belonging to the central cones, in addition to those connected with the cones of the part, and to the increase of outer granules connected with the occurrence of rods towards the border of the *macula.*" *

"At the inner surface of this layer, the cone-fibres combine in a plexus, the bundles of which, near the centre of the *macula*, are directed obliquely towards the inner surface of the retina; between the centre and the circumference of the *macula* they assume a direction nearly parallel to the retinal layers, and at the circumference of the *macula* they run nearly vertically." † Fig. 10 shows the oblique course of human cone-fibres which have proceeded from the edge of the *macula.*

The inward attachment of the fibres to the *membrana fenestrata* is effected by means of bodies called rod and cone spheroids. Before describing these, it will be necessary to direct our attention to the

Membrana fenestrata. This is a flat, transparent, granulated membrane, whose characteristic is a quantity of large *lacunæ*, or *fenestræ*, freely distributed over the surface, and giving the membrane its title. The *membrana fenestrata* consists of a single layer of fused, irregular, multipolar cells, which *may* contain *lacunæ*, and *do* contain granules. From the edge of each cell issue long, short, and branched processes, either connected with each other or with the processes of the adjacent cells. The space between two processes of any given cell is either quite filled up in this way, or *lacunæ* are found

* Hulke on the Anatomy of the Fovea Centralis of the Human Retina, *Phil. Trans.* 1867.

† Hulke's Lectures on the Histology of the Eye, *British Medical Journal* for 1869, vol. 2.

between them. The *membrana fenestrata* is found in every part of the retina, except in the *fovea*.

We are now enabled intelligently to examine the rod and cone spheroids. The inner termination of the rod-fibres are either club-shaped or spindle-shaped *granular* swellings. When the rod-spheroid is club-shaped, it is bodily attached to the membrane ; when spindle-shaped, one of the cell-processes runs outward for inosculation in the base of the rod-spheroid. *The rod-spheroids* are arranged round, and close to, the *edges of the lacunæ.*

The granular nature of the cone-spheroids is much less marked than that of the rod-spheroids. *They are not attached bodily to the substance of the membrana fenestrata*, the connection being made by processes running off the marginal edges of the cone-spheroid, as natural prolongations of its envelope. The cone-spheroids, whilst always found near to, are however, further removed from the edges of the *lacunæ* than are the rod-spheroids.

Since the *rod-spheroids* and *membrana fenestrata* are both described as granular, we must presume that they have a character common with that of the outer granules. I therefore regard the whole system included between the *membranæ limitans externa* and *fenestrata* as muscular in various degrees, and I will henceforth term it THE MUSCULAR SYSTEM OF THE RETINA.

We have now to imagine the *membrana fenestrata*, a very finely-attenuated membrane, stretched after the manner of a drum-head, but so as to form an outwardly convex and inwardly concave surface spread horizontally throughout the retina, except in the *fovea*, where it is absent. If the reader will represent to himself a round violin-bow, the hairs completely surrounding the stick instead of merely extending along one side, the bow tapering towards its outer extremity so as to have the form of a cone; if he will moreover consider this bow twittering against the perimeter of a *lacuna* of the *mem-*

brana fenestrata, he will, from my point of view, see the relation obtaining between the windowed membrane and the outer elements of the internal granule layer. The *membrana fenestrata* receives tremors from the lacunal edges as they are throbbed against by the external row of inner-granule elements; and, since a set of rod-spheroids is situated in immediate proximity to, and around, the border of each *lacuna*, this system of rod-spheroids would, first of all, be excited into tremoral motion through the twittering imparted at the lacunal edge. The tremoral motion would, in turn, be carried from the rod-spheroids along the rod-fibres to the intensely developed muscular rod-granules, which would magnify the tremor prior to being carried to the inner surface of the *membrana limitans externa.* The behaviour of the rods situate on the opposite side of the membrane in a direct line with the rod-fibres, has been already described.

But, a part only of the tremoral action due to the twittering of the outer element of the inner granule layer has been accounted for; and, as the tremor of the *membrana fenestrata* is not supposed to be exhausted in setting the rod-spheroids into action, it would, after causing these to vibrate, pass with a diminished vigour to the territory occupied by the inner terminations of the processes of the cone-spheroids. These processes, seen at the foot of *zf*, fig. 8, extend from either side of the imaginary prolongation of the line *zf.* When the tremor has struck the foot of the left-hand process, the "pull" of the cone-fibre will have an opposite tendency of direction to that which it will assume on the tremor striking the right-hand process.* The "pull" of the cone-fibre on the inner surface of the *membrana limitans externa* will consequently be alternately towards the left and right

* This action will be more easily traced if we imagine the cone-thread *zf* and the processes shown in fig. 8, to be transferred to fig. 9, where the *course* of the fibres is more plainly visible.

hand, thus giving the communicating inner-cone segment a corresponding set of alternate motions, independent of those received by it from the rod. The extension of this explanation to all the rod-spheroids which surround a *lacuna* can be performed by the reader.

For several reasons, the action of the cone-spheroids would be feebler than that of the rod-spheroids. Firstly, the cone-spheroids are further removed from the source of excitation than are the rod-spheroids, and the *vis* of the vibration will consequently be appreciably diminished before reaching the ground which the former occupy. Secondly, the cone-spheroids are so attached to the membrane as to take on the surplus dilute tremor after a comparatively languid fashion. Thirdly, their inferior markings betray a correspondingly inferior power of assimilating muscular action. Now this feeble pull of the cone-spheroid will be transmitted to the *membrana limitans externa*, and to the inner segment of its corresponding cone in alternately opposite directions, just as the tremoral wave strikes the left-hand or right-hand cone-process. What will be the result of this independent action of the inner cone-segment?

On the inner rod-segment receiving its jerk from within, it abuts, as we have seen, against its neighbouring cone-segment. But the force of this collision on the latter will be broken by the cone's own independent motion received through the left-hand cone-process—a motion which will be in the same direction as that impressed on the cone through collision with the rod. The "pull" received by the cone from the right-hand process will, on the contrary, be in the opposite direction from that just described, and will assist the elastic nature of the cone material to exert its buffing power, and to restore the rod to its normal position. Whence we infer that the effect of the *independent* alternate swings of the cone (as distinguished from those received *through collision* with the rod) is to afford smoothness of action. This smoothness will be imparted successively, to the action of the rods, to the action of the retina, and to the action of the whole eye.

There are no outer granules in the *fovea*, those in connection with foveal cones being found at the edge of the *macula* (*v*, fig. 13): nor does the *fovea* contain any portion of the *membrana fenestrata.* The course assumed by the foveal cone-fibres in proceeding for attachment to the membrane is oblique; the most central fibre (continuous with cone *z* in fig. 13) bends sharply, immediately after issuing from the inner end of its granule to join the membrane, and assumes a direction nearly horizontal and parallel with the plane of the *membrana fenestrata.* This arrangement will cause the central cone of the *fovea* to be excited with more powerful action than any of the other cones. For the granule of the central cone will respond more effectually than any of its fellow central-granules to an inward propulsion; since it will be worked at the acutest angle of all against a neighbouring system of granules and fibres; the resistance of this system serving as a fulcrum or fixed pulley for the fibre of the central cone to work against; so that the latter may derive all that superiority of "purchase," which a cord working round a fixed pulley possesses over one pulled "dead," that is, immediately in the line of the desired direction. The farther any one of the cone-fibres, seen in fig. 13, is situated from the centre of the fovea, the less effective will be its pull, since the more obtuse the angle at which a fibre works round the pulley-system, the more will it approach the condition of a straight line, such as that assumed by each of the fibres in fig. 9.

Now the brunt of cone-resistance must ultimately be referred to the central cones generally, and to the central cone particularly, so that where the cone-resistance *must* be greatest, the *means* of resistance *is* greatest.

The arrangement of the central-cone granules and fibres is thus another means towards securing smoothness of rod action, retinal action, and eye action.

We conclude from the absence of the *membrana fenestrata* and outer granules in the *fovea*, that these structures are not involved in any operation which may be conducted uniquely in the visual axis of the retina.

The *membrana fenestrata* comes in its turn to be regarded as yet another medium for the attainment of smooth oscillation, through reasons precisely similar to those which led us to view this function as the *raison d'être* of the *membrana limitans externa.*

The elements included between the *membranæ limitans externa* and *fenestrata* I term the muscular system of the retina.

INTERNAL GRANULE LAYER.	Radial Fibres.
GRANULATED LAYER.	Radial Fibres.
GANGLIONIC CELL LAYER.	Radial Fibres.
OPTIC FIBRE LAYER.	
Membrana limitans interna.	
Membrana hyaloidea (of the vitreous).	

RADIAL FIBRES.—These are common to all the layers still to be treated, and as little is to be said concerning them, we will dismiss them at once with a few remarks. These do not suffer degeneration after section of the optic nerve, and are consequently not nervous elements. They are considered to be, merely, fibres of connecting tissue serving to unite the *membranæ limitans interna* and *fenestrata.*

A radial fibre is shown in figs. 6, 8, and 9, marked *r*, also in fig. 1, extended between the *membranæ fenestrata* and *limitans interna;* in the latter case, as well as in fig. 9, in juxtaposition with its appropriate nucleus. The radial fibres were supposed by their discoverer, H. Müller, to extend from the rods and cones to the *membrana limitans interna*, but later and more careful investigation has shown this opinion to be incorrect; *nor is it even* *generally the fact that, in Mammalia, the fibres of the muscular system and the fibres of Müller are attached to directly opposite portions of the membrana fenestrata.*

"From all that I have seen, I think I am warranted in assuming that the triangular truncated swellings, and not the divisions and ramifications which also frequently occur, represent the true condition, of these fibres at their termination." (Kölliker.) "At the limiting membrane of the retina, they (the fibres of Müller) end in a somewhat triangular swelling." (Quain.) M. Krause testifies to the justice of these descriptions, by thus delineating the inner terminations of the radial fibres (see figs. 1, 6, and 9, *mli*). I view these triangular swellings as means for securing powerful restraining power or "purchase" on the internal limiting membrane, so as to counteract the strain which the retinal muscular system must exert in distending the retina.

INTERNAL GRANULE LAYER.— On inspecting the representation of the elements of the retina, other than the radial fibres and their nuclei, included between the *membranæ limitans interna* and *fenestrata*, the reader will find these, specially and exceptionally, denoted by dots (fig. 1)—a sign *that they are considered nervous.* That this is their nature Henlé has no doubt; "the corpuscles of the internal nuclear layer being considered by him as nerve-cells of a smaller order than those of the cellular layer." (Quain.) Extreme caution is, however, evidently a prominent feature of M. Krause's intellectual character; for, whilst he does not hesitate in his type-scheme to include the outer as well as the interior elements of the internal granular layer among the nervous elements and *even to show them in anatomical continuity* with the ganglionic cells within, he is found, on the other hand, expressing himself that the nervous nature of the outer row of internal granules is *probable* (wird vermuthet). But, whilst he hesitates to speak decidedly on the point, the facts of marking them nervous in his type-scheme, and exhibiting them as connected with the ganglionic cells within, sufficiently indicate in which direction his bias tends.

I regard, then, the outer elements of the inner granule system (*gri*, in figs. 1 and 10), seen intruding in the *lacunæ* of the *membrana fenestrata*, as forming the outer termination of a nervous system. Little more is to be said of these most-external elements than that they are unipolar (see fig. 10), whilst the remaining inner elements are multipolar; and that they are larger than their more inwardly situated colleagues.

The middle and internal ranks of the internal granule layer do not call for much special mention. It may however be stated that the middle layer consists of elements which resist 3 per cent. acetic acid, each pair sending, inwardly and outwardly, fibres whose finer tenuity and feebler resistance to reagents enable them to be directly distinguished from the radial fibres; and that the internal layer, at the place where it joins the granulated layer, consists of large granules, each containing a large nucleus and some cell-substance, *and not unlike small ganglion-cells.*

"At the centre of the *fovea* this layer is every thin; and its numerous granules are not clearly separated from the outermost cells of the ganglionic layer." *

From these remarks we glean that, THE CONSTITUTION OF THE NERVOUS ELEMENTS IN THE FOVEA DIFFERS FROM THAT FOUND MORE LATERALLY.

