Thomas Young: The Foundations of Light, Color, and Optics

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Introduction

Named after his father, Thomas Young (Fig. 1) was born at Milverton in Somersetshire, England, on the 13th of June, 1773, the eldest of ten children. His parents were strict Quakers, and an anonymous contemporary "who had the advantage of long and intimate acquaintance with that distinguished scholar and philosopher" attributed "the power he so eminently possessed of an imperturbable resolution to effect any object on which he was engaged" to his upbringing in the Religious Society of Friends [1]. An early biographer restated this in a different way: "Nor was there anything which he thought worthy to be attempted which he was not resolved to master" [2]

His intellect was both a blessing and a curse. His perhaps overly broad interests and difficulty communicating his ideas resulted in his being underappreciated during his lifetime. He made contributions to many fields, but may be best remembered for his trichromatic theory of color vision that was expanded upon by Hermann von Helmholtz and James Clerk Maxwell decades after his death and confirmed by modern neurophysiologists. Helmholtz, the inventor of the ophthalmoscope, famously said that Young "had the misfortune to be too far in advance of his contemporaries."

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Child Prodigy

To say that he showed great intellectual powers at a young age may be an understatement. He was able to "read with fluency" at age two and said he had perused the entire *Bible* twice by age four.Primarily an autodidact, he had a command of English, Latin, Greek, Italian, French, Hebrew, Chaldee (Biblical Aramaic), Persian, Syrian, and Arabic at age 14.

Accommodation

At age 19 in 1793, his paper "Observations on vision" was read by his great-uncle Richard Brocklesby M.D. F.R.S. to the Royal Society and then published in its *Philosophical Transactions* [3]. He addresses previous speculation on the mechanism of accommodation put forth by, among others, Kepler and Descartes, both of whom felt elongation of the eye explained the change in focus, then dismisses the possibility that the ciliary processes are responsible for the change in the shape of the crystalline lens. "Those who maintain that the ciliary processes flatten the crystalline, are ignorant of their structure." He does not indicate who held this opinion.

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Fig. 1 Portrait of Thomas Young by Henry P. Briggs

Based on his own dissection of an ox eye ("I have not yet had an opportunity of examining the human crystalline, but from its readily dividing into three parts, we may infer that it is similar to that of the ox"), he concludes that the crystalline lens consists of muscles and tendons and that contraction of these muscles changes the shape of the lens to produce accommodation. As for an elongation of the eye's axis, "as a bell shakes a steeple, so must the coats of the eye be affected by any change in the crystalline; but the effect of this will be very inconsiderable." He goes on to discuss what are now called phosphenes, visual phenomena produced by pressure on the eye.

Young was immediately embroiled in controversy as the eminent John Hunter F.R.S., 20 years Young's senior, claimed precedence for the idea that the lens is intrinsically muscular. There was even innuendo that Young had heard of Hunter's idea at a dinner party in 1791 at the house of Sir Joshua Reynolds. Concerned that he was being accused of plagiarism, Young wrote to those who had attended the dinner to ask if any visual researches had been discussed.

He was, however, elected to the Royal Society in 1794, the week after his 21st birthday. He wrote to his mother, "I hope I am not thoughtless enough to be dazzled with empty titles which are often conferred on weak heads and on corrupted hearts" [4]

He was to go on to demonstrate that the eye retained its ability to accommodate under water where the refractive power of the cornea is effectively neutralized. "It has been observed that the central part of the crystalline become rigid by age, and this is sufficient to account for presbyopia." He eventually was to have the personal experience of presbyopia, his eye having "lost almost the whole of its power of accommodation soon after fifty" [5]

Medical Student at Edinburgh, Göttingen, and Cambridge

Young decided to pursue a career in medicine and studied at Edinburgh and Göttingen, receiving a degree from the latter in 1796 for a thesis (in Latin) on the human voice. Because the politics of English medicine at that time required a degree from Oxford or Cambridge to obtain licensure in London from the College of Physicians, he enrolled at Emmanuel College, Cambridge, in 1797.There he acquired the sobriquet "Phaenomenon Young" as he already seemed to know what his fellow students (and tutors) were still learning. Later that same year his great-uncle and mentor, Dr. Richard Brocklesby, died, leaving him a furnished house in London and about £10,000. This assured him of a comfortable life as a gentleman scholar, which was fortunate as he never achieved great success as a practicing physician.

