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BIOGRAPHICAL MEMOIR

OF

OGDEN NICHOLAS ROOD

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BY

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Ogden N. Rood

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BIOGRAPHICAL MEMOIR OF OGDEN NICHOLAS ROOD.

OGDEN NICHOLAS ROOD, member of the National Academy of Sciences since 1865, was born at Danbury, Connecticut, February 3, 1831. Professor Rood was of Scottish descent, the family having lived near Edinburgh. They came to this country at an early day in the colonial period and settled at Lanesboro, Massachusetts. A few years before the Revolutionary War, one member of the family, Azariah Rood, purchased a tract of land in the town of Jericho, Vermont. His was the third family to settle in that neighborhood, and during the Revolution his house was the most northerly inhabited point in the State and subject to frequent attacks by the Indians. On this account the family was forced to abandon the property and to return to Lanesboro until after the close of the war. Professor Rood's father, the Reverend Anson Rood, was a grandson of Azariah Rood and one of a family of eight sons. Anson Rood was educated by his older brother, Dr. Herman Rood, who was one of the early biblical scholars of this country and who was for many years Professor of Hebrew in Dartmouth College. After graduation from that institution Anson Rood entered the ministry of the Congregational Church and was ordained at Danbury, Connecticut, in 1829, two years before the birth of his son, Ogden Nicholas Rood.

On his mother's side, Professor Rood was likewise descended from a family active in the intellectual and practical life of colonial times. His mother, Alida Gouveneur Ogden Rood, was a direct descendant of John Ogden (1610-88), the first of his name in America, who was one of the founders of Elizabeth, New Jersey, and who afterwards settled at Hempstead, Long Island, and in 1650 became one of the magistrates of the colony of Connecticut.

Professor Rood was graduated at Princeton College in 1852. During the two following years he was successively a graduate student at Yale, an assistant at the University of Virginia, and an assistant to Professor Silliman. His preparation for work as a physicist was completed by four years of study in Germany

(1854-58), a period which was divided between scientific study at the universities of Berlin and Munich and practice in oil painting.

The year 1858 was an eventful one. In it he married Miss Prunner, of Munich, returned to the United States, and entered upon his profession as a teacher. His first appointment, as Professor of Chemistry in the newly organized and short-lived institution known as the University of Troy (New York), was well calculated to bring out the innate qualities of the man. Some men become investigators merely under the stress of outward demand. They force themselves to research from sense of duty, from motives of ambition, for recognition, or to gain place. Not so Rood, who was increasingly productive under the most trying circumstances and when no original work was expected of him. His motive and the passion for research which filled him is finely voiced in his inaugural address at Troy, delivered July 20, 1859:*

"The mere desire of wealth, though it may influence many to touch lightly on the surface of these studies (the physical sciences), still is not a motive of sufficient strength to enable one to toil a lifetime, content with such rewards merely as are found in the pursuit itself. This calls for a more powerful and nobler motive—and it is found in the intense desire to solve some of the profound mysteries with which we are surrounded, in the longing to obtain some glimpses into the inner world, into the secret laboratory of nature. And now it would be proper, having indicated these lesser advantages, to speak of the nobler end of such study, of its beautiful and spiritual purpose; to speak of natural philosophy as a revelation from 'The great God, who maketh and doeth all things well.' But if you have not listened to His voice, speaking in His yellow sunbeam; in His banded rainbows and purple sunsets; in the violet flash of His lightning, and in the war of His tempests; or in His white crystalline snow with its blue shadows, and in His dark rivers congealed into transparent highways, solid as the rock; neither would you meditate on any crude thoughts that I might suggest."

These words were spoken in an environment as foreign to such ideals as well can be imagined, for the Troy University of that date—and its days were even then numbered—was, to quote the

* Columbia University Quarterly, December, 1902. Notice of Ogden N. Rood, by J. H. Van Amringe.

words of Dr. Vincent, of the Union Theological Seminary, spoken at Rood's funeral, "in its first crude stage, lodged in a huge, pretentious and uncomfortable building and almost devoid of the ordinary appliances of a common school."*

In the same tribute to his friend and former colleague Dr. Vincent gives a vivid picture of the surroundings into which the young physicist had been injected by fate:

"I shall never forget" (he says) "his unconcealed and vigorously expressed disgust when, fresh from the plethoric libraries and well-appointed laboratories of a German university, he found himself, with the title of Professor of Chemistry, in a so-called library, where four or five hundred volumes, chiefly of classical authors, were displayed on a dreary expanse of shelving; in an ill-lighted lecture-room with a few bottles of chemicals, and with a handful of students, half trained in country academies, and the most of them without any interest whatever in what he was appointed to teach them.