Kölliker and H. Müller assert that some of the internal granules are in connection with processes of the ganglion-cells, whilst Schultze objects, that the thickness of these processes had more resemblance to the thickness of the radial fibres than to that of ganglion-cell processes.

* Hulke on the Anatomy of the Human Eye, *Phil. Trans.* 1867.

Subsequently Ritter, Manz, and Hulke maintained that the connection of the internal granules with the ganglion-cells, by means of processes issuing from the latter, holds good for amphibia. I conclude from sifting this evidence, that the inner granules are connected with processes of the ganglion-cells, and this connection is also accepted by M. Krause (see fig. 1).

Neither the granulated layer nor the middle and internal granules of the internal granule layer are shown in fig. 1. These occupy successively outward positions in the gap where the dotted line is alone seen joining the external stratum (*gri*) of the internal granular layer with the processes of the ganglion-cells (*g g*).

The GRANULATED LAYER proper, is made up of nervous processes extending outwardly from the ganglion-cells. "The granular (granulated) layer is resolved . . . into a very finely fibrillated, spongy web . . . .

"The only nervous elements occurring in it are the internuncial fibres * which traverse it, and the outermost ganglion-cells imbedded in its inner surface. The term granular . . . simply expresses its appearance under a low power." † These undergo fatty degeneration after peripheral section of the optic nerve.

The GANGLIONIC CELL LAYER, or nervous layer as it is sometimes termed, is next found in our progress towards the *membrana limitans interna.* "THE GANGLIONIC CELLS ARE MULTIPOLAR, and are connected with processes, outwardly with the granulated layer, and inwardly with the fibres of the optic nerve, AND HAVE EXACTLY THE SAME CHARACTER AS THOSE OF THE BRAIN . . . They are mostly pyriform or roundish, or are drawn out into three to five angles; AND THEY

* Excluding the radial fibres. S.

† Hulke's Lectures on the Histology of the Eye, *British Medical Journal*, 1869, vol. ii., page 234.

ALL POSSESS ONE TO SIX, OR EVEN MORE, LONG, PALE, BRANCHED PROCESSES, first observed by Bowman (Lectures on the Eye, p. 125), *similar to those of the central nerve-cells* (see fig. 1, *gg*). In all cases where these nerve-cells are seen upon perpendicular sections, *one to two of these processes proceed outwards, and are lost in the inner granule layer*, whilst the others run horizontally, and are *in part continued into genuine varicose optic fibres, in part connect together the more remote nerve-cells.* The nuclei of these nerve-cells, *which behave towards reagents like those of the brain*, . . . generally possess a very distinct nucleolus." (Kölliker.)

It need scarcely be said that, consequent on section of the optic-nerve, these cells are filled with fat-drops, and the substance of the cells with fatty granules; that, in short, the cell-processes undergo fatty degeneration. From the ganglion-cells run processes outwardly and inwardly.

Now a congeries of ganglionic cells, such as is the ganglionic cell layer, is neither more nor less than a ganglion. What is the nature of a ganglion? " Besides the cerebro-spinal centre and its nervous cords, the nervous system contains certain bodies, called ganglia, which are connected with the nerves in various situations. These bodies, though of much smaller size and less complex nature than the brain, agree nevertheless with that organ in their elementary structure, and, in a certain extent also, in their relation to the nervous fibres with which they are connected; and this correspondence becomes even *more apparent in the nervous system of the lower members* of the animal series. For these as well as other reasons, THE GANGLIA ARE REGARDED BY MANY AS NERVOUS CENTRES TO WHICH IMPRESSIONS MAY BE REFERRED, AND FROM WHICH MOTORIAL STIMULI MAY BE REFLECTED OR REMITTED; BUT OF LOCAL AND LIMITED INFLUENCE AS COM-

PARED WITH THE CEREBRO-SPINAL CENTRE, AND OPERATING WITHOUT OUR CONSCIOUSNESS AND WITHOUT THE INTERVENTION OF THE WILL." (Quain.)

The sensor and motor nerves never act *directly* on each other, but *through* the cineritious nervous matter abounding in the cerebro-spinal axis and ganglia. Therefore, since the retinal ganglion-cells have the same characteristics as the grey matter of the brain, I regard the fibrils running from within to the retinal ganglion (the congeries of the retinal ganglionic-cells), as afferent, or sensor, nerves; those running from the opposite side of the ganglion, *i.e.*, outwardly, as efferent, or motor, nerves; the exceptionally close contiguity of the power-receiving-and-emitting ganglion to its motor and sensor nerves, being accounted for by the exceptionally rapid rate of communication which, in this instance, must be effected between these nerves.

The OPTIC-FIBRE LAYER, sometimes called the nerve-fibre layer, is finally reached. This is an expansion of the optic nerve. "In its course from the optic commissure to the eye, this nerve has the same structure as the ordinary nerve, and its varicose dark fibres and borders . . . form a polygonal . . . surrounded by an ordinary neurilemma. Arrived at the eye, the optic nerve loses its sheath in the sclerotic coat, which possesses an opening for the passage of the nerve, in the shape of a funnel with the base outwards; the inner neurilemma likewise terminates on the inner surface of the sclerotic, and also on the choroid, so that the tubules of the optic nerve in their further course in the interior of the eye, pass on independently without their envelopes of connective tissue. Within the canal of the sclerotic, and up to the slight elevation or *colliculus* which it forms on the inner surface of the retina in its passage forwards, the optic nerve is still white, and furnished with dark border tubules; but from thence onwards, its elements in man and many other animals become quite clear-yellowish, or greyish-transparent, *like the finest tubes in the central organs.* . . . These tubules are distinguished from other pale terminations of nerves by the absence of nuclei in their course, by a somewhat stronger refractive power, and by a constant recurrence in the dead body of varicosities. The two latter characteristics lead us to regard the contents of the tubes as not being nervous medulla of the ordinary kind, but rather as of a partially *semi-fluid* nature, and perhaps somewhat fatty, so that WE SHOULD CLASS THE NERVE FIBRES OF THE RETINA WITH THE MOST DELICATE ELEMENTS OF THE BRAIN. . . .

"With regard to the course of the nerve fibres in the retina . . . they radiate in all directions from the *colliculus nervi optici,* and form a connected membraneous expansion, extending to the *ora-serrata*, only interrupted at the yellow spot. . . . At the yellow spot only, *a small portion of the optic fibres proceed directly to the* inner end; much the larger portion of the fibres destined *for the lateral* portions of the spot, describe a series of curves which take larger and larger sweeps as they are directed further forwards. AT THE YELLOW SPOT ALL THESE FIBRES LOSE THEMSELVES IN THE DEEPER PORTION AMONG THE NERVE CELLS, so that here there is no superficial layer of optic fibres; the nerve fibres of this spot probably arise from the processes of its cells." (Kölliker.) THE CONSTITUTION OF THE OPTIC NERVE IS THEREFORE DIFFERENT IN THE YELLOW SPOT AND FOVEA, FROM THAT WHICH IT ASSUMES IN MORE ECCENTRIC PARTS OF THE RETINA.

"*External to the yellow spot, the fibres become more and more spread out, and at last reassume a straight course.*

"As for the termination of these nerves, the most recent investigations render it more than probable *that* *they all pass into processes of the nerve cells of the retina*, a condition which, histologically speaking, would be better designated by saying that they all take their origin from these cells." (Kölliker.) "The mode of ending of the fibres is unknown." (Quain.) This is also the opinion of M. Krause, and, it may be added, of the mass of modern histologists.

Consequent upon section of the optic nerve, the pale optic fibres fattily degenerate and exhibit, on their inner surface, ROWS OF LITTLE SPARKLING FAT GRANULES (*op*, figs. 11 and 12). These would appear to be, in the normal condition of the eye, an innumerable quantity of short fibrils proceeding inwardly from, and at right angles to, the main optic fibres, after the fashion of the "wing lights" of a theatrical proscenium.

The layers included between the inner surface of the *membranæ fenestrata* (not included) and *limitans interna* I term the NERVOUS SYSTEM OF THE RETINA.

It is presumed that the short nerve fibrils represented in the degenerated retina by the "ROWS OF LITTLE SPARKLING FAT GRANULES" (*op*, figs. 11 and 12), are directly "irritated" into mechanical action by the waves of light, just as we know the *Mimosa sensitiva* to be so excited. Now, it cannot be concealed that many eminent thinkers—*e. g.*, Mr. Stuart Mill, do not accept the undulatory theory of light, "that succession of felicities," as some one has called it. In view of this circumstance, I will say to those of my readers to whom optical theories do not form their chief interest, that the undulatory theory of light assumes, pervading all matter—the densest bodies and the interplanetary spaces not excepted—the existence of a fluid, highly rarified and elastic (known sometimes as "the universal," at others as "the luminiferous" ether), capable, among other things, of undulating when excited by visible objects, in a similar, although not identical, manner with that in which the undulations of the air are excited by sounding bodies, and the undulations of the ocean by gravity.

Now, I maintain, with all deference, that the authority which any sensible person, not himself a physicist, would seek for his acceptance or rejection of the undulatory theory of light would be, not that of psychologists, logicians, political economists, or essayists—how illustrious soever they may be—but of eminent *physical* philosophers. The testimony of the highest physical authorities in favour of the undulatory theory would fill volumes. I will content myself, however, with citing the testimony of two writers, than whom none are better qualified to pass an opinion on this question.

" A simple and beautiful experiment on the interference of polarized light, due to Fresnel and Arago, enabled them to bring Dr. Young's law to bear on the colours produced by crystallized plates on a polarized beam, and by so doing afforded a key to all the intricacies of these magnificent but complex phenomena. Nothing now was wanting to a rational theory of double refraction but to frame an hypothesis of some mode in which light might be conceived to be propagated through the elastic medium supposed to convey it, in such a way as not to be contradictory of any of the facts nor to the general laws of dynamics. This essential idea, without which everything that had been before done would have been incomplete, was also furnished by Dr. Young, who, with a sagacity which would have done honour to Newton himself, had declared that, to accommodate the doctrine of Huyghens to the phenomena of polarized light, it is necessary to conceive the mode of propagation of a luminous impulse through the ether, differently from that of a sonorous one through the air. In the latter, the particles of the air advance and recede; *in the former, those of the ether must be supposed to tremble laterally.*

"Taking this as the groundwork of his reasoning, Fresnel succeeded in erecting on it a theory of polarization and double refraction, so happy in its adaptation to facts, and in the coincidence with experience of results deduced from it by the most intricate analysis, that it is difficult to conceive it unfounded. If it be so, it is at least the most curious artificial system that science has yet witnessed; and whether it be so or not, so long as it serves to group together in one comprehensive point of view a mass of facts almost infinite in number and variety, to enable us to reason from one to another, and to establish analogies and relations between them; on whatever hypothesis it may be founded, or whatever arbitrary assumptions it may make respecting structures and modes of action, it can never be regarded as other than a most real and important accession to our knowledge." *

"It is true, the explanation of one set of facts may be of the same nature as the explanation of the other class; but then, that the cause explains both classes gives it a very different claim upon our attention and assent, from that which it would have if it explained one class only. The very circumstance that the two explanations coincide, is a most weighty presumption in their favour. It is the testimony of two witnesses on behalf of one hypothesis; and in proportion as these two witnesses are separate and independent, the conviction produced by their agreement is more and more complete. When the explanation of two kinds of phenomena, distinct and not apparently connected, leads us to the same cause, such a coincidence does give a reality to the cause, which it has not while it merely accounts for those appearances which suggested the supposition. This coincidence of propositions inferred

* Discourse on the Study of Natural Philosophy, by Sir J. F. W. Herschel, page 261.

from separate classes of facts is exactly what we noticed in the Novum Organum Renovatum (b. ii. c. 5, sect. 3), as one of the most decisive characteristics of a true theory, under the name of Consilience of Inductions.