His tenure at Cambridge forced him to depart from his Quaker roots, as membership in the Church of England was a requirement for matriculation at either Oxford or Cambridge until late in the nineteenth century. He learned little from his tutors and fellow students, but spent much time studying and experimenting on sound and speech. In his autobiographical sketch written in 1826–1827, he speaks of himself in the third person, "His pursuits, diversified as they were, had all originated in the first instance from the study of physic: the eye and the ear lead him to the consideration of sound and of light."

He read a paper at Emmanuel in 1799 that includes the lines, "should further experiments tend to refute any opinions that I have suggested, I shall relinquish them with as much readiness as I have long since abandoned the hypothesis with I once took the liberty of submitting to the Royal Society on the functions of the crystalline lens." He appears to have temporarily abandoned his idea that the lens was a muscle that changed in shape to produce accommodation.

London and Optics

Having satisfied his required residence in Cambridge, Young moved back to London and read "On the Mechanism of the Eye" to the Royal Society in November, 1800 [6]. This long and detailed paper includes another reference to the appearance of ciliary processes upon dissection as "wholly irreconcileable [sic] with muscularity."

> Whatever their use may be, cannot easily be determined: if it were necessary to have any peculiar organs for secretion, we might call them glands, for the percolation of the aqueous humour; but there is no reason to think them requisite for this purpose.

He also seems to return to his former opinion in regards to the lens as the active structure in accommodation. He remains troubled that he cannot find any nerves going to the lens. This is also the paper where he identifies astigmatism (although he did not coin this term) by refracting his own eyes and describes a variation of an instrument called an optometer for measuring refractive error and accommodation.

He also measures his own blind spot:

> To find the place of the entrance of the optic nerve, I fix two candles at ten inches distance, retire sixteen feet, and direct my eye to a point four feet to the right or left of the middle of the space between them: they are then lost in a confused spot of light; but any inclination of the eye brings one or the other of then into the field of view.

From these observations he concludes:

> … the diameter of the most insensible part of the retina,[is] one-thirteenths of an inch.

He does not make the modern distinction between optic nerve and retina, but his calculation comports well with the 1.5–2 mm. diameter of the optic nerve determined by direct measurement.

Lloyd comments that "the first reliable observations on the area of the visual field must be credited to Thomas Young, who gave the extent of the field as upwards 50°, inwards 60° and outwards 90°. Young also pointed out that 'the whole extent of perfect vision is little more than ten degrees'" [7]

Light as a Wave

One year later he returned to give another Bakerian Lecture (one of four), "On the Theory of Light and Colours" [8]. Here he refers to Newton's Theory of Light and states that, because of the "stupendous velocity it implies, has been ever thought liable to difficulties." He proposes instead "a luminiferous ether, rare and elastic in a high degree, pervades the whole universe" and that "undulations" in this ether leads to the perception of color. The fundamentals of this characterization of light as waves had been proposed by Huygens in 1678.

In 1803 Young described experiments in support of his wave theory of light [9]. He is credited with performing the "two slit experiment" in which two parallel slits illuminated by light produce the interference fringes that would be expected if light behaves as a wave. In fact the paper generally cited for this experiment, his 1803 Bakerian Lecture published in 1804 makes no mention of slits. It does describe fringes produced by a needle hole in a "piece of thick paper" and a previously described observation by Grimaldi (no reference given) of fringes "formed by an object which has a rectangular termination." There are no diagrams associated with this lecture.