"But even under these depressing conditions his native energy, versatility, and fertility of resource displayed themselves. The apparatus which the poverty-stricken college could not furnish him, he manufactured with his own hands, enough at least to meet the very limited requirements. To those students who cared nothing for chemistry or physics, he was simply and serenely indifferent. He was a conscientious teacher, and any one who desired to learn, might learn; but very few desired to learn, and he quietly filled his class-register with zeros, which marked the numerous pitiable displays in his lecture-room. But when he did, now and then, meet with a student who showed an interest in his teaching, there were no lengths to which he would not go to instruct, encourage, and advance him. He would devote himself to him in hours and out of hours. He would take him to his private room, and lecture to him, and experiment with him, and lend him books, and all this, week after week, as though he had no object in his professional life beyond the proficiency of that particular subject.

"Separated in some degree, by our situation, from the social life of the city, the members of the faculty were thrown very much upon each other, and our relations were very intimate. Naturally inclined to solitude, he (Rood) proved himself, nevertheless, a most genial, stimulating, cheerful, and appreciative companion. No one would have thought of setting him down as a recluse. He was always ready to exchange a jest, and to see

*Dr. Martin E. Vincent, Columbia University Quarterly, December, 1892, p. 57.

the humorous side of a thing; and yet one was always conscious of an undercurrent of serious purpose. Into the narrow life of the infant college he threw himself with enthusiasm. He treated the various annoyances, inconveniences, and hardships with a kind of grim humor and tolerance, and he made the best of everything, and extracted from his experience a great deal of real enjoyment and solid achievement.

"Apparently one of the idlest and most indifferent of men at times, he was really one of the most busy and intent of men at all times. Often, when he appeared to be merely amusing himself, he was most hard at work in some definite direction. For months at a time he would spend many hours of each day with his rifle, at a rough shooting gallery among the hills back of the college, strolling leisurely homeward toward sundown with his paper targets in his hand; but by and by appeared a careful treatise on the American rifle. On a ramble, or while engaged with any piece of mechanical work, his eyes were continually busy noting phenomena, and divining new laws and principles; and the results of these observations were continually coming to light in papers in the American Journal of Science and Arts. Now he was experimenting with the stauroscope; again, while grinding a microscopic slide, he was noting the muscular contraction induced by contact with vibrating bodies, and comparing the symptoms and sensations produced by electricity and by mechanical vibration. Then his attention was directed to the phenomena of circulation in the eye. In his reading about Australia, the boomerang awakened his curiosity; and he set himself to study the principle of that barbarous instrument, and might often be seen on the college campus throwing the models he had prepared and studying their curves as they flew outward and returned. During the whole time of his residence in Troy he was studying the infant science of photography, wandering over the hills with his camera, photographing all sorts of objects, experimenting on all sorts of processes, and recording and tabulating innumerable data.

"And when he had found something, his instinct was to go and tell it. Without any such intention, he managed to draw us all into the current of his own interest. His enthusiasm was contagious, even to those who possessed little scientific knowledge. The ardor of a true huntsman is kindled by companionship. His life was one perpetual chase of the facts and laws of the physical universe; and though his zeal would have sustained him in a lonely pursuit, his pleasure was greatly enhanced by the intelligent sympathy of another. He liked to awaken the interest of even a mere boy in what he was doing. One day, some years ago, I went to see him in his laboratory, having with me a lad of sixteen who was preparing to enter the School of Mines. He kept us there for something like two hours, showing the boy all kinds of wonders in the laboratory, especially the operation of the Röntgen rays, on which he was then experimenting.

"His zeal in the pursuit of physical science was intense and consuming, and never slackened while he lived. The more closely Nature guarded a secret, the more obstinately was he bent on discovering the master-key. He was impatient of everything superficial. He desired, and was determined to know, not only facts, but laws; not only laws, but ultimate principles. Even at that early period of his career he was *en rapport* with various notable specialists and high authorities and was occasionally visited by them at Troy."

Many who have witnessed or taken part in the development of scientific investigation in America will recognize this description as characteristic not merely of the ill-fated institution where Rood served his apprenticeship, but of the conditions which existed in nearly all American colleges of the period. Such scientific work as was done was due to men in whom the unquenchable fire burned and who were independent of environment. Such a man was Joseph Henry, much of whose most important work was done years before, in the academy of the neighboring town of Albany. Such in later years was Brace, who built up a great center for physical research on the Nebraskan frontier. That Rood was such a spirit, indomitable and irrepressible, the notable series of papers published by him during his four years at Troy bear witness.

PAPERS OF THE TROY EPOCH.