"That Newton's first rule of philosophizing, so understood, authorizes the inferences which he himself made, is really the ground on which they are so firmly believed by philosophers. Thus, when the doctrine of a gravity varying inversely as the square of the distance from the body, accounts at the same time for the relation of times and distances in the planetary orbits, and for the amount of the moon's deflection from the tangent of her orbit, such a doctrine becomes most convincing; or, again, when the doctrine of the gravitation of all parts of matter which explained so admirably the inequalities of the moon's motions, also gave a satisfactory account of a phenomenon utterly different, the precession of the equinoxes. *And of the same kind is the evidence in favour of the Undulatory Theory of Light, when the assumption of a length of an undulation, to which we are led by the colours of thin plates, is found to be identical with that length which explains the phenomena of diffraction; or, when the hypothesis of transverse vibrations, suggested by the facts of polarization, explains also the laws of double refraction. When such a convergence of two trains of induction points to the same spot, we can no longer suspect that we are wrong. Such an accumulation of proof really persuades us that we have to do with a vera causa."* *

If my reader, then, agrees to accept, on the authority of Sir John Herschel and Dr. Whewell, the reality of the undulatory theory, he can scarcely refuse, so far as I can judge, to accompany me one step further, and acquiesce in the *possibility*, *at least*, of the ethereal undulations to

* Whewell's Philosophy of Discovery, page 190.

set the rows of fine inner nerve-fibrils into vibration. The possibility of this fibrile vibration being granted, the conduction of the vibration through the pale optic fibres follows. The fibrils proceeding from the outer side of the optic fibre layer would then take up, in turn, the vibratory impulse, and convey it to the ganglion-cells.

We have seen that sensorial nerve action is always carried into, motorial nerve action always carried out of, a ganglion, or what essentially agrees in character and nature with a ganglion. The object of leading vibratory fibrils into a semi-fluid mass, such as the grey matter of the brain and ganglia is, would reasonably be accounted for as follows. The grey matter being semi-fluid, and therefore highly mobile, would possess the susceptibility of being set into stronger excitement than the solid sensory nerve-fibrils themselves. The highly intense action of the contents of the ganglion-cells being communicated to the efferent, centrifugal, motory nerves proceeding outwardly from the ganglion, it follows, in the event of the latter being the more delicate of the two sets of fibres, that they will tremble more intensely than the sensory fibres. But the nerve fibrils proceeding from the optic-nerve fibres to the ganglion, *are actually* coarser than those proceeding from the outer side of the ganglion towards the granulated layer (fig. 1). The motor fibres will therefore act under more intense excitation than the inner (sensor) fibres. The nervous force is, therefore, intensified in issuing outwardly from the ganglion.

Again, since the internal elements of the inner granule layer are multipolar, whilst those of the outer or lacunal stratum are unipolar, the successive layers of internal granules (reckoning from within) come to be viewed as successive condensors of nerve-force destined ultimately to impart tremoral action to the edges of the *lacunæ* of the *membrana fenestrata*. Thus, the intensity of the condensed tremors there imparted will be vastly superior to that which marked its origin on the inner surface of the pale optic fibres.

The throbs of the outer elements of the inner granule layer would be communicated first to the sides of the *lacunæ* or *fenestræ*, and then to the spheroids, for further assumption by the granules of the retinal muscular system. The ultimate effect of the nervous force has been already traced.

This theory, then, involves the principle that nerve force and muscular force are identical in kind, although various in degree. That this relation of nerve force and muscle force actually obtains, is strongly suggested by our knowledge that the electrical states of the muscles and nerves are identical—that exactly the same relation obtains between electro-motive force and given nerve conditions, as between electro-motive force and equally posited muscle conditions.

The following conclusions of Du Bois Reymond, quoted by Professor Bain, will not be without interest.

"The muscles and nerves, including the brain and spinal cord, are endowed during life with electro-motive power."

"This electro-motive power acts according to a definite law, *which is the same* in the nerves and in the muscles, the law of the antagonism of the longitudinal and the transverse sections. The longitudinal surface is positive, and the transverse section negative."

"*Every minute particle of the nerves and the muscles must be supposed to act according to the same law as the whole nerve or muscle. The total currents are, in fact, the combined effect of these currents circulating round the ultimate particles.*"

"*The current in muscles, when in the act of contraction, and in nerves when conveying motion or sensation, undergoes a sudden and great negative variation of its intensity.*

It has not been ascertained whether, in the act of contraction, the muscular current is only diminished, or wholly vanishes, or whether it changes its direction."*

The following quotation from Hartley, will tend to throw some additional light on vibratory or tremoral fibre action.

"Prop. IV. These vibrations backwards and forwards of the small particles, are of the same kind with the oscillation of pendulums, and the trembling of particles of sounding bodies. They must be conceived to be exceedingly short and small, so as not to have the least efficacy to disturb or move the whole of the bodies of the nerves or brain. For, that the nerves themselves should vibrate like musical strings, is highly absurd. . . . . . Now, that external objects impress vibratory motion upon the medullary substance of the nerves and brain (which is the immediate instrument of sensation), according to the first proposition, appears from the continuance of the sensation mentioned in the third; since no motion, besides a vibratory one, can reside in any part for the least moment of time. External objects *being corporeal*, can act upon the nerves and brain, *which are also corporeal*, by nothing but impressing motion in them. A vibratory motion may continue for a short time in the small medullary particles of the nerves and brain without disturbing them, and after a short time would cease, and so would correspond to the above mentioned short continuance of the sensations; *and there seems to be no other species of motion that can correspond thereto.*

"Prop. V. The vibrations mentioned in the last proposition are excited, propagated, and kept up, partly by the ether, *i. e.*, by a very subtle and elastic fluid, and partly by the uniformity, continuity, softness, and active powers of the medullary substance of the brain, spinal marrow, and nerves. . . . . Sir Isaac Newton supposed the

* The Senses and the Intellect, 2nd edition, page 63.

nerves, when singly taken, to be pellucid, *because otherwise they could not be sufficiently uniform for the purpose of transmitting vibrations freely to and from the brain;* the opacity of any body being, according to him, an argument that its pores are so large and irregular as to disturb and interrupt the vibrations of the ether. For the same reason, we must suppose the fibrils of the medullary substance of the brain to be pellucid when singly taken. . . . . Firstly, we are to conceive that when external objects are impressed on the sensory nerves, they excite vibrations in the ether residing in the pores of these nerves, by means of the mutual actions interceding between the objects, nerves, and ether. *For there seem to be mutual actions of all the varieties between these three in all the senses, though of a different nature in different senses.* Thus, it seems that light affects the optic nerve and the ether; and also, that the affections of the ether are communicated to the optic nerve, and *vice versâ.* . . . . Secondly, we are to conceive that the vibrations thus excited in the ether will agitate the small particles of the medullary substance of the sensory nerves with synchronous vibrations, in the same manner as the vibrations of the air in sounds agitate many regular bodies with corresponding vibrations or tremblings. And here, the uniformity, softness, and active powers of the medullary substance, must be considered as previous requisites and assistance. A want of uniformity in the medullary substance would argue a like want of uniformity in the ether contained within it. The hardness of it, if it extended to the particles, would cause an inaptitude to vibratory motions in the particles of the particles, *i. e.*, in the infinitesimal particles considered in this and the foregoing propositions. And a want of active powers in these particles would suffer the excited motions to die away prematurely.

"*One may conjecture*, *indeed*, *that the rays of light* *excite vibrations in the small particles of the optic nerve by a* DIRECT AND IMMEDIATE ACTION. For, it seems probable from the alternate fits of easy transmission and reflexion, that the rays of light are themselves agitated by very subtle vibrations, and consequently that they must communicate these directly and immediately to the particles of the optic nerve. And it may be also, that sapid and odoriferous particles are agitated with specific vibrations, and that they communicate these, directly and immediately, to the small particles of the gustatory and olfactory nerves respectively, as well as to the adjacent ether. Upon this supposition, the vibrations of the ether must be conceived as regulating and supporting the vibrations of the particles, not as exciting them originally. Thirdly, the vibrations thus excited in the ether and particles of the sensory nerves, will be propagated along the course of these nerves up to the brain. For, the ether residing in the medullary substance, being of an uniform density on account of the smallness of the pores of the medullary substance and uniformity of the texture before taken notice of, will suffer the excited vibrations to run freely through it. And the same uniformity, together with the continuity, softness, and active powers of the medullary substance, will further contribute to the free propagation of the vibrations; since, on these accounts, it follows that the particles which were last agitated, may easily communicate their agitations or vibrations to the similarly posited and equal contiguous ones without interruption, and almost without any diminution of force. This free propagation of vibrations along the course of the nerves, may be illustrated and confirmed by the like free propagation of sounds along the surface of water, which has sometimes been observed in still, calm nights."*

These remarks made before the labours of Dr. Thomas

* Observations on Man.

Young or of Professor Krause, apply, with some little modification, to the present discussion.

The following is an *aperçu* of the manner in which, on our theory, light affects the eye into actual tremoral action of the orbito-ocular muscles.

The apparatus concerned in the tremoral motion of the retina may be divided under two heads: the first being an auxiliary to motion; whilst the second is devoted to reducing the effect of friction to a *minimum*.

THE FIRST VARIETY OF RETINAL FACTORS.

1. The waves of light affect the nerve fibrils (revealed in the degenerated eye as rows of little fat granules) on the internal surface of the pale optic fibres, into tremoral action.

2. This tremoral action passes through the optic fibres to the processes extending from their outer surface to the retinal ganglion.

NOTE that the number of processes issuing from the nervous layers situated outwardly from the pale optic-fibre layer, becomes fewer as we approach the *membrana fenestrata*; thus at the inner surface of the pale optic fibres in the degenerated eye, the name of the number of "wing-light" processes issuing from a small area of the fibres is legion, whilst *only one* process is seen proceeding from within to each of the comparatively large elements of the most external stratum of the inner-granule layer. These phenomena point to the function of each successive stratum (reckoning from within,) being that of a *condensor* of the nervous force received from the immediately adjacent internal stratum.

3. The tremoral action is continued through the ganglion, where it is magnified.

4. The multipolar processes of the ganglion, seen issuing therefrom in the granulated layer, convey the nervous force (highly intensified) to the innermost row of

the internal-granule layer, whence it is successively conducted through various ranks of granules, and finally concentrated in the elements occupying the *lacunæ* of the *membrana fenestrata.*

5. The pulsations induced, from within, in the outermost row of inner granules, induce tremoral action in the *membrana fenestrata.*

6. The tremoral action of the *membrana fenestrata*, is taken up by the rod-spheroids.

7. The rod-spheroids are thus excited into muscular action.

NOTE.—The identity *in kind* of nerve force and muscle force is here implied.

8. The muscular action of the rod-spheroids is communicated to the rod-granules; which, being highly developed muscular organisms, will finally communicate to the inner surface of the *membrana limitans externa* an intensified rendering of the twittering initiated in the optic-fibre rows of granules.

9. The action of the rod-granule will be such as to pull that part of the *limitans externa* with which it is mediately or immediately in connection, inwards.

10. The inward motion of the *limitans externa* will cause the inner rod-segment on the outer side of that membrane (opposite the rod-granule connection) to jerk, and to collide against an inner cone-segment.

11. The outer rod-segment will receive a jerk from the action of the inner rod-segment; the junction of each pair of segments being maintained, during the jerk, by the axis fibre. The reaction, caused by the abutting of the outer rod-segments on the outer cone-segment, will convert the jerk of the outer rod-segment into an oscillatory movement, since the inner end of the outer cone-segment equally with the inner end of the outer rod-segment is capable of motion in a socket joint. The

oscillation of the outer cone-segment is limited (by the axis-fibre); therefore, the oscillation of the outer rod-segment will also be limited. The shorter length of the inner cone-segment permits the co-operation of rod-oscillation with buffing cone-power.

12. The entire retina, from the *limitans interna* (*merely* "*applied*" to the hyaloid) to the choroid (*merely* "applied" to the rods), will be in vibration.

13. The reaction of the retina will set the whole eye-ball into a corresponding motion of oscillation; the whole effect of the motion being such as would result were it to originate from the place of intimate junction of the choroid and retina.

14. The effect of the vibration or oscillation of the eye on the orbital muscles, and, through the orbital muscles, on the nerves which convey the oculo-orbital muscular impressions to the brain, will be qualitatively identical with, but quantitatively different from, the effect produced on the mind in those instances when the excursions of the muscles are due to volition.