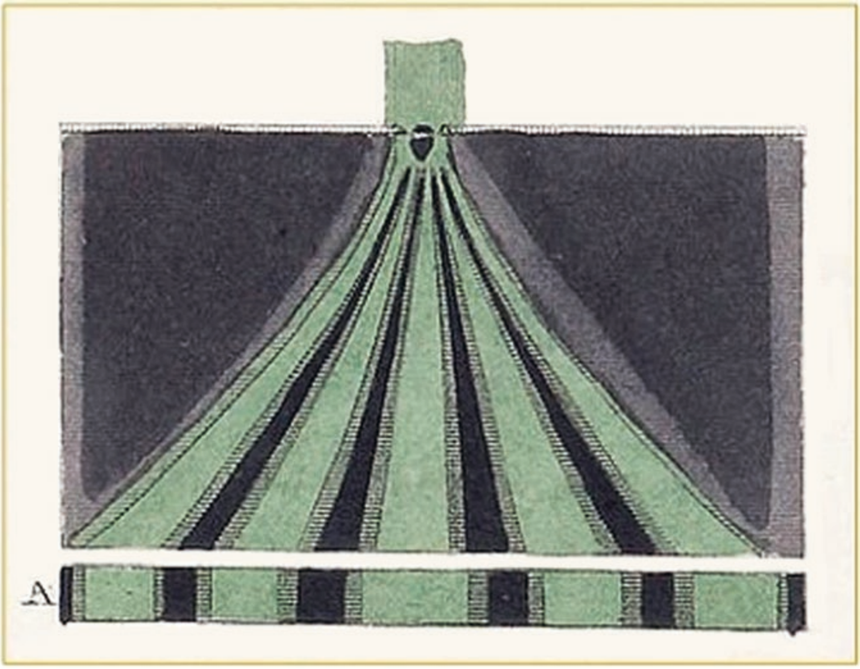

Fig. 2 Young's diagram of what is now known as the two slit experiment. His caption: "The manner in which two portions of colored light, admitted through two small apertures, produce light and dark stripes or fringes by their interference, proceeding in the form of hyperbolas; the middle ones are however usually a little dilated, as at A"

He did describe and diagram an experiment (Fig. 2) in his *Lectures on Natural Philosophy* published in 1807 [10], but he refers to "small apertures" and not slits. There is some doubt whether Young actually performed the two slit experiment. Modern historians of science point out that he does not specify the light source used or other experimental conditions, nor does he provide specific measurements as he usually did [11]. He never returned to this experiment in his subsequent publications.

In any event, even if this were a thought experiment, it has been performed and confirmed many times by others (Fig. 3).

Young had generalized from sound waves to light waves—in distinction from Newton's prior characterization of light as corpuscular (particles). Robinson characterizes him as "*The Anonymous Polymath Who Proved Newton Wrong,*" [12] but Young expressed great admiration for Newton and goes on at length to explain why various optical phenomena can only be explained if light behaves as a wave. Actually, modern physicists consider both Young and Newton correct; light behaves as particles in some situations and as waves in others—the "wave-particle duality of light."

Color Vision

The insight in his 1801 Bakerian lecture that has had the most lasting effect was Young's postulation that the undulations of red, yellow, and blue were related to each other "in magnitude as the numbers 8, 7, and 6" and that these "primitive" colors combined to produce other color sensations. Young later changed the "principal pure colours" to red, green, and violet in his essay on "Chromatics" in the 1817 *Supplement* to the *Encyclopedia Britannica*—one of his more than 60 contributions to this work on a wide variety of subjects (When the sensitivities of cones could actually be measured in the twentieth century, their peak wavelengths are nearer red, green, and blue.)