To this period belong a very interesting group of notes and communications, some of the latter in the form of letters to Silliman and to Wolcott Gibbs, which appeared in the American Journal of Science.

The first of these papers, dated at Troy, on Christmas day, 1858, describes a study of the polarization of light by passage through glass strained by sudden cooling. The article, although based on the work of von Kobell and of Dove, considerably extends and supplements their observations, and it contains in addition a new and ingenious method for the detection of circular polarization.

It was during this period that Rood made his first excursions into the realm of physiological optics—a domain in which he was later to travel far and make notable conquests. In 1860 he investigated the after-images produced by observing a bright sky through open sectors in a revolving disk, demonstrated their subjective character in contravention of the views of J. Smith, and showed the relation of the phenomenon to those previously observed by Fechner.

His explanation, which was based upon persistence of vision, is noteworthy: "The occurrence and sequence of these subjective colors," he says, "may easily be explained by supposing that during the interval of rest or shadow the action of the yellow rays diminishes more rapidly than that of the red, the red more rapidly again than that of the blue." In his Modern Chromatics* Rood subsequently outlined a method for testing this supposition, although he does not appear to have performed the experiment. When, however, persistence of vision as a function of the wave length of the exciting light was first definitely determined, in 1884,† the facts were found to agree with the assumption quoted above.

Rood's experience as an art student in Munich brought the problems of vision and color very near to him from the first, and he was always considering the numerous themes that lie in the middle ground between physics and painting. In 1861 he published a note on the relation between our perception of distance and color, in which he ascribed the increased vividness of coloring apparent upon viewing a landscape with the head lying under the arm to the fact that one's sense of distance is lost and one looks as at a picture. This view he verified by observations through total reflecting prisms and in other ways. In the same year he made some experiments connected with Dove's theory of luster, in which he brought into combination in the stereoscopic field a variety of surfaces, such as tin-foil and yellow paper, which gave the effect of gold leaf; of tin-foil and orange-colored paper, which when blended appeared like copper; of tin-foil combined with paper tinted with ultramarine, in which the com-

* Modern Chromatics, p. 206.

† Nichols, Am. Journal Science (3), XXVIII, p. 243.

posite image had the appearance of graphite. He found that a photograph of a surface of tin-foil, which gave a suggestion of metallic structure, served almost as well as the foil itself, although gray paper would not produce the effect. He also described experiments for the production of luster in which only one eye was used.

His paper on the practical application of photography to the microscope, which likewise appeared in 1861, was one of the earliest contributions to this subject. In it he described a simple but practical form of micro-camera with details of the still new art of wet-plate photography, printing, and the like. He also gave a method of making stereomicrographs and of photographing living organisms. The disagreement of opinion among microscopists as to the true character of the markings of *Pleurosigma angulatum* also attracted his attention, and by means of a magnifying power of a thousand diameters he succeeded in establishing the circular character of the lines of this infusorial shell as against the hexagonal. In order to determine more definitely than was possible by direct observation the character of microscopic forms, he applied the method of reflection commercially used in testing optical surfaces, and was thus able to settle certain points still in controversy.

During the year 1862 Rood was employed in the construction of a spectrometer with four large prisms—one of flint glass and three containing carbon bisulphide. With this instrument he obtained a spectrum 10 feet long and of excellent definition. In a letter to Wolcott Gibbs he described observations on the absorption spectrum of a solution of didymium nitrate, with which substance Gladstone had recently been experimenting. By the use of a strong solution and a cell twelve inches in thickness, Rood was able to find twelve bands instead of the two already observed. He also wrote an account of Dove's photometer, with some original suggestions as to the method of construction. His most important contribution during this year, however, was the very interesting paper on the study of electric sparks by aid of photography, in which "end on" views of the sparks were obtained by allowing the discharge to pass through the photographic film and then developing and enlarging the negative.

In 1863 the chair of Physics at Columbia College became vacant, and Rood was a candidate for this position. His chief competitor was F. A. P. Barnard, who became president of the college, while Rood was appointed to the professorship.

It was still the day of small things in science in America. Everywhere there was the same lack of equipment and but little time for or incentive to investigation. Even Columbia, one of the oldest of American institutions, which reached back to colonial times, was just emerging from the now almost inconceivable age of darkness, when one professor was thought to suffice for all the sciences.

PAPERS OF THE EARLIER YEARS AT COLUMBIA.

Rood's first scientific contribution after his transfer to New York was a brief but very lucid paper *on the green tint produced by mixing blue and yellow powders.*

After a statement of the older theory, based on the Newtonian primary colors, he quotes Helmholtz on the production of white by the mixing of yellow and blue light from the spectrum and gives his explanation of the green of the mixed pigments as due to absorption. This he verifies by observations with the spectroscope upon strips of paper painted with ultramarine, chrome yellow, and a mixture of the two. The color produced by whirling a disk with alternate sectors of the same yellow and green and the appearance of the spectrum of the light reflected from the revolving disk are described. A set of curves gives a semi-quantitative character to the results.