15. Just as space qualities—form, distance, position—are *specially* revealed in the voluntary exercise of the oculo-orbital muscles, so these qualities are *generally* presented in the involuntary exercise of those muscles. In this respect, visual perception has its analogue in musculo-tactual perception; for, in the latter process, as Mr. James Mill remarks, whether we sit, stand, walk, or lie down, the feeling of resistance (and, it may be added, of extension) is ever present to us.

16. The tremoral action of the whole eye corresponds with that part of visual perception concerned in affording a knowledge of space qualities; the remaining portion of the operation, namely, the perception of colour, not being effected by means of the tremoral action of the eye-ball, but through the vibratory action of foveal nerve-fibrils, in a way which will be pointed out in Section II.

17. As what we see is coloured space; as we cannot see space that is not coloured; it follows, since the tremoral action of the eye-ball conduces to the notion of visual *space* only, that the eye-ball *may* continue to vibrate during darkness, although with less vigour than when exposed to light, on the principle that a pendulum placed in circumstances favourable to oscillation, will continue in action for many hours after the original propulsion has ceased.

THE FRICTION-REDUCING ELEMENTS OF THE RETINA.

1. The three membranes, external and internal *limitans* and *fenestrata*, have a friction-reducing function, since they convert a multitude of independent *sharp* pulls into a system of mutually connected *deadened* ones.

2. The oily substance between the outer and inner baccilar segments having obviously a lubricating office, must also have the function of reducing friction.

3. The nature of the cones is buffing or staying, and they must thus be viewed as friction-reducing elements.

NOTE.—This opinion is confirmed by the manner in which the internal connections of the cones, namely, the cone-spheroids, are attached to the *membrana fenestrata*. This being effected by means of processes issuing from opposite sides of the base of each cone-spheroid, it will be evident that the "pull" of each of these processes will tend to turn its cone fibre, and consequently its cone, in alternately opposed directions. One of these "pulls" will have for effect, to aid the cone to recede before its asilient rod, at the *commencement* of the rod's oscillation; the effect of the other "pull" will be to aid the restraining influences of the *membrana limitans externa* and of the axis fibre, and thus to limit the arc of the rod's oscillation; and by thus preventing suddenness of recoil of the rods, to afford smoothness of action to the buffing power.

4. The choroidal granules are viewed as friction rollers.

REMARKS ON SECTION I.

Whilst the retina, and therefore the eye, must vibrate at different rates for different colours, it is probable that the same rate is maintained for different intensities of the same colour, since intensity merely depends, *cæteris paribus*, on the *height* of the waves, and not on their *rate* of motion. Thus, when we view a red object, the eye vibrates at the rate of 480,000,000,000,000 times per second; when a violet object is seen, the eye's rate of vibration is 720,000,000,000,000 times per second; and, since the red and violet rays are those found at each extremity of the spectrum, the rate of vibration of the eye for intermediate colours must be found between these figures. The red waves, which have the slowest motion, are the broadest; the violet waves, which have the most rapid motion, the narrowest. As we advance from the red to the violet, so do we find the successive waves narrower in breadth and more rapid in action.

The various intensities of light of a given colour are due to different heights of the waves, and consequently to various degrees of wave force. In intense light therefore, the waves have greater moving power than in dilute light. But under dilute light the eye receives a greater quantity of waves, and a greater number of rods are then set in action than under intense light.

I consider it highly probable that the non-coincidence of the visual and optic axes is, if not a necessity to ocular oscillation, at least a prime factor in securing the *prompt* respondence of the mobile elements of the retina to the motile power of light. A consideration of the action of spectacles confirms the justice of this opinion. One of the uses of positive glasses is, no doubt, in presbyopia (weak sight due to age), to make the image impinge on its normal spot. But a convex lens is, so to speak, also a ray condenser and a light intensifier no less than a ray director, as any one may perceive by successively throwing the image of an external object on a screen, by the aid of stronger and stronger convex lenses, when each consecutive image will be seen brighter than its predecessor. The function of each consecutively stronger lens is, therefore, to render the efficacy of light more and more powerful. Now it is a well-known fact that presbyopes can see, under intense light, equally well with lenses weaker than those required under dilute light; and the explanation commonly given of this phenomenon is this: "The bright light is a principal point, not so much because the retinal images are by it more strongly illuminated, but because the pupil contracts; the circles of diffusion therefore become smaller, and the visual images less diffused." * If this explanation were a sufficient account of the phenomenon, it would follow that when a stenopæic apparatus—a pair of spectacle-frames fitted with solid plates (instead of glasses), having in the central plane a pin-hole or minute slit—is added at night to a pair of day-spectacles, the effect should be equal to that of glasses of greater power. That such is sometimes the result is, no doubt, true. But this is not the rule, but the exception; for in the great majority of instances the stenopæic apparatus has no perceptible influence. I regard, as I have stated, a strong convex lens as, *inter alia*, a means for strongly concentrating light-force on the nervous rod-connections, and, consequently, for securing more vigorous rod-action. A weak convex lens, that is, a weak, light-force condensor, must, on the contrary, be esteemed as acting with relative feebleness (on the nervous rod-connections, and therefore) on the rods; it being thus held that presbyopia arises not merely from the flattening of the crystalline lens, but also from the rigidity of the apparatus engaged in setting the eye into tremoral action—the effect of increasing years.

* Donders, 216.

This result is amply corroborated by a consideration of those peculiarities of vision known as hypermetropia and myopia—defects which, for our purpose, may be defined as respectively resulting from abnormal shortening and lengthening of the eyeball. In hypermetropia the image is thrown behind the retina; and a convex lens is consequently requisite to bring the image forward. Now, the light-intensifying and (according to my view) force-intensifying property of a convex lens is here equally, as in the preceding case, additionally utilized.

For, an hypermetropic eye has other diagnostics than the shortening of the antero-posterior axis. "The rule is that hypermetropia depends on a peculiar typical structure of the eye, which may be called the *hypermetropic structure.* The hypermetropically formed eye is a small eye, in all its dimensions; less, therefore, than the emmetropic, but especially in that of the visual axis. . . . . The hypermetropic is, in general, *an imperfectly developed eye.* If the dimensions of all the axes are less, *the expansion of the retina also is less*, to which moreover a slighter optic nerve, and *a less number of its fibres, correspond.*"* The eminent ophthalmologist might here have added to the circumstance of the hypermetropic eye developing a smaller quantity of optic-nerve fibres than the normal eye, that the rods of the former *must not only be fewer*, *but necessarily shorter than those of the latter*. "As to the functions of the hypermetropic eye, we, in the first place, often find the *acuteness* of vision diminished . . . . It is evident that, with glasses which neutralize the hypermetropia, *the acuteness of vision* becomes greater than it was without glasses."† One of the offices of a lens placed before an hypermetropic eye would, therefore, under our theory, be to afford that increase of light-motive power to the rods which, compensating for their abnormal pau-

* Donders, 245. † Ibid. 255.

city of number and shortness of length, would render the actual effect of their oscillation equal to that of the rods in the normal eye.

Our theory is here strongly confirmed by the angle which obtains, in hypermetropes, between the optic and visual axes. This is very much larger than in any other condition of sight, increases with the hypermetropia, and is frequently so marked as to cause the patient to appear as if labouring under squint. Now, as was previously explained, the greater the excentricity of the end of the visual axis, the greater the leverage in favour of the moving-force of light; so that this particular conformation (most probably acquired) of the hypermetropic eye is highly favourable to the furtherance of the compensatory action offered to the light by the few and short rods; since the greater the excentricity of the *fovea*, the more powerful leverage will light have to work with. An hypermetropic eye is essentially an *open* eye, suggesting the patient's endeavour to free the eyeball from the trammelling influence of the eyelids, so as to respond the more effectually to the motile power of light.

Precisely the opposite line of argument must be pursued when considering the myopic eye. In this case the abnormal length of the antero-posterior axis may be accepted as the principal cause of the effect, and as the type of the affection. Just as, in the hypermetropic eye, the angle between the optic and visual axes is *greater* than that obtaining in the emmetropic eye, so in myopia this angle is less than in the normal state. From the abnormal size of the myopic eyeball results these consequences: the focus of the image of the external object falls short of the retina, and the rods are unnaturally numerous and long. Hence, among other things, the force of natural light upon the enormously developed rods will, in myopia, be too intense, and some means must therefore be employed for reducing its efficacy. One of these means is secured by *pressing the eyelids together* — a common act of myopes, when desirous of seeing distinctly; the effect of which is, by "braking" the velocity of the eye's oscillation, to help to reduce the oscillation to the normal state. Concave lenses will aid in effecting this end. The properties of these lenses are in every respect the opposite of those of convex glasses. The concave glass will then, not only prolong the focus of the image, but will *dilute*, instead of concentrating, the light. Concave lenses will therefore contribute to *weaken* the intensity of oscillation of the myopic eye. Finally, the small angle (probably acquired) which here obtains between the visual and optic axes will also contribute to lessen the "purchase" of light on the motile elements of the eye. These results are corroborated by the ability of myopes to distinguish minute objects under dilute light at a short distance, for at short distances *less light* enters the eye (through the spontaneous closure of the pupil for large angles of axial convergence) than when the object is situated further off.

I will close this section with two quotations from Dr. Carpenter, with the view of shedding some information on two important doctrines that I have advanced. The following extract, illustrative of the nature of ciliary action, may render more intelligible our doctrine of the rapid vibration of delicate nerve-filaments. "They (cilia) are always found in connection with cells of whose substance, as we have seen among Protophytes, they *may be considered as extensions*. The form of the filaments is usually a little flattened, and tapering gradually from the base to the point. Their size is extremely variable, the largest that has been observed being about 1-500th of an inch in breadth, and the smallest about 1-1300th. When in motion, each filament appears to bend from its root to its point, returning again to its original state, like the stalks of corn when depressed by the wind; and when a number are affected in succession with this motion, the appearance of successive waves following one another is produced, as when a corn-field is agitated by successive gusts. When the ciliary action is in full activity, however, little can be distinguished save the whirl of particles in the surrounding fluid; but the *back* stroke may often be perceived, when the *forward* stroke is made too quickly to be seen; and the real direction of the movement is then opposite to the apparent. In this back stroke, when made slowly enough, a sort of feathering action may be observed; the thin edge being made to cleave the liquid, which has been struck by the broad surface in the opposite direction. It is only when the rate of movement has considerably slackened, that the shape and size of the cilia, and the manner in which their stroke is made, can be clearly seen. It has been maintained by some, that the action of the cilia is muscular; but they are often too small to contain even the minutest fibrillæ of true muscular tissue, and no such elements can be discerned around their base; their presence in plants, moreover, seems distinctly to negative such an idea" *

Our closing quotation will serve to illustrate the Relation of Voluntary and Involuntary Actions to each other and to Consciousness; a difficult topic, yet one intimately wrapped up in our discussion. "It may be asserted with some confidence, that no effort of the Will can exert that direct influence on the muscles, which our ordinary phraseology and even the language of scientific reasoners would seen to imply; but, on the other hand, that the Will is solely concerned in determining the result; the selection and combination of muscular movements required to bring about this result not being effected by the Will, but by some intermediate agency. If it were otherwise, we should be dependent on our anatomical know-

* Carpenter on the Microscope, 3rd edition, page 483.

ledge for our power of performing the simplest movement of the body; whereas we find the fact to be, that the man who has not the least idea of the mechanism of muscular action can acquire as complete a command over his movements, and can adapt them as perfectly to the desired end, as the most accomplished anatomist could do.

"Nothing can be more simple, to all appearances, than the act of rolling the eyes upwards or downwards, to one side or the other, in obedience to a determination of the Will; and yet the Will does not impress such a determination upon the muscles. That which the Will really does is to cause the eyeballs to roll in a given direction, in accordance with a visual sensation. Now, on the other hand, the Will may determine to fix the eyes upon an object; and yet this very fixation may be only attainable by a muscular movement, which movement is directly excited by the visual sense, without any exertion of the voluntary power over the muscles. Such is the case when we determinately look steadily at one object, while we move the head horizontally from side to side; for the eyeballs will then be moved in the contrary direction by a kind of instinctive effort of the external and internal recti, which tends to keep the retinæ in their first position, and to present the motions of the images over these. So, when we look steadily at an object, and incline the head towards either shoulder, the eyeballs are rotated over their antero-posterior axis (probably by the agency of their oblique muscles), apparently with the very same purpose, that of preventing the images from moving over the retinæ. Now, we cannot refuse to this rotation any of the attributes which really characterise the so-called voluntary movements; *and yet we are not even informed by our own consciousness that such a movement is taking place*, but know it only by observation of others, or by reflection in a mirror.