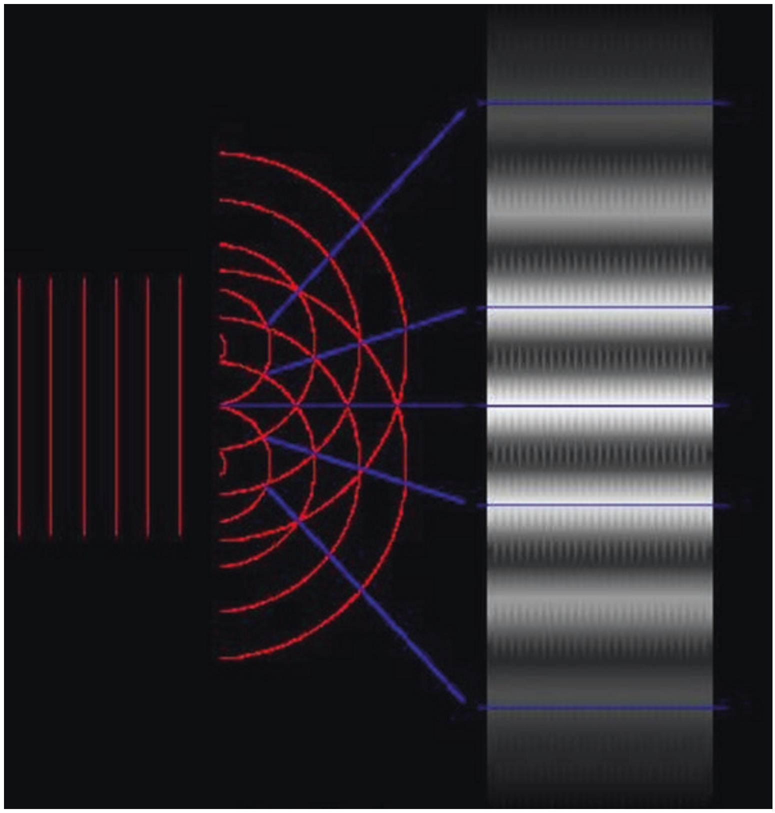

Fig. 3 A modern diagram of the two slit experiment. From http://www.shmoop.com/optics/young-double-slit.html, https://upload.wikimedia.org/wikipedia/commons/thumb/8/8b/Two-Slit_Experiment_Light.svg/2000px-Two-Slit_Experiment_Light.svg.png

In "Chromatics" he more clearly states his theory: [13]

> If we seek for the simplest arrangement, which would enable it [the eye] to receive and discriminate the impressions of the different parts of the spectrum, we may suppose three distinct sensations only to be excited by the rays of the three principal pure colours, falling on any given point of the retina, the red, the green, and the violet; while the rays occupying the intermediate spaces are capable of producing mixed sensation, the yellow those which belong to the red and green, and the blue those which belong to the green and violet.

Professor at the Royal Institution

Young was appointed Professor of Natural Philosophy in the Royal Institution, which had been founded in 1799 and given its Royal Charter in 1800. Officially the Royal Institution of Great Britain and still in existence at its original location on Albemarle Street in London, this ambitious and quintessentially British undertaking was to include, "an industrial school for artisans; a collection of models of fireplaces, grates, stoves, steam engine, spinning wheels, etc.; a professor was to be appointed and provided with a well-equipped lecture room; and a convenient club with a restaurant and school of cookery…" [14]. From its outset the Royal Institution has as one of its primary goals attempted to expose the general public to the ideas and discoveries of science.

Young gave a series of lectures there in 1802–1803 that, according to his own assessment, were "never either very popular or very fluent." His anonymous, but sympathetic, biographer comments, "As a lecturer at the Royal Institution, Dr. Young was apt, in no small degree, to pass the capacities of his audience…. His style was compressed and laconic; he…gave more matter than it would perhaps have been possible for persons really scientific to have followed at the moment without considerable difficulty."

Fig. 4 A satiric view of a lecture at the Royal Institution. "Scientific Researches! New Discoveries in PNEUMATICKS-or-an Experimental Lecture on the Powers of Air" (1802). Sir Humphry Davy (discoverer of sodium and potassium) to the right with bellows. In the center is Thomas Young experimenting on Sir John Hippisley (farting). Note the heterogeneity of the audience

These lectures did not do much to enhance Young's reputation (Fig. 4). His more serious efforts were met with a barrage of criticism. An unsigned review, but known to be written by Henry Peter Brougham (who would eventually become Lord Chancellor) in the recently established *Edinburgh Review* of "On the Mechanism of the Eye" states, "As this paper contains nothing which deserves the name, either of experiment or discovery, and, as it is in fact destitute of every species of merit…Has the Royal Society degraded it publication into bulletins of new and fashionable theories for the ladies who attend the Royal Institution?" [15] Brougham had reason to resent Young, who had previously savaged his work, "such an author appears to be confined in his conception of the most elementary doctrines, and that he fancies he has made an improvement of consequence, when, in fact, he is only viewing an old object in a new disguise" [16]

Physician in London

He finally received his M.D. from Cambridge in 1808 and became a Fellow of the Royal College of Physicians in 1809. He eventually obtained an appointment at St. George's Hospital in 1811.