In July of the same year appeared his paper *on the production of thermo-electric currents by percussion.*

The chief interest in this paper lies in the illustration that it affords of the author's characteristics as an experimenter. The problem proposed was of the utmost simplicity; its answer obvious in advance: If a ball be allowed to fall upon a metal plate, the heat of impact will be proportional to the square of its velocity, and consequently to the height from which it falls. If this heat be developed in a thermo-junction, the current produced will afford a measure of the kinetic energy and should also be proportional to the height from which the ball falls. To attain this proportionality experimentally involves the fulfillment of various conditions, and it is the clear insight into these and the very simple and sufficient means by which they are met that show the power and skill of Rood as a physicist and give the paper its value.

There followed in the same year an admirable experimental verification of Fresnel's explanation of the successive changes of color in the image of a source of white light when reflected at grazing incidence from a matte surface. Assuming with Fresnel that the color changes are due to interference, the angle at which the reflected image, after turning from white to red with decreasing incidence, disappears must depend upon the size of the particles of which the surface is made up. Rood measured this angle of disappearance in the case of various surfaces smoked with lampblack and a surface coated with magnesium oxide. He then compared the computed size of the reflecting particles with the size determined by measurement under the microscope and found the theory completely confirmed.

In the following year (August, 1867) appeared the first of Rood's papers read before the National Academy of Sciences. It formed the first part of his well-known memoir *on the nature and duration of the discharge of a Leyden jar connected with an induction coil.* Wheatstone's classical attempt to determine the duration of such discharges by means of a revolving mirror had been published more than thirty years before (1835), and Fedderson's, now equally classical and much more important investigations, which led to the discovery of the oscillatory discharge, had been described in 1858. Rood cleared up the discrepancy between the negative result of Wheatstone, who concluded that the duration of the spark was less than a millionth of a second, and Fedderson's greatly elongated and complex images of sparks as viewed with the revolving mirror, which showed durations of from .00004 to .00007 of a second. At the same time he extended the research, with many ingenious modifications of method, to the case of jars actuated by means of a coil, upon which phase of the subject nothing had been done.

The failure of Wheatstone to obtain the phenomena later described by Fedderson was shown to be due to his method, which really yielded measurements only of what we now call the pilot spark. This portion of the discharge, which Rood terms the *first explosive act*, he studied with great refinement of method and he showed its duration to be certainly less than four-ten-millionths of a second.

This topic was to receive much further attention during the coming years, but in the meantime we find Rood busying himself with refinements and modifications of the Bunsen photometer. The results of these experiments form the subject of his next two papers.

In the summer of 1870 he availed himself of the opportunity offered by a violent thunder-storm to make an impromptu study of the duration of lightning. The hastily improvided apparatus consisted of a paper disk revolved by hand upon a hatpin as an axle. The speed of revolution was estimated at twelve turns per second, and the duration of some of the flashes was found to be about 1/500 of a second. A description of this experiment was communicated to the American Journal of Science in the form of a letter to Dr. Wolcott Gibbs.

Not contented with the experimental demonstration given in his first paper on the Leyden jar, that the duration of the pilot spark was less than four-ten-millionths of a second, Rood continued his attack upon the problem, and in June, 1871, he published measurements reaching down to the incredibly small interval of .000000040 seconds (forty-billionths of a second). The way in which this extraordinary sensitiveness of method was achieved can best be conveyed by a few quotations from the second paper:

"If two black lines of a certain breadth, inclosing between them a white line of equal breadth, be illuminated by the spark, and their images formed on the observing plate by the lens and mirror, the three lines will evidently be seen unaltered in appearance, provided, 1st, that the mirror is stationary or revolving at a sufficiently slow rate; or, 2d, the same effect will be produced with a rapidly revolving mirror and a truly instantaneous spark. If, however, the illumination of the spark last sufficiently long so that * * * superposition has been attained, then, owing to the retention of impressions on the retina, the distinction between the black and white lines will be obliterated and a tint of gray produced. * * * Instead of using only two lines, the same result can far more easily be attained by ruling paper with a large number of fine black lines equidistant and inclosing white spaces of their own breadth, as then the chances for observation are greatly multiplied. * * * With the mirror revolving 340 times a second, using platinum points and a striking distance of two millimeters, the lines were still seen with an eyepiece, as bright and clear as though the mirror had been stationary, implying, as the apparatus was then arranged, a duration for the first act of less than three-ten-millionths of a second, which interval would have been required for destructive superposition. Nothing more could be done with paper, and accordingly I covered a glass glate with lampblack by smoking and poured upon it a few drops of alcohol, which, acting like a slight cement, enabled me to rule lines upon it with a dividing engine. After many trials and microscopic examinations a plate was produced with lines, black and white, of equal breadth, and the spark being discharged behind them, they were brightly illuminated. Their image was thrown upon the observing plate, and by using a sufficient magnifying power and counting, it was ascertained that the breadth of the image of a single line, black or white, was 1/12 of a millimeter. Hence the time required for their obliteration with a velocity of 340 per second was ninety-four-billionths of a second (.000000094); still on experimenting it was evident that the duration of the discharge was less than this quantity, as the lines were always plainly to be seen.