The muscular contractions which are concerned in the production of vocal tones are, in like manner, always accounted voluntary; and yet it is easy to show that the Will has no direct power over the muscles of the larynx. For we cannot raise or depress the larynx as a whole, nor move the thyroid cartilage upon the cricoid; nor separate nor approximate the arytenoid cartilages, nor extend nor relax the vocal ligaments, by simply *willing* to do so, however strongly. Yet we can readily do any or all these things by an act of the Will exerted for a specific purpose. We conceive of a tone to be produced, and we *will* to produce it; a certain combination of the muscular action of the larynx takes place, and in most exact accordance with one another; and the predetermined tone is the result. . . . .

"Now, what is true of the two preceding classes of actions is equally true of all the so-called voluntary movements; for in each of them *the power of the Will is really limited to the determination of the result; and the production of that result is entirely dependent upon the concurrence of a "guiding sensation," which is usually furnished by the very muscles that are called into action.* IT IS OBVIOUS, THEREFORE, THAT WE HAVE TO SEEK FOR SOME INTERMEDIATE AGENCY, which *executes* the action *determined* by the Will; and when the facts and probabilities already stated are duly considered, they tend strongly in favour of the idea that even VOLUNTARY MOVEMENTS ARE EXECUTED BY THE INSTRUMENTALITY OF THE AUTOMATIC APPARATUS, *and that they differ only from the automatic, or instinctive, in the nature of the stimulus by which they are excited;* the determination of the Will here replacing, as the *exciting cause* of its action, the sensory impression which operates as such in the case of an instinctive movement, *and which is still requisite for its guidance.*

This view of the case derives a remarkable confirmation from the analysis of two classes of very familiar phenomena; the first consisting of cases in which movements that are ordinarily automatic are performed by voluntary determination, or simply in response to an idea; the second consisting of those in which movements originally voluntary come by habit to be automatically performed. Of the first class, the act of coughing is a good example . . . . ; a tendency to yawn is . . . . frequently induced by looking at a picture of yawners, or by speaking of the act, or by voluntarily commencing the act, which may then be automatically completed.

The automatic performance of actions which were originally voluntary has already been fully discussed, and we have, therefore, only to remark here, that the fact very strongly supports the view now advanced as to the *singleness* of the mechanism which serves as the instrument of both classes of actions. *It would be difficult to explain either set of phenomena satisfactorily on the hypothesis that there is a distinct system of fibres for the volitional and the automatic movements;* since it is not readily to be conceived how a set of movements originally performed by the one can ever be transferred to the other; whilst, on the other hand, it is easy to understand how the same motorial action may be excited in the automatic centres, either by an *external* impression conveyed thither by an afferent nerve from a sensory surface (as that of irritation in the air-passages which excites the act of coughing), or by a stimulus proceeding from the convoluted surface of the cerebrum, and conveyed along those connected fibres which Reil, with great sagacity, termed the nerves of the internal senses. . . . .

If the activity of the cerebrum be suspended, or otherwise affected without any affection of the automatic apparatus, movements which have long been habitually performed in a particular sequence may be kept up, when the Will has once set them in action, through the automatic mechanism alone; the impressional, or sensational, change produced by such action supplying the stimulus which calls forth the next.

"THE SENSORY GANGLIA ARE THE INSTRUMENTS WHEREBY WE ARE RENDERED CONSCIOUS OF EXTERNAL IMPRESSIONS, and also the seat of those simple feelings of pleasure and pain which are immediately linked on that consciousness: for it can scarcely be doubted that such feelings must be associated with particular sensations in animals that have no ganglionic centres, since we must otherwise regard the whole series of Invertebrated Tribes as neither susceptible of enjoyment nor capable of feeling pain or discomfort. And it likewise seems probable that the SENSORY GANGLIA ARE THE SEATS OF THOSE PERCEPTIONAL ACTS, WHICH BRING THE CONSCIOUSNESS INTO DIRECT RELATION WITH THE EXTERNAL OBJECT THAT AROUSED THE SENSATION; SINCE THE RECOGNITION OF EXTERNALITY SEEMS EVIDENT IN THE ACTIONS OF THE TRIBES JUST REFERRED TO . . .; that the cerebrum must be considered in the light of an organ superadded for a particular purpose, or set of purposes, and *not as one which is essential to life;* that it has no representative among the Invertebrata (except a few of its highest forms which evidently present a transition towards the Vertebrated Series); and that, at its first introduction in the class of fishes, it evidently performs a subordinate part in the general action of the Nervous System." *

* Carpenter's General Physiology, 3rd edition, p. 618.

SECTION II.

We now turn our attention to the FOVEA CENTRALIS, and the yellow spot of which the *fovea* is the centre. "On removing the sclerotica and choroid," says Mr. Bowman, "the yellow spot seems more transparent than the rest of the nervous sheet; no fold appears, but in its centre a minute dot, which seems like a circular hole, through which we can look through the vitreous humour. I have, on some occasions, seen this hole so distinctly, and with so definite a margin, that it seems impossible to deny its reality; but whether it occupies the whole thickness of the retina, being a deficiency in all its layers, I am unable positively to say. . . .

"The colour of the spot does not appear to be confined to *one single texture*, but appears to bathe *all the textures*, except those of Jacob's membrane (rod-layer), in a common cloud of rich yellow, deepening towards the centre. *The colour is here and there in minute grains of deeper hue;* but, in general, it does not seem to lie in proper pigment-cells, but to stain fibres, vesicles, and granules alike. The colour soon disappears after death, or in water. *I recently, however, left a retina in water for a fortnight, and still found it retaining some of its original hue at this spot; in the dried retina, it is permanently retained*" (Lectures). "The yellow colour of the *macula lutea* is *deepest towards the centre*, and is due to a pigment which imbues all the layers except the columnar" (Quain). "This colour proceeds from a diffuse stain of the retinal tissues" (Hulke). We have before quoted from Mr. Hulke to show that the superficial layer of optic fibres (that whence spring the wing-like light rows of fibrils, regarded in Section I. as primordial elements in the eye's vibration) does not exist in the yellow spot. It is also absent in the *fovea*. The superficial layer of optic fibres would, then, appear to be *solely* involved in the oscillation of the eyeball. According to the same eminent authority, we know that, in all probability, the foveal nerve-fibres probably arise from the processes of its cells. THE SYSTEM OF NERVE-FIBRES IN THE FOVEA AND YELLOW SPOT IS THUS TOTALLY DISTINCT FROM THAT FOUND IN OTHER PARTS OF THE RETINA, and the latter system must therefore be excluded from present consideration.

At the *fovea centralis* the inner granule layer "is very thin;" "the ganglionic cells do not lie in a continuous band, but are continued in a double or treble series through a finely areolated matrix of connective tissue;" "the outer granule layer is absent from the centre of the fovea."*

We gather from these extracts that the yellow colour of the *macula lutea* "is not confined to *a single texture*, but that it "bathes" *all the textures*. We further glean that ALL THE ELEMENTS IN THE FOVEA ARE NERVOUS, with the sole exception of the bacillar layer, of which the only constituents here found are the cones.

The investigations of Mr. Hulke show moreover that the *fovea* is not a hole, but a minute conical pit whose mouth is directed inwardly. "In vertical sections through the artificially hardened *macula*, the *fovea centralis* is seen to be produced by the radial divergence of the cone-fibres from a central point, and by the thinning and curving of the inner retinal layers towards the outer surface of the retina as they approach this point. The thickness of the retina decreases in a rapid uniform curve from the edge to the centre of the *fovea*, and very slowly from the foveal edge towards the *ora serrata*. Since the maximum thick ness coincides with the edge, and the minimum with the

* Hulke on the Anatomy of the Fovea Centralis of the Human Retina, *Phil. Trans.*, 1867.

centre of the fovea, *the former is the most elevated, the latter the most depressed, part in the macula.*"* See fig. 13.

Mr. Bowman and Mr. Hulke appear to be virtually of accord with respect to the nature of the yellow colour, and describe it as a "stain," or as something that could be derived, as it were, from a dip in a bath. Now, something which *preserves* its colour "when *immersed in water for a fortnight*," or which "*retains it permanently in the dried retina*," appears to me to be something more than what would be due to a dab with a brush or to a douse in a pot. I opine that we must here plunge below the surface; that the propositions of MM. Bowman and Hulke are explanations, rather in the *popular* than in the *scientific* sense of the term.

If we wish to succeed in ascertaining the signification, the nature and function of this yellow phenomenon, we must perforce start from the known to the unknown. All that we know of the phenomenon is that it is yellow.

We must graft what we know in the present case on what was known in former cases; in other words, we must link the present truth on others previously evolved. We therefore proceed to look up the copious index of that exhaustive anatomical work, Quain's "Anatomy."

There, under the heading "yellow," we find, in addition to "Yellow Spot," four yellow sustances *only*, namely—

Yellow cartilage,
,, fibres of areolar tissue,
,, ligaments of the vertebræ,
,, tissue.

And, on referring to the pages of the book in which these subjects are treated, we discover that *they have the common property of being elastic.*

Once more calling to mind Newton's rules for philoso-

* Hulke on the Anatomy of the Fovea Centralis of the Human Retina, *Phil. Trans.*, 1867

phizing, "We are not to admit other causes of natural things than such as are both true and suffice for explaining the phenomena;" "Natural effects of the same kind are to be referred to the same causes, as far as can be done,"—we are bound to frame the following physiological induction. ALL YELLOW ANATOMICAL SUBSTANCE IS ELASTIC.

Mr. Mill would undoubtedly deny to this proposition the character of an induction. He would characterise it as, in Lord Bacon's language, "Inductio per enumerationem simplicem, ubi non reperitur instantia contradictoria,"* and say that, like the three planetary laws of Kepler, it is "a mere summing up of what was asserted in the various propositions from which it was drawn." If, however, "Induction is proof," † if it consists in the transmutation of the unknown into the known, then, since Kepler's labours placed humanity in possession of real laws of nature, of which without him we had been ignorant, I fail to see how they are unworthy of the title of inductions. That these laws are demonstrated more neatly by the method of Newton than by that of Kepler, I am not disposed to deny. Still, they were items in the sum of human knowledge before Newton was born, and would have remained so, had Newton never lived; nay, but for Kepler's laws, the theory of gravitation had been impossible.

"Kepler did not *put* what he had conceived into the facts, but *saw* it in them." ‡ We rejoin that Kepler "put" the ellipse that he had conceived into the facts, precisely as Newton "put" the inverse duplicate force that he had conceived into the facts. "For the duplicate proportion, I can affirm that I gathered it from Kepler's theorem about twenty years ago," § says Newton himself. What

* *Logic*, 6th edition, vol. i., p. 349.
† Ibid., p. 340. ‡ Ibid., p. 331.
§ Brewster's Life of Newton, vol. i., p. 258.

difference, save one of degree, exists then, between Kepler's deduction from Tycho Brahe's labours that Mars revolves under certain conditions, and Newton's deduction from Kepler's labours, that the moon revolves under certain conditions? Mr. Mill would not deny to the latter the title of induction. Nor are there any substantial reasons, so far as I can conceive, why he should refuse the same dignity to the former. They are equally good *deductions* from good premisses, and are therefore equally, good *inductions.*

In truth, it is extremely difficult, if not impossible, for any discoverer or inventor to account satisfactorily to himself for the order or manner in which his conceptions originated. How much more difficult must it then be for critics to account for those conceptions? The mistake which the latter class of writers make on this subject, arises from erroneously assuming that phenomena which are first in the order of demonstration are also first in the order of knowledge. That this is not the fact, lies on the surface. No one can doubt that the properties of Euclid's fifth proposition, that the property of his forty-seventh proposition was known before Thales and Pythagoras achieved their demonstrations, exactly as Archimedes and Galileo ascertained mechanically the areas of the parabola and cycloid previously to the invention of their demonstrations. Each guest, says Uncle Toby, brings part of his entertainment. Each discoverer brings part of his discovery.