Sir Benjamin Brodie, who was at St. George's with Young and later became the first surgeon to be president of the Royal Society, said of him, "The students at the hospital complained that they learned nothing from him. I never could discern that he kept any written notes of cases, and I doubt whether he ever thought of his cases in the hospital after he had left the wards. His medical writings were little more than compilations from books, with no indication of original research. I offer these observations as a matter of justice to others, and not in depreciation of Dr Young, whose great original genius displayed in other ways, place him in the

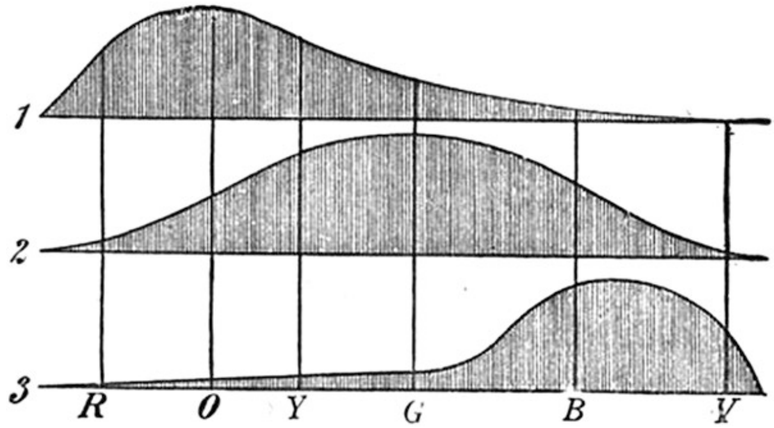

Fig. 5 Helmholtz's response curves for the three color receptors from his 1860 *Handbuch der Physiologicschen Optik*

foremost rank of those whose names adorn the annals of our country" [17]

He delivered the Croonian Lecture to the Royal Society in 1808. He applied hydraulic principles to the circulation of blood and argued against the then popular idea that peristaltic contraction of the larger arteries was a major factor in blood flow [18].

Young returned to an old pattern in 1809 for a lecture series published as *A Syllabus of a Course of Lectures on the Elements of the Medical Science*. He admitted "they were little frequented, on account of the usual miscalculation of the Lecturer, who gave his audience more information in a given time, than it was in their power to follow." As his biographer Robinson correctly observed, "Great thinkers do not always make great lecturers."

His 1813 *An Introduction to Medical Literature, Including a System of Practical Nosology* did not sell well, but he prepared a second edition (1823). He published *A Practical and Historical Treatise on Consumptive Diseases* in 1815 and was disappointed that it did not attract more patients with these disorders to his practice.

Young's Legacy

Young's failure to remain focused on one field and his inability to explain his ideas more clearly served to diminish his impact on scientific thinking during his lifetime. It remained for subsequent generations to mine his voluminous works and ensure his reputation as an innovator.

Long after Young's death at age 55 in 1829 (His choice for his epitaph, "He may be said to have been born old, and to have died young") Hermann von Helmholtz and James Clerk Maxwell, working in the 1850s, resurrected the three retinal receptor explanation of color vision that Young had implied. Heesen asserts that Maxwell deserves precedence for the concept of "coterminal response curves" (i.e. that each of the three receptors is sensitive to overlapping spectra) (Figs. 5 and 6) that explains how just three retinal receptors could account for the perception of multiple colors and argues that the Young-Helmholtz theory of color vision would more properly be called the Young-Maxwell theory or at least the Young-Helmholtz-Maxwell theory [19] (A small irony: Maxwell was also Young's wife maiden name).

Whatever his faults as a lecturer and writer (One tutor at Emmanuel commented "He was… worse calculated than any man I ever knew for the communication of knowledge"), he was a towering intellect. Fonda catalogues Young's contributions to optics: mechanism of accommodation by the lens, exposition of the phenomenon of interference of light waves, calculation of the wave lengths of seven colors in the spectrum, the first measurement of astigmatism, the first measurement of the field of vision and size of the

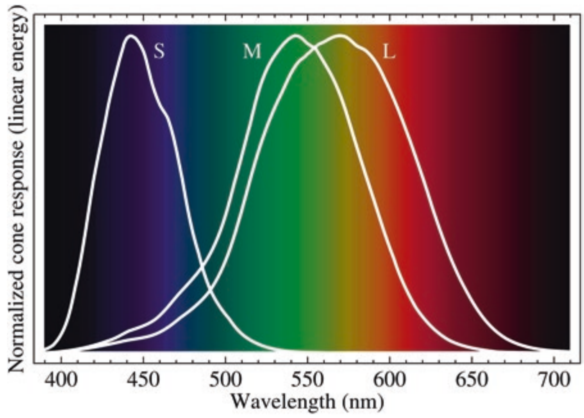

Fig. 6 A modern diagram of cone responses. The cones are designated S for short wavelengths, M for medium wavelengths, and L for long wavelengths, rather than by color. Note that the modern diagram reverses Helmholtz's color order. From https://commons.wikimedia.org/wiki/File:Cone-fundamentals-with-srgb-spectrum.svg (I, the copyright holder of this work, release this work into the public domain. This applies worldwide. In some countries this may not be legally possible; if so: I grant anyone the right to use this work for any purpose, without any conditions, unless such conditions are required by law