"Before finally abandoning the attempt to determine the actual duration of the discharge, another effort was made; a second lampblack plate was prepared, in which the breadth of the image of a line was 1/24 of a millimeter. * * * Platinum wires 1/86 of an inch in diameter were used with a striking distance of five millimeters; * * * it was proved successively that the duration was less than eighty, sixty-eight, fifty-nine, fifty-five-billionths of a second; and finally the lines, after growing fainter and fainter, entirely disappeared, giving as the result a duration of forty-eight-billionths of a second."

When the striking distance was reduced to one millimeter, the duration was found to be slightly greater than forty-one-billionths, at three millimeters it was between forty-one and forty-eight-billionths, and at ten millimeters' spark length it was between forty-eight and fifty-five-billionths of a second.

In connection with these investigations Rood published a brief note in which he called attention to the fact that these exceedingly minute durations of illumination by means of the electric spark not only sufficed for the mere production of the sensation of light, but likewise for the detection of somewhat intricate detail in the objects illuminated.

He also applied his method to further studies of the character of lightning and elaborated a very ingenious and precise method for the determination of the duration of oscillatory discharges. The apparatus which he devised for this purpose was of admirable simplicity. It consisted of a black disk with one narrow radial sector of white color. Mounted upon the same axle and traveling with it was a smaller disk, with a similar white sector, the position of which could be shifted about the shaft so as to give any desired angular displacement of the two sectors.

When at rest this combination appeared as a circular surface with a radial white line near the periphery and nearer the center a second radial white line with an angular displacement depending on the adjustment of the smaller disk. When in rapid revolution and illuminated by an oscillatory spark, two series of equally spaced white lines were seen, diminishing in intensity according to the factor of damping of the electric circuit. At a certain speed the tail of one of these groups would coincide radially with the head of the other and the velocity of the disk would then afford a measure of the duration of the train of oscillations.

With this device Rood greatly extended his studies of the oscillatory discharge. They brought him indeed to the very threshold of a great domain, but it was not yet thrown open for exploration. Maxwell's great work had not yet been published and the significance of certain fundamental equations in Helmholtz's earlier papers was not yet revealed. The needed theoretical foundation for the developments which were later to be made in this field had not yet been laid.

After the completion of these investigations, which chiefly occupied the period from 1869 to 1873, various minor papers appeared, including among others the following titles: *On secondary spectra* (1873); *On a convenient eyepiece micrometer* (1873); *On an optical method of studying the vibrations of solid bodies,* and *On a property of the retina first noticed by Mr. Tait* (1877).

A paper on the horizontal pendulum, which was printed in 1875, is especially notable. It illustrates the never-failing response of Rood's mind to the novel and ingenious in physics, his admiration for a device or method of surpassing delicacy, and his passion for trying out such things when once suggested.

In this case the extraordinary results obtained by Zöllner with the horizontal pendulum stimulated him to the construction of an instrument based upon the same principle, but of his own design. The purpose seems to have been to see what degree of delicacy could be attained rather than the carrying out of any definite research. The result was an apparatus that surpassed even the more modern interferometer as a means of detecting minute differences of length. The probable error of single readings of the adjusting screw corresponded in some cases to 1/24,950,000 of an inch, or little more than 1/1,000,000 of a millimeter!

At this period Rood's scientific activity was, however, chiefly directed to physiological optics and the theories of color, and he busied himself with the studies which were soon to find masterly expression in the volume entitled *Modern Chromatics.* His article on the constants of color, which appeared in the Popular Science Monthly in 1876 and was reprinted in the Quarterly Journal of Science, has the same admirable simplicity of form and happy lucidity which characterizes his now classical volume on color. In this paper, after describing the three constants, *purity, luminosity,* and *hue,* and methods of determining each, he points out the enormous number (400,000,000) of variations distinguishable by the eye which may be obtained by changing, by barely sensible gradations, the saturation and brightness of all possible combinations of the hues of the spectrum. The substance of this paper was reproduced with little modification in *Modern Chromatics,* of which it forms the third chapter.