"Induction is always colligation,"* although "it is the *nature* and *number* of the instances, and not their being the whole of those which happen to be known, that make them sufficient evidence to prove a general law."†

With all respect, I again beg to differ with Mr. Mill. That induction is not always colligation, the most cursory appeal to facts is sufficient to show. There is no colliga-

* *Logic,* vol. i., p. 338. † Ibid., p. 323.

tion in the evolution of a geometrical induction. There was no colligation when Malus discovered polarization of light by reflection, when Franklin discovered the identity of lightning with common electricity, or when Madame Galvani discovered that law of animality which immortalized her name.

What then is the "*nature*" of the instances that makes them sufficient evidence to prove a general law? While Mr. Mill is quite aware "that error lurks in generalities," he is strongly partial to the vague and indeterminate. I therefore propose to convert his abstraction into particular propositions, and to analyze the latter. "For men imagine that their reason governs words, whilst, in fact, words react upon the understanding; and this has rendered philosophy and the sciences sophistical and inactive. Words are generally formed in a popular sense, and define things by those broad lines which are most obvious to the vulgar mind; but when a more acute understanding or more diligent observation is anxious to vary those lines, words oppose it."*

Mr. Mill seldom loses an opportunity of vaunting the *experimentum crucis*, and I am quite alive to the merits of that method of interrogating Nature. Yet surely this is not the "nature," the alembic through which he would bring credulity or incredulity to the test! Do we believe any truths with stronger faith than those of geometry? Yet we do not solve geometrical problems by the *experimentum crucis*. Did philosophers of the day of Marriotte believe any physical laws more fully than those of gaseous volumes? Yet Regnault showed the *experimentum crucis*, on which they were founded, to be fallacious.

To insist, then, that we are to disbelieve the law of a phenomenon because revealed to us by a process whose "nature" is *par dégradation* liable to error, is equivalent to saying that we are not to believe anything at all. And, indeed, there can

* *Novum Organum*, LIX.

be no more solid title to the general tenure of Laws of Nature than this, that *they must be universally held true until shown false by better evidence than that on which they were originally established.* The validity of all knowledge rests ultimately on Opinion, or, as Montaigne has it, "Science n'est rien autre chose que Sentiment." *

Moreover, all truth must be held as actually containing a *modicum* of error. The genius of the differential calculus is that of all knowledge. The most potent of all our intellectual tools is only true on a condition which is physically impossible; for the chord, arc, and tangent never can be equal. Similar lemmas support the whole fabric of geometry. The preliminary propositions of Euclid are, in the main, derived through experience. But usually included amongst these are two that, undoubtedly, are not so obtained. We never experienced a point which had position without magnitude, nor a line which had length without breadth. "Their existence, so far as we can form any judgment, would seem to be inconsistent with the physical constitution of our planet at least, if not of the universe." † Yet, the moment we discard these figments, the whole geometrical fabric totters to the ground.

Thus, even in the most impregnable of our intellectual fortresses do we find certain ineliminable elements of insecurity, which a more extended scrutiny will show to be common to all knowledge. *Nous veillons dormants, et dormons veillants.* It was not altogether an infelicitous picture that Plato drew of Man, chained backwards to the light in his den and seeing nothing of Nature but her shadow.

But then the "*number*" of the instances has to do with the evidence, before it can prove a general law. Is this number ten, a hundred, a thousand? If so, why

* *Apologie de Raymond Sebond*, Essais de Montaigne.
† Mill's *Logic*, vol. i., p. 255.

not nine, ninety-nine, nine hundred and ninety-nine? Why may not the law fail in the eleventh, hundred and first, thousand and first instance?

"*Number*," then, equally with "*nature*," appears to be a treacherous security for the validity of our beliefs. Of course, when we desire to obtain a law of a mathematical series, of population, of prices, and of other phenomena of which number is of the *essence* of the problem, we are forced to engage a number of facts in the discussion. So far, however, as the determination of a law is concerned, which shall be *to demonstration*, beyond the possibility of error, a single instance is as valuable as the colligation of a myriad.

A fact is, therefore, not to be disbelieved simply because the instances in which it is met are too mean or too few. Accordingly, after an extensive survey of induction, Mr. Mill is forced to confess himself defeated in discovering a scientific definition of the process. "When a chemist announces the existence and properties of a newly discovered substance, if we confide in his accuracy, we feel assured that the conclusion he has arrived at will hold universally, though the induction be founded but on a single instance. We do not withhold our assent, waiting for a repetition of the experiment; or, if we do, it is from a doubt whether the one experiment was properly made,—not whether, if properly made, it would be conclusive. Here, then, is a general law of nature, inferred, without hesitation, from a single instance—an universal proposition from a singular one. Now mark another case, and contrast it with this. Not all the instances which have been observed since the beginning of the world in support of the general proposition that all crows are black, would be deemed a sufficient presumption of the truth of the proposition to outweigh the testimony of one unexceptionable witness who should affirm that in some region of the earth, not fully explored, he had caught and examined a crow, and had found it to be grey. Why is a single instance, in some cases, sufficient for a complete induction, while in others myriads of concurring instances, without a single exception known or presumed, go such a very little way towards establishing an universal proposition?" *

The answer appears to be that, in these as in all other cases, the warrants for our belief and disbelief are to be found in the Laws of Association. We have learnt by experience that a chemical experiment, repeated after the original manner, will be followed by unique results. We have also learnt by experience that the attributes of poultry-life, dog-life, cat-life, horse-life, cow-life, man-life, and, to a great extent, animal life generally, are respectively compatible with variety of colour in poultry, dogs, cats, horses, cows, men, and, to a great extent, animals in general. The logical associational doctrine of belief would appear to be this: WE ARE TO BELIEVE WHAT IS REVEALED THROUGH THE LAW OF CONTIGUITY, UNLESS WE ARE REMINDED BY THE LAW OF SIMILARITY THAT THE NEW RELATION OF CAUSE TO EFFECT IN THE PHENOMENON CONFLICTS WITH A PREVIOUSLY ASCERTAINED COGNATE LAW. The Law of Similarity is thus the ultimate warrant for our credence.

For these reasons I see no efficient reason why the reader should hesitate to accept the proposition, All yellow anatomical substance is elastic. I do not say that our proof of this law is the most cogent that could be imagined—for varieties in cogency of demonstration must be expected,—but that (1) it is the only proof possible in the circumstances, and (2) if it be held invalid, there must be an end to physiological discussion.

The induction, All yellow anatomical substance is elastic, may be set as the major premiss of a syllogism which we proceed to construct.

* *Logic*, vol. i. p. 352.

All yellow anatomical substance is elastic.
The *macula lutea* is yellow.
Therefore the *macula lutea* is elastic.

And since the yellow colour does not vanish when the retina is either immersed in water for a fortnight or is permanently dried, I conclude *that what gives to the yellow spot its characteristic colour is an independent ultra-microscopic substance.* Moreover, since various elements, occupying various depths, are found in the *macula*, I further conclude that the substance indicated by the yellow colour is not *a* texture, but a *series* of textures. The observation of Mr. Bowman, that "the colour is here and there in minuter grains of deeper hue," would indicate that the textures have different thicknesses.

Of course it would have been more satisfactory if, instead of arriving at this result in so roundabout a way, I had been able to take the textures between my fingers and demonstrate, by sight and feeling, their elastic nature. That this process cannot be performed is, however, simply a misfortune, not a fault, since the primary intent of the Author of Nature was not so to create that His works should assume the form most favourable to scientific inquiry. "In the sciences which deal with phenomena in which artificial experiments are impossible (as in the case of astronomy), or in which they have a very limited range (as in physiology, mental philosophy, and the social science), induction from direct experience is practised at a disadvantage generally equivalent to impracticability; from which it follows that the methods of those sciences, in order to accomplish anything worthy of attainment, must be to a great extent, if not principally, deductive."* We must, in short, endeavour to procure marks of marks, and reason in this way, "Whatever is a mark of any mark is a mark of that which this last is a mark of."†

* *A System of Logic*, by J. S. Mill, 6th edition, vol. i., page 422.
† Ibid., page 203.

"He (Professor Kölliker) refers moreover to the excessive contraction of erectile organs which is induced by cold, and to the effect of warmth in favouring their enlargement." (Carpenter.) I infer that since microscopic observation of the *macula* takes place in the dead and therefore cold subject, that in the living and warm subject the textures of the yellow spot would be largely expanded, since the textures of the *macula* would be included in those which expand by heat and contract by cold. I also conclude that, in the living subject, the form of the *fovea* will be similar to that seen under the microscope, but on a dwarfed scale.

The dimensions of the fovea will then diminish to an increase of heat, just as the pupil diminishes to an increase of light; but, since an increase of light-intensity is always accompanied by an increase of heat-intensity, *the fovea will contract with an increase of light-intensity.* Now the effect of cold on a normal eye would be to "pucker" up the yellow textures, and thus cause them to present, towards the foveal edge of the *macula*, a deeper hue; *a phenomenon actually found in the dead, and therefore cold, retina.* Hence the conclusion that in life, since the yellow textures would then be much expanded, the more central hue would be much paler, and the dimensions of the foveal pit much narrower than in the dead subject.

We thus arrive at the following proposition: THE MACULA LUTEA IS A SYSTEM OF ELASTIC CURTAINS WHICH CONTRACT UNDER WEAK, AND EXPAND UNDER STRONG, LIGHT; THE AMOUNT OF CONTRACTION AND EXPANSION DETERMINING THE DIMENSIONS OF THE FOVEA. These various dimensions would, if we could observe them, serve as a photometer or thermometer to indicate the intensity of the light or heat acting on the *macula.*

The truth that the eye is non-achromatic is as old as the days of Frauenhofer. He found that a very fine thread placed at the focus of the object-glass in a telescope is seen distinctly through the eye-piece when the telescope is illuminated by red light, but that it disappears from view under violet light, unless the position of the eye-piece is altered. It is, however, found necessary to diminish the distance between the eye and object-glasses to a greater extent than the difference between the refrangibilities of the red and violet rays would account for. This requisite excess of motion of the eye-piece must therefore be referred to the eye itself, and we must conclude that the eye is anachromatic.

The action of the crystalline lens on white light is, in all probability, the same *in kind* as that of an ordinary artificial bi-convex lens; namely, to break up a pencil of white rays into the prismatic colours of the spectrum. Now, since we are proceeding on the principle that colour-preception takes place *only* in the *fovea*, we need only regard, for our present purpose, the central pencil.

If the central pencil impinged the crystalline lens at right angles to the surface of the latter, the central beam would pass through unrefracted. But as the optic axis is at right angles to the surface of the crystalline, whilst the visual axis makes an angle with the optic axis, the visual axis will impinge the crystalline obliquely. The central ray will therefore impinge the crystalline obliquely, and will be broken up into a prismatic spectrum; the violet rays being nearest the lens, the red rays furthest removed from it, and the remaining rays ranged in their due order between red and violet; the shape of the system of spectrum rays being that seen in fig. 14. Now, as the form of this system of rays is *exactly that of the fovea*, namely, a cone with the base inwards, the conclusion is that the small fovea is, in life, the receptacle of the spectrum of the central pencil. (Compare figs. 13 and 14.)

I am led to conclude further that, since each colour is dependent upon the rate of vibration of the undulatory ether, that the nerve-elements—in which, as we know, the *fovea* alone abounds—include a system of sympathetic fibrils whose nature is respectively elective for various colours; that each coloured ray has its own set of sympathetic fibres constitutionally fitted to vibrate isochronously with the undulations of some particular colour which it is naturally destined to receive. Under this aspect, the function, *par excellence*, of the crystalline comes to be regarded as that, not of attracting or conducting a picture to a screen, but simply of marshalling the respective colours of the disintegrated central pencil on their appropriate foveal nerve-fibres.*

Since violet rays result from the most intense ethereal undulations which abound in the spectrum, the most inward foveal sympathetic nerve-fibres (namely, those on which the violet waves will play) will be so constituted as to vibrate most rapidly, whilst the outermost set of fibrils, namely, those recipient of red rays, will vibrate least violently. The question here arises, What is to hinder the intense action of a given set of these nerve-filaments from being communicated to an outwardly adjacent set, *e.g.* the undulations of violet nerve-fibrils (responding to the action of violet waves, namely, 699,000,000,000,000 undulations for the second) from being communicated to the outwardly adjacent indigo nerve-fibrils (which under indigo rays vibrate at the rate of 658,000,000,000,000 undulations to the second)? If we cannot point out a means obviously intended for preventing this intercommunication of nerve-filaments, our theory must fail, for we should otherwise be unable to account for the distinctness with which we are impressed by specific colours.