blind spot [20]. (Actually, Edme Mariotte "was the very first to try to determine the size of the blind spot" in 1717—which is why it has been called the "Blind Spot of Mariotte" [21])

In addition to his eponymous theory of color vision, there is the Young modulus for elasticity, the Young-Laplace equation for capillary pressure, the Young–Dupré equation for surface free energy, and the Young temperament for the tuning of musical instruments. He also found time to be Secretary of the Board of Longitude and Superintendent of the *Nautical Almanac* and serve as actuary for the Palladium Insurance Company while simultaneously attempting to translate hieroglyphics using the Rosetta Stone. Concerned that his attention to so many fields would reflect poorly on his ability to practice medicine, he published many of his papers anonymously, which probably also diminished his reputation among fellow "natural philosophers," as they were then known (The term *scientist* wasn't coined until after Young's death).

Young felt that his work on light and colors, "though it did not occupy a large portion of my time, I conceived to be of more importance than all that I have ever done, or ever shall do besides" [22]. In his own lecture at the Royal Institution, Maxwell stated, "So far as I know, Thomas Young was the first who, starting from the well-known fact that there are three primary colours, sought for the answer to this fact, not in the nature of light, but in the constitution of man" [23]

References

1. Anonymous. Memoir of the life of Thomas young, M.D., F.R.S., with a catalogue of his works and essays. London: John & Arthur Arch, Cornhill; 1831. p. 5–6.
2. Pettigrew TJ. Thomas Young in Medical portrait gallery, vol. IV. London; 1840. p. 4.
3. Young T, Brocklesby R. Observations on vision. By Thomas young, communicated by Richard Brocklesby, M.D. F.R.S. Phil Trans R Soc Lond. 1793;83:169–91.
4. Robinson A. The last man who knew everything; Thomas young, the anonymous polymath who proved Newton wrong, explained how we see, cured the sick, and deciphered the Rosetta stone, among other feats of genius. New York: Pi Press; 2006. p. 39.
5. Anonymous. op cit. p. 52.
6. Young T. The Bakerian lecture: on the mechanism of the eye. Phil Trans R Soc Lond. 1801;91:23–88.
7. Lloyd RL. The history and evolutions of perimetry. Australas J Optom. 1936;19(9):131.
8. Young T. The Bakerian lecture. On the theory of light and colours. Phil Trans R Soc Lond. 1802;92:12–48.

9. Young T. The Bakerian lecture. Experiments and calculations relative to physical optics. Phil Trans R Soc Lond. 1804;94:1–16.
10. Young T. Lectures on natural philosophy, vol. 1. London; 1807. p. 464.
11. A Robinson. op cit. p. 124–124.
12. Ibid.
13. Wood A, Oldham F. Thomas young; natural philosopher; 1773–1829. Cambridge: Cambridge University Press; 1954. p. 110–1.
14. Ibid. p. 118.
15. Robinson. op cit. p. 115.
16. Wood and Oldham. op cit. p. 156.
17. Ibid. p. 79.
18. Young T. The Croonian lecture: on the functions of the heart and arteries. Phil Trans R Soc London. 1809;99:1–31.
19. Heesen R. The Young-(Helmholtz)-Maxwell theory of color vision; 2015. http://philsci-archive.pitt.edu/id/eprint/11279.
20. Fonda G. Bicentenary of the birth of Thomas young, M.D., F.R.S. Br J Ophthalmol. 1973;57:803–8.
21. Brøns J. The blind spot of Mariotte; its ordinary imperceptibility or filling-in and it facultative visibility. London: H.K. Lewis and Co. Ltd; 1939.p. 16.
22. Wood and Oldham. op cit. p. 179.
23. Ings S. A natural history of seeing; the art and science of vision. New York: W.W. Norton & Company; 2007. p. 224–5.