Modern Chromatics formed the culmination of Rood's many contributions to the physics of color, although he continued to the end of his life to practice painting, of which art he was a notable amateur. One problem, however, in this domain, that of the photometry of lights differing in color, he continued to ponder and investigate, and it was in this connection that, many years later, he made his greatest discovery.

The year of the issuing of *Modern Chromatics* (1879) was further notable for the publication of an ingenious and suggestive paper entitled *A method of studying the reflection of* *sound waves.* This is one of the least known but at the same time most original and, in view of the possibilities which it affords for a quantitative investigation of the reflecting power of different surfaces, one of the most important of Rood's contributions to science.

The starting point of this research was the study of the familiar device of producing a tremulo effect in reed organs by means of a revolving paddle wheel or fan. The accepted explanation of the action of the attachment was erroneous, and Rood verified his surmise that it was really due to reflection of the sound waves from the surfaces of the revolving blades. He found not only that he could reproduce the tremulo by placing a revolving disk with open sectors behind a reed or other sounding instrument, but that the reflection, which was selective, could be obtained with a disk having alternating sectors of different materials. He was thus able to compare the reflecting powers of different surfaces.

MODERN CHROMATICS.

Rood's delightful volume, which appeared in 1879 under the title *Modern Chromatics,* is a masterpiece. Its lucidity and simplicity of treatment place it in the same rank with Tyndall's classical books on *Sound* and on *Light.* Like these, it is good literature as well as good science, and contains sound physics shorn of all unnecessary technicalities, and stated in terms easily comprehensible by any intelligent reader.

"It has been my endeavor also" (says the author in his preface) "to present in a simple and comprehensive manner the underlying facts upon which the artistic use of color necessarily depends. The possession of these facts will not enable people to become artists; but it may to some extent prevent ordinary persons, critics and even painters, from talking and writing about color in a loose, inaccurate, and not always rational manner. More than this is true; a real knowledge of elementary facts often serves to warn students of the presence of difficulties that are almost insurmountable, or, when they are already in trouble, points out to them its probable nature; in short, a certain amount of rudimentary information tends to save useless labor."

The book is full of telling illustrations gathered by a close observer of mountains, clouds, and sky, of foreground and distance, and of light and shade. The point of view is as often that of the painter as it is that of the physicist. This rare combination gives it a unique interest alike to the artist and the student of science. Speaking of the mixture of colors by the blending which occurs when small objects differing in tint are mingled at too great a distance for the discrimination of details, for example, the following passage occurs:

"Thus the colors of the scant herbage on a hillside often mingle themselves in this way with brown lines of the dried leaves; the reddish or purplish brown of the stems of small bushes unites at a little distance with their shaded green foliage; and in numberless other instances, such as the upper and lower portions of mosses, sunlit and shaded grass-stalks, and the variegated patches of color on rocks and trunks of trees, the same principle can be traced."

There are many such bits which serve a double purpose. They give the physics of effects familiar to the colorist of which he usually lacks the explanation and reveal effects unnoticed by the non-observant layman to whom the physics may be well known.

The point of view of the painter appears indeed in the most unlooked-for places, as in the chapter on the production of color by interference, where the color combinations seen in the observation of certain crystals are described. "They often astonish," we are told, "and dazzle by their audacity and total disregard of all known laws of chromatic composition. * * * They are laid on with such an unfaltering hand that all these wild freaks are performed comparatively with impunity."

The appeal of the author to readers of artistic training was such that *Modern Chromatics* was widely read by the painters of the time, both at home and abroad. This was the more remarkable, since it has always been difficult to persuade those who use color as a medium of expression to master the real physics of their subject.

The invasion of the impressionists occurred a few years later, and members of that school on both sides of the water assumed to find in Rood's treatise the philosophical basis of their method. In one sense they were right, for naturally any effects whatever that can be produced by the use of color must have a physical foundation. What Rood, however, to whom much of the work of this school was abhorrent, thought of being hailed as the *father of impressionism* is told by his son, Mr. Roland Rood,* in an article in *The Scrip.* After pointing out the relations of the work of Constable and Turner to that of the impressionists, he adds:

"While acknowledging, however, their descent from the artists across the Channel, the impressionists count it their chief glory to have founded themselves upon science. They assert that they are the only painters who approach nature without a preconceived idea; that all they carry to it are the formulæ of Helmholtz, Chevreul, and Rood; and that of these it is Professor Rood, who in his work on color (including with his own researches those of Chevreul and Helmholtz) has done most for them. They refer to his work as 'The Impressionist's Bible,' and, as Mr. Van Ingen says in his lecture reported in *The Scrip* for February, they 'carry it under their arm.' The explanations of the oversensitivity of certain nerves of the eye to strong light, causing it to appear yellow; the dullness of certain nerves to weak light, making it bluish or purplish in tone; the principles of successive contrast, and more particularly of simultaneous contrast; the chapters on color constants, on the duration of the impression on the retina, on color mixture, on complementary colors, etc., etc., have been seized upon by these Frenchmen as the true explanations of many of the phenomena which for centuries have been puzzling painters. They look at the book as an endorsement of the new art and a blow at the old.