* It would thus appear that perception of any particular colour involves the vibration of its elective foveal nerve-fibres in particular; that the perception of white colour involves the simultaneous vibration of *all* the foveal nerve-fibres.—S.

A somewhat similar difficulty occurred to Dr. Thomas Young, who devoted much attention to this subject. I quote from a communication, offered by that sagacious philosopher to the Royal Society as the Bakerian Lecture for 1820; the passage I have in view being preceded by a quotation from Newton's *Optics*. "Considering the lackingness of the motions excited in the bottom of the eye by light, are they not of a vibratory nature? Do not the most refrangible rays excite the shortest vibrations, the least refrangible the largest? May not the harmony and discord of colours arise from the proportions of vibrations propagated through the fibres of the optic nerve into the brain, as the harmony and discord of sounds arise from the proportions of the vibrations of the air?" (*Optics*, qu. 13, 14.) Dr. Young then proceeds: "*Scholium.* Since, for the reason here assigned by Newton, it is probable that the motion of the retina is rather of a vibratory than of an undulatory nature, *the frequency of the vibrations must be dependent upon the constitution of this substance.* Now, as it is almost impossible to conceive each sensitive part of the retina to contain an infinite number of particles, each capable of vibrating in perfect unison with every possible undulation, it becomes necessary to suppose the number limited, for instance, to the three principal colours, red, yellow, and blue, of which the vibrations are related in magnitude nearly as the numbers 8, 7, and 6, and that each of the particles is capable of being put in motion, less or more forcibly, by undulations differing less or more from a perfect unison; for instance, the undulations of green light, being *nearly* in the ratio of $6\frac{1}{2}$, will affect equally the particles in unison with yellow and blue, and produce the same effect as a light composed of these two species; and each sensitive filament of the nerves may consist of three portions, one for each principal colour. Allowing this statement, it appears that any attempt to produce a musical effect from colours must be unsuccessful, or, at least, that nothing more than a very simple melody could be imitated by them; for the period which, in fact, constitutes the harmony of any concord, being a multiple of the periods of the single undulations, would in this case be wholly without the limits of sympathy of the retina, and would lose its effect in the same manner as the harmony of a third or fourth is destroyed by depressing it to the lowest note of the middle scale. In hearing, there seems to be no permanent vibration of any part of the organ."* "In consequence of Dr. Wollaston's correction of the description of the prismatic spectrum compared with these observations, it becomes necessary to modify the supposition that I advanced in the last Bakerian Lecture respecting the proportions of the sympathetic fibres of the retina; substituting red, green, and violet for red, yellow, and blue, and the numbers 7, 6, and 5 for 8, 7, and 6."†

After the most careful consideration that I have been able to bestow upon this question, I have been unsuccessful in convincing myself that the limitation of the number of vibrating particles to three can in any way favour the solution of the difficulty. It would certainly not be presuming too much to insist that, to the Creator, the provision of an *innumerable* (the meaning of Dr. Young's term "infinite") quantity of fibres, fitted to vibrate isochronously with their respectively incident waves, is a matter of no greater moment than the provision of *three* such sets. Nor would such an arrangement probably exceed in delicacy or minuteness the constitution of many other elements of the eye, *e. g.* the ultimate composition of the fibres of the crystalline lens, or of those of the choroidal granules. Moreover, Dr. Young's hypothesis of three sets of fibres does not

* Dr. Thomas Young's Bakerian Lecture, *Phil. Trans.* for 1820, page 20.

† Ibid, 395.

touch our real dilemma, since under his supposition there is nothing to prevent an intensely excited set of fibrils from imparting its excitation to an adjacent set destined to vibrate under the action of a more feebly undulating pencil of waves. Dr. Young's assumption, in short, does not account for our distinct perception of specific colours.

Before pursuing the interesting inquiry, we will glance at the results which, in this section, have already been secured. We have good reasons for believing that,

1. The *fovea* contains nervous filaments.

2. The yellow spot is made up of an innumerable quantity of textures (having the function of curtains), with the power of expansion or contraction under strong or weak light, arranged parallel to each other and perpendicularly to the visual axis.

3. The crystalline lens has the power of breaking up the white ray involved in perception into a spectrum. What is thrown into the place of colour-apprehension in the *fovea* is, for a white external object, a series of spectrum rays.

4. These spectrum rays are adapted to fall on a system of sympathetic nerve-fibres; an inner set of fibres of this system being constituted so as to vibrate under a larger number of undulations to the inch, and therefore more rapidly, than an outwardly adjacent set.

5. For a particular colour, only a *particular* set of foveal nerve-fibres vibrates, whilst for white light *all* the foveal nerve-fibres simultaneously vibrate.

6. The function of the accommodative power of the crystalline lens is to cause the fibres (particularly or generally, according as the incident light is coloured or white) to be impinged by the respective waves for which they are constitutionally adapted. And, we have finally alighted on a dilemma which, if we cannot obviate, will be a serious obstacle to the reception of our doctrine.

I believe I may venture to declare, without incurring the risk of being deemed presumptuous, that in the course of this now-extensive investigation I have adduced a number of facts which, from the natural way in which they jump with, or fit into, the general laws here developed, are, regarded quantitatively or qualitatively, highly remarkable in the event of this theory being untrue. The ease and naturalness with which the absence of confusion of colour is deductively accounted for by the action of the curtains of the *macula* will be found certainly not less striking.

THE NUMBER OF UNDULATIONS TO THE SECOND IS GREATEST AT THE VIOLET END OF THE SPECTRUM, AND GRADUALLY DIMINISHES IN THE SUCCESSIVELY CONTIGUOUS COLOURS. THE RED RAYS RESULT FROM THE FEWEST UNDULATIONS PER SECOND.

THE HEATING POWER OF THE SPECTRUM IS LEAST IN THE VIOLET RAYS, AND GRADUALLY INCREASES IN THE SUCCESSIVELY OUTER COLOURS, UNTIL IT IS AT A MAXIMUM IN THE RED RAYS. (Brewster's *Optics.*)

A consideration of the operation of these laws on the nerves of the *fovea*, and on the yellow curtains of the *macula*, will reveal the existence of a system calculated to overcome the difficulty foreseen by Dr. Young.

Suppose violet light to be thrown in the *fovea*, the crystalline being "accommodated," so as to cause violet waves to play on the violet foveal fibres (fibres destined for the reception of violet waves). These "violet" fibres are then vibrating isochronously with the undulations of violet light, whilst the calorific power of the thermal element of the violet rays (calorific force being here at its minimum) will just be powerful enough to expand the yellow curtain situated at the outer end of the set of violet nerve-fibres, thus excluding from contact with the "violet" fibres all those situated behind them. Violet fibres being thus alone in vibratory action, the perception of VIOLET

COLOUR would be distinct, and completely unmixed with that of any other colour. The vibration of the whole eye occurring simultaneously and isochronously with that of the violet nerve-fibrils, would make up the impression of VIOLET SPACE.

Suppose, again, indigo light to enter the eye, the crystalline lens being duly "accommodated:" the indigo waves will not agitate the violet fibres, because—firstly, they make a more acute angle with the visual axis than do the violet waves, and consequently fall behind the latter; secondly, even were the indigo waves or fibres to impinge the violet fibres, the latter would not move, because violet fibres are fitted to be excited into action by a wave-force of 699 units, whereas indigo waves have only a moving force of 658 of these units; thirdly, as indigo light has twice the calorific force of violet light, the indigo thermal rays will have force sufficient to extend the violet *and* the indigo curtains: the "violet" curtain* will therefore exclude the violet fibres from taking on the agitation of the indigo fibres. (See fig. 14.)

The nerve-fibrils situated behind the indigo nerve-fibrils will be likewise excluded from assuming the agitation of the latter fibres, by reason of the indigo curtain being extended, thus cutting off the connection with the fibres without.

The indigo fibres, being those now solely excited, will give the impression to the brain of INDIGO COLOUR; and, as the eyeball will be isochronously and simultaneously oscillating with the indigo foveal nerve-fibrils, the total impression on the mesencephalon will be VIOLET SPACE.

If the incident light be blue, since blue rays make a more acute angle with the visual axis than do indigo rays; since blue rays are agitated by a force of only 622

* I call the violet curtain that situated in the plane immediately behind the violet nerve-fibres. A corresponding terminology will designate the curtain situated behind each of the remaining sets of nerve-fibres.—S.

units, whilst indigo rays will not move under a force inferior to 658 units; since, *inter alia*, the indigo curtain is expanded, cutting off communication between the indigo and blue rays, the blue nerve-fibrils will be agitated without influencing their internally adjacent nerve-fibrils. The blue curtain, too, is expanded. The reason is evident. The calorific intensity of blue rays is thrice that of violet, and twice that of indigo rays. The calorific force of blue rays will, therefore, be sufficient to expand the violet, indigo, and blue curtains. And, since the blue curtain is expanded, the nerve-fibrils externally adjacent to the blue curtain will also be cut off from the vibratory influence of the blue nerve-fibrils. The blue-colour-perceiving fibres being alone agitated in the *fovea*, will thus convey to the brain the distinct impression of BLUE COLOUR. The compound mesencephalonic impression, resulting from the simultaneous and isochronous vibration of the blue foveal nerve-fibrils and oscillation of the eyeball, will be that of BLUE SPACE.

A similar explanation applies to any colour of the spectrum. Let the incident ray be red. Red, being the most external of the rays of the spectrum, will strike the visual axis at the most acute angle of all, and would fall behind the rest (see fig. 14). The calorific intensity of red light is such as to have the power of extending all the curtains. And, as the moving force of red light is only equal to 477 units, whilst orange, yellow, green, blue, indigo, and violet fibres demand a moving force of 506, 535, 577, 622, 658, and 699 of these units of force respectively, we have, as before, several convincing reasons why none of the foveal nerve-fibres, save the red fibrils, should vibrate.

The vibration of the red foveal nerve-fibrils will convey to the optic centre the impression of RED COLOUR. And as this proceeds with the simultaneous and isochronous oscillation of the eyeball, the resultant mental impression will be that of RED SPACE.

In the case of the eye receiving white light, the action of the crystalline lens would be to cause each of the component rays to impinge its appropriate set of nerve-fibres. Each foveal nerve-vibrating element would now be in action, each curtain would be down, and each set of nerves be simultaneously conveying its vibrations to the mesencephalon. We here require "no mind-overbearing-the-sense" argument to persuade us that the resultant effect of the separate nerve-vibrations on the optic centre will be white, because we know by experience that a rapidly rotating disc, carefully painted with the colours of the spectrum arranged in their due order and in the proportions that they are known to occupy, gives the effect of WHITE COLOUR.

The simultaneous vibration of all the foveal fibrils with that of the eyeball gives for a resultant effect the perception of WHITE SPACE.

NOTE.—The conversion of the impression of colour due to the vibration of the foveal fibres into the impression of coloured space through the additional action of the eyeball, will be clearly understood, if we remember how vividly the rapid circulation of a burning stick in the dark produces the impression of a burning ring.

What will be the state of the fovea under white light? Firstly, all the foveal nerve-elements will be simultaneously set in a state of vibration. Secondly, the yellow curtains will all be extended close to the visual axis. Moreover, the tension of any curtain will be more intense under the action of a given pencil of white light than under the action of one only of the component colours of that pencil. For, during the incidence of white light the violet curtain will not merely be influenced by the thermic force of the violet ray, but by a portion of that contained in the indigo, the blue, the green, the yellow, the orange, and the red rays. But, we see objects more distinctly under a given beam of white light than under one of the component rays of that beam. Therefore a small *fovea*, intense light, and distinctness of vision go together, just as a small pupil, intense light, and distinctness of vision go together. The action of the *macula* and pupil would appear thus to proceed *pari passu*, and it is thus just possible that the iris may take its action through the *macula*.