"That Professor Rood in his *Modern Chromatics* endorses impressionism is an assertion frequently enough made; but what he himself thought about the matter is not so generally known. I once had the opportunity of finding out. I had been abroad studying painting in the Paris art schools, and had also tasted impressionism in Giverny; my head was filled with violent violets and chrome yellows, and the forms of solid bodies seemed a la Giverny, as illusory as dreams. In this state of mind, with his book 'under my arm,' I went to call on my father to tell him that all the excellence of my pictures was due to his recipes. My enthusiasm was instantly cooled, however, when I saw him. He seemed ill and mentally much depressed.

"'Are you ill?' I asked.

"'No,' he replied; 'I am very well, but I have just been to see an exhibition of paintings at the galleries of Durand Ruel,' and he groaned.

"'What are they?'

*Professor Rood's Theories of Color and Impressionism, by Roland Rood, in *The Scrip,* Vol. I, p. 215, April, 1906.

" 'They are by a lot of Frenchmen who call themselves "impressionists;" some are by a fellow called Monet, others by a fellow called Pissarro, and a lot of others.'

" 'What do you think of them?' I ventured.

" 'Awful! Awful!' he gasped.

"Then I told him what these painters said of his theories. This was too much for his composure. He threw up his hands in horror and indignation, and cried:

" 'If that is all I have done for art, I wish I had never written that book!'

"Some years later I had the opportunity thoroughly to discuss the question with him. It was in the country, and together we tried many experiments in landscape painting, always referring to his book for the rules. At times he seemed doubtful if in fact he had not endorsed impressionism; he seemed to feel that possibly while searching for truth in one direction he had also uncovered it elsewhere. Turner he understood and considered logical. The conclusion, however, to which he finally came is summed up in the last statement he made to me regarding the matter:

" 'My son, I always knew that a painter could see anything he wanted to in nature, but I never before knew that he could see anything he chose in a book.' "

LATER PAPERS.

Three chief topics occupied Rood in the period between the publication of *Modern Chromatics* (1879) and his death, in 1902. These, taken in the order in which his papers dealing with them appeared, were: *The production and measurement of very high vacua* (1880-81); *The photometry of lights differing from each other so greatly in color as to be incapable of comparison by the ordinary methods* (1893-99); and *The measurement of the exceeding high electrical resistances of various dielectrics, such as glass, ebonite, quartz, and amber* (1900-02).

In the meantime the problems of color measurement continued to receive attention and in 1892 he published an important paper under the title *On a color system.* In this work, which involved the preparation of hundreds of carefully graded paper disks, the coefficients of reflection and brightness of which were determined, he started with a pair of disks of complementary colors, and by comparing these with other disks differing from them slightly in tint was able to build up a complete system of numerically connected hues until step by step the whole range of colors was included. In the following year he made a valuable contribution to the vexed question of the nature of the X-rays, in which he based his conclusion, that they consist of ether vibrations of short wave-length, upon a series of experiments on the reflection of such waves from a surface of platinum.

The study of high vacua was undoubtedly suggested by the work of Crookes, whose ingenious demonstrations of the varied phenomena of the electric discharge of rarefied gases and whose speculations as to their nature were attracting universal attention. In 1876 Rood published a paper describing experiments upon the Crookes radiometer which confirmed, to his own satisfaction at least, Stoney's theory of the action of that instrument.

Three years later Crookes, with a wealth of ingenious and brilliant experiments on *radiant matter,* revived and greatly extended the almost forgotten work of Hittorf. The phenomena offered a most attractive and promising field for further research, and indeed, as we now know, were the starting point for the most striking and important developments in the history of modern physics. It is noteworthy and characteristic that Rood selected as a subject for study, instead of the phenomena of the electric discharge, the question of the highest possible vacuum, and that by simple but effective modifications of the Sprengel pump he was able to carry the rarefaction of tubes to an unattained point.

Where Crookes had produced and measured vacua of 1/17,000,000 of an atmosphere, Rood reached 1/390,000,000, and did not consider even then that he had reached the utmost limit of experimental possibilities.

Subsequent investigations, it is true, led physicists to doubt the reliability of the indications of the McLeod gauge, which he used in his determinations, and for a time all measurements of very high vacua were questioned, but it is now conceded that with proper precautions approximately correct results are attainable.

By his discovery, which was announced in the first of his three papers dealing with flicker photometry, Rood contributed an entirely novel and very important principle to the science of physiological optics and placed in the hands of the student of illumination a valuable tool. That lights so differing in composition as to produce unlike color impressions upon the retina are incapable of direct photometric comparison had been universally recognized since the enunciation of the scientific basis of the art of photometry by Helmholtz.

Many indirect devices and methods had been proposed to avoid this difficulty and Rood himself had long had the problem in mind. Indeed, he published a paper in 1878 showing that, while a direct balance of values was impossible, one could obtain a fairly reliable estimate of the relative brightness of two surfaces differing in color by making the one certainly brighter and then certainly darker and striking an average. In his return to the attack in 1893 he showed, however, that by taking advantage of a property of the retina entirely unknown to physiologists and physicists the difficulty of comparing unlike illuminations vanished altogether.

When we gaze at a surface that fluctuates not too rapidly in brightness, there is a sense of flickering, and the same is true when two surfaces differing in brightness are alternately presented to our field of view. If now the illumination of the two surfaces be gradually equalized, the flickering will diminish and will disappear at equality. This is obvious when we have similar surfaces as to color illuminated by the same quality of light and it forms a criterion quite independent of brightness that may be used in photometry. Rood showed that the disappearance of flicker occurs in the case of two surfaces unlike in color or illuminated by light differing altogether in composition, and that in these cases also its disappearance was a reliable criterion of equality of brightness. Thus a new and invaluable method in photometry, that has since been extensively employed, was established. The principle of flicker photometry was soon after searchingly and exhaustively tested and verified by Whitman,* whose results have since been abundantly confirmed by many others, and what might well be designated as the *Rood effect* is an accepted fact in physiological optics and an inestimable boon to experimental psychologists, students of color, and photometricians.

The remaining three years of Rood's life were given to investigations in quite a different field. The problem which engaged

*Whitman, F. P.; Physical Review, Vol. III, 1896.

him was that of the measurement of exceedingly high electrical resistances, and with his usual fertility he devised a method which immensely extended the possible range of such determinations. The limit of even approximate estimates had been about 50,000 megohms. Rood's measurements of certain dielectrics ran to 2,000,000,000 megohms.

In this, his last research, a quality reappears which is typical of his genius. To many investigators a method is of interest only as a means to some definite result which they wish to attain. Others there are, and Rood was of this class, to whom a beautiful and ingenious method is in itself worth while. They spend themselves for it at no matter what cost of time and labor, even if they have no immediate and definite use for it. Rood had a passion for the development of delicate experimental methods. He delighted in the *tour de force* required to push the sensibility of an apparatus to its limit or in the invention of some novel device for determining the hitherto unmeasurable. At one time he devised a means for determining details which the microscope failed to reveal; at another he modified and defined Bunsen's photometric device so as to greatly enhance its sensitiveness. Where Wheatstone measured intervals of time not greater than a millionth of a second, he carried the determination down to times as much smaller relatively as a quarter of a minute is smaller than an hour. With his horizontal pendulum he could measure mechanically distances equivalent to ten Angström units, or a five hundredth of a wave-length of green light. His modification of the Sprengel pump further reduced the gas in the ordinary Crookes vacuum as a common air pump with valves would take out the air from a receiver at atmospheric pressure and to about the same extent. Finally, in the last of the three papers on high resistances, published but a few months before his death, he describes measurements, by a unique method of his own, of resistances so great that it is difficult to find a concrete expression for them. In the finest copper wire (No. 40) such a resistance would have a length sufficient to make a coil of one thousand turns with a diameter equal to that of the orbit of the earth. These things and others like them he did for the joy of doing them; and it is supreme achievement attained in this spirit that marks one of the highest types of the man of science.

Rood died on the twelfth of November, 1902, after having served on the faculty of Columbia University for thirty-eight years. During this long period he had the satisfaction of seeing his department grow from the meager beginnings in which he found it to an institution of the first rank, handsomely housed, richly endowed, and adequately equipped.

In his early days the emptiness of his environment at Troy did not prevent him from becoming an investigator. Later the far more dangerous environment of New York failed to corrupt him. In it he lived his own life, untouched by the commercial spirit that has wrecked so many promising careers in science, and died as he had lived, devoted to science and to art, a lover of the country and of children, a loyal friend, a simple-hearted man of genius.

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