From what has been stated, it is evident that those points in the *fovea* which are situated in the same vertical planes as the yellow curtains cannot contain nervous elements. The foveal nerve-cells would therefore appear to be arranged as an innumerable series of vertical strata, parallel to each other, and divided by spaces which, containing no nerve-elements, are merely, so to speak, grooves for admitting the play of the curtains. The more feeble the light, and consequently the heat, which enters the eye, the more will the curtains contract or "pucker" together. The more the curtains "pucker," the greater will be their breadth, and the more must any curtain separate the two series of nerve-elements which are found situated in vertical planes on either side of it. Under weak light, then, the spaces which separate the foveal nerve-elements are broader than under intense light.

Now, the spectrum received in the fovea is, in quality, neither nore nor less than the spectrum which, in an ordinary prism experiment, is intercepted by a screen. But this spectrum is known to contain the Frauenhofer dark lines, now counted by thousands and daily increasing in number. We must therefore conclude that the foveal spectrum contains these lines. The further inference is forced on us, that the spaces in the spectrum occupied by the Frauenhofer lines *mark the places of the curtains;* that the loci of the dark lines in the spectrum are directly in the same vertical planes with the curtains; that for each dark line there exists in the plane of that line a corresponding curtain, and *vice versâ;* that, where an unusually thick " line " is seen in the spectrum, there is in the plane of that " line " a correspondingly thick curtain. This inference is again strikingly confirmed by Sir David Brewster's observation that the angles subtended by the Frauenhofer lines "*increase enormously as the sun passes from the meridian to the horizon.*"* The lines of the spectrum in the *fovea* should therefore be broader the more the sun passes from the meridian towards the horizon. But the lower the sun descends, the greater the heat absorbed by the atmosphere from the solar rays, and the less, consequently, the power of solar heat to expand the foveal curtains. The less the foveal curtains are expanded, the more, as we have seen, will they be puckered up, and the thicker will they be; so that, *under all circumstances the breadth of the curtains and of the lines of the spectrum correspond.*

It would appear, then, that under weak light a great number of nerve-elements is exposed in one plane, and that distinctness of vision is in a direct proportion to the sparseness of the foveal nerve-elements exposed—a result which exactly tallies with our experience, that under feeble light a larger image is necessary for perception than under intense light. The visual axis would then appear to be, in the mathematical sense, the " limit " of the incident pencil, the line to which it tends and with which it never really coincides, although, by imagining the intensity of the incident light as great as we please, we may make the error smaller than any quantity assignable. Thus we infer that the law of perception forms no exception to laws of phenomena in general, but is a tendential law.

The apprehension of Colour takes place then in the *fovea*, through the vibration of the foveal nerve-elements (regulated by the system of yellow curtains), during the simultaneous apprehension of Space by the oscillation of

* Brewster's *Optics*, edition 1853, page 91.

the whole eye; the two simultaneous sets of motions making up the physical condition ancillary and antecedent to the mental state known as the perception of Visual Space.

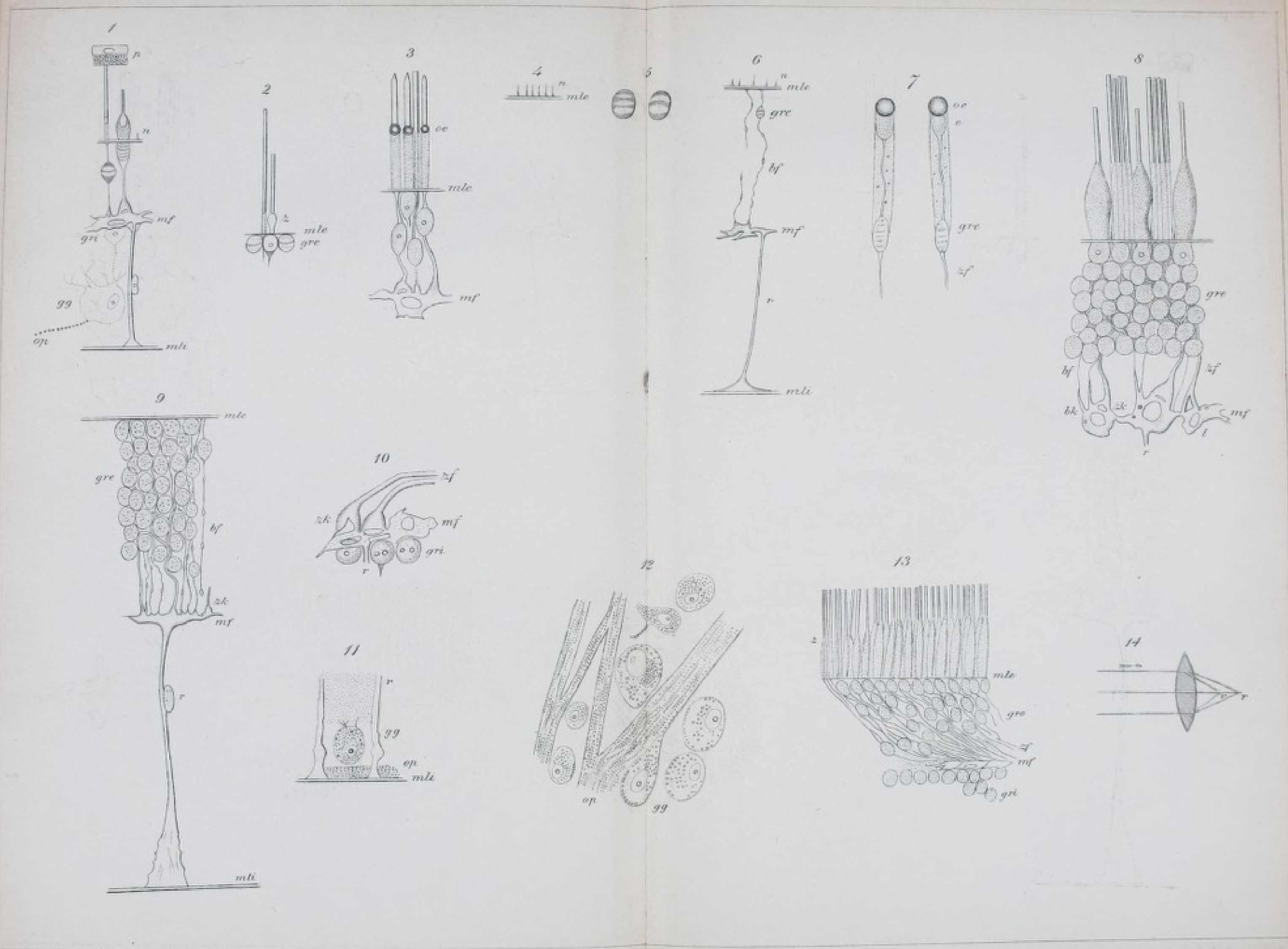
The theory correlates, through undulations, mental with physical phenomena, as equally branches of Kinetics.

DESCRIPTION OF THE PLATE.

Figs. 1 to 13 (inclusive) are taken from KRAUSE'S MEMBRANA FENESTRATA; 14 is from GANOT'S ELÉMENS DE PHYSIQUE. The following is the signification of the letters found in figures 1 to 13 (inclusive):—

p. Retinal pigment.
oe. Oil drop.
e. Ellipsoidal body.
zf. Cone fibre; *zk*, cone spheriod.
bf. Rod fibre; *bk*, rod spheroid.
gg. Ganglion-cells.
mli. Membrana limitans interna.
n. Needle.
mle. Membrana limitans externa.
gre. External granule.
gri. Internal granule.
r. Radial fibre.
op. Optic fibres.

Fig. 1. SCHEME FOR ILLUSTRATING THE CONSTITUTION OF THE RETINA IN VERTEBRATES.—*p*, a pigment-cell in juxtaposition with a rod. The outer segment is homogeneous; in the inner segment is seen a rod-ellipsoid and an axial thread. A cone is seen on the *membrana limitans externa* next the rod. The inner segment of the cone contains a cone-ellipsoid. A needle, *n*, is also seen arising from the membrane. The connection inwardly of the rods and cones with the *membrana fenestrata*, interrupted by the *membrana limitans externa*, is restored by means of the rod and cone fibres. Each of these threads is respectively interrupted in its course by a rod and cone granule (of the outer granule layer; the former shows



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three, the latter five, highly light-refracting cross stripes (discs). A cell of the *membrana fenestrata* is connected by a thick radial fibre (to which an oval granule is attached) with the *membrana limitans interna*, *mli.* An external granule, *gri*, of the internal granule layer is seen lying in a *lacuna* of the membrana fenestrata, *mf.* The multipolar ganglion-cell, *gg*, as well as the optic fibre, *op*, are marked, by dotting, as nervous elements; the connection of the granule, *gri*, with a ganglion-cell is conjectured, or thought probable (wird vermuthet).

Fig. 2. Rod and cone of the mouse: *z*, cone inner segment; *gre*, outer granules. The rod-granules are distinguished by the cross stripes being most distinctly marked. The outer segments are very long.; *mle*, *membrana limitans externa.*

Fig. 3. Vertical section of the retina of *Falco Buteo.* Three cones and a rod, with their outer and inner segments, oil drops, *oe*, rod and cone granules, rod and cone spheroids. The rod and cone fibres run into the cells of the *membrana fenestrata*, *mf.*

Fig. 4. Needles springing from the *membrana limitans externa* of the human retina.

Fig. 5. Two human rod-granules.

Fig. 6. From the retina of the dog: *mle*, *membrana limitans externa; bf*, two varicose rod-threads; *gre*, a striped rod granule; *mf*, a cell of the *membrana fenestrata; r*, radial fibre; *mli*, *membrana limitans interna.*

Fig. 7. Two cones from the retina of the fowl (the outer segments not being given), three weeks after section of the optic nerve. The cones are perfectly normal: *oe*, oil drops completely occupying the whole breadth of the cone; *e*, a cone-ellipsoid with the axis-fibre connecting it with an outer granule; *gre*, outer (cone) granules, with numerous stripes; *zf*, cone-threads.

Fig. 8. Vertical section of the human retina at the back of the eye. The inner layers of the retina are torn

away; *gre*, outer granules; *zf*, cone-fibre; *zk*, cone-spheroid; *bf*, rod-fibre; *bk*, cone-spheroid; *mf*, cells of the *membrana fenestrata*; *l*, *lacunæ* of the latter; *r*, radial fibre.

Fig. 9. Vertical section of part of the retina of the cat: *gre*, outer granules; *bf*, varicose rod-fibres running from the rod-spheroids to the *membrana limitans externa;* the connection of the outer is broken; *zk*, cone-threads; *mf*, cell of the *membrana fenestrata;* *r*, radial fibre, with its oval nucleus; *mli*, *membrana limitans interna.*

Fig. 10. Two human cone-spheroids, with curved cone threads taken at the edge of the *macula lutea.* A vertical section at the meridian, the *fovea centralis* being considered as the pole; *zk*, cone-spheroid; *zf*, cone threads; *mf*, *membrana fenestrata;* *gri*, external row of the inner granules; under the middle one is seen a broken radial fibre; the left-hand one is seen intruding in a *lacuna* of the *membrana fenestrata;* *r*, radial fibre.

Fig. 11. Vertical section of the retina of the rabbit, twenty-one days after section of the optic nerve: *mli*, *membrana limitans interna;* *op*, fattily degenerated optic fibres; *gg*, fattily degenerated ganglion-cells and their processes, the latter running into the granulated layer.

Fig. 12. The same eye as that of fig. 11, observed immediately after the death of the rabbit. Superficial view of the fattily degenerated ganglion-cells. The little granules are seen at the edges of the cells (*gg*). The processes of the ganglion-cells are now easily recognized by their little fat-granule: *op*, optic fibres, likewise fattily degenerated.

Fig. 13. A vertical section in the meridional direction through the edge of the human *fovea*, in order to show the termination of the *membrana fenestrata*: *z*, slender cones of the *fovea;* *mle*, *membrana limitans externa*

gre, cone-granules; *zf*, cone fibre layer; *mf*, the last cells of the *membrana fenestrata; gri*, inner granules.

Fig. 14 shows the action of a bi-convex lens in decomposing light; *v* and *r* are the internal and external extremities of the spectrum thus produced; *v*, representing the *locus* of the violet ray, and *r* that of the red ray.

THE END.

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