NATIONAL ACADEMY OF SCIENCES

ERNEST FOX NICHOLS

1869—1924

A Biographical Memoir by

E. L. NICHOLS

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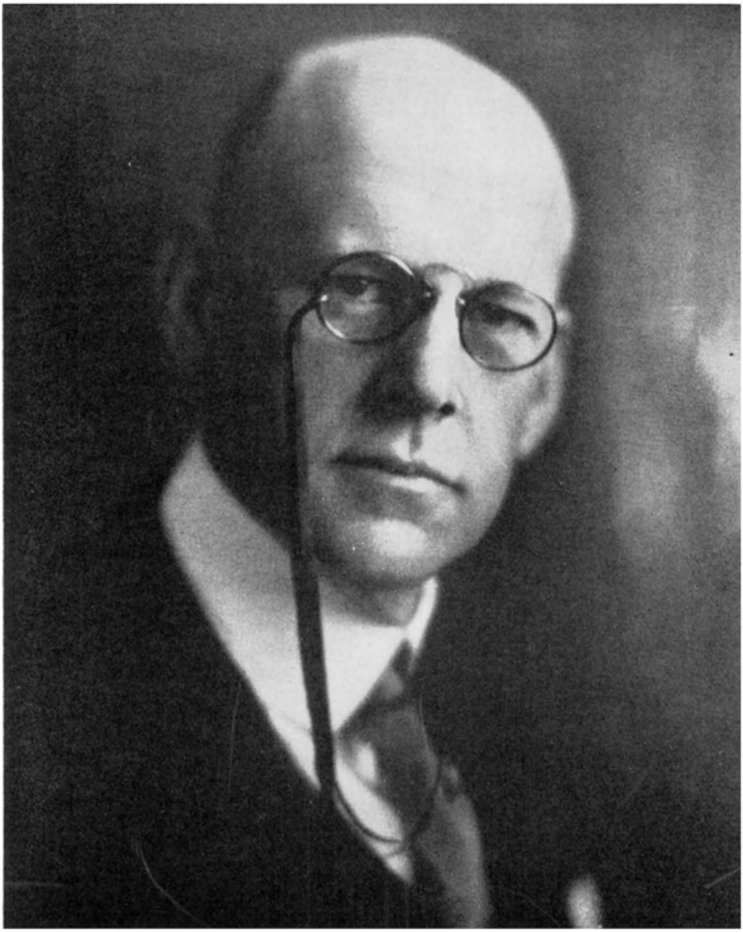

ERNEST FOX NICHOLS

BY E. L. NICHOLS

One winter evening in the year 1885 the present writer lectured at the Kansas Agricultural College. It was an illustrated talk on experimental physics to students who thronged the college chapel. Some three years later, when that event had passed into the realm of things half forgotten, two young men appeared at the physical laboratory of Cornell University. They explained that they had been in the audience at Manhattan on the occasion just mentioned and had been so strongly interested that they had decided then and there to devote themselves to the study of physics. Now, having finished their undergraduate course they had come east to enter our graduate school. One of these two Kansas boys, both of whom were then quite unknown to the writer, was Ernest Fox Nichols.

Nichols was born in Leavenworth, Kansas, on June 1, 1869. He was soon left parentless, a lonely boy but with means to help him obtain an education, and went to live with an uncle and aunt, Mr. and Mrs. Fox, of Manhattan, in that State. He was tall, fair, clear-eyed, of open countenance and winning smile, and there was that about him which once seen was never forgotten. Citizens of Ithaca who met him casually while he was a student more than thirty-five years ago, still remember him with fondness as one recalls some very special friend.

The scientific activities of Ernest Fox Nichols fall into several well-marked periods separated by intervals of more or less complete inactivity so far as published research was concerned. These gaps, some of which were of considerable duration, were by no means times of idleness. It was rather that other duties and interests, always more or less urgent, then became dominant. Each period of activity had a new theme, a *Leitmotif,* and in this way, rather than by the intervening breaks, they are to be distinguished.

The Cornell Period (1888-92)

This period was devoted chiefly to training and to gaining an acquaintance with the great scientific domain of radiation in which his lifework was to lie. The experimental investigations undertaken at this time were suggested primarily for the purpose of giving practical experience in the technique of research. While they did not have the fundamental importance of some that were to follow they afforded results of more than passing interest.

The first of these researches was a study of the absorption of infra red radiation in various optical media. The instruments were a spectrometer, with a linear thermopile in the eyepiece, and a galvanometer. To make measurements even in the more intense regions of the infra red spectrum with a thermopile implied a galvanometer of high sensitiveness and the one constructed by Nichols for these experiments had a needle and mirror weighing only 48 m. g. It was one of the most sensitive instruments of its kind that has ever been constructed.

Several very interesting facts, at that time not known, were established by these experiments. Among them were the nonselectivity of lampblack in this portion of the spectrum (out to $3.\mu$); the abruptness of the change from opacity to diathermancy of hard rubber at the edge of the visible spectrum; the increase of transmission by quartz with increasing wave length, and the fact not then generally recognized that alums in solution have no effect on the diathermancy of the water in which they are dissolved. Similarly it was shown that the solution of various substances in alcohol did not modify the transmitting power of that solvent for the rays of those portions of the infra red spectrum covered by the investigation. This research appeared in the first volume of the then newly established *Physical Review* under the title *"Transmission Spectra in the Infra Red."* It was immediately followed by a similar study of the ultra violet spectrum which was published in the second volume of the *Review*.

The mastery of a weak-field galvanometer of high sensibility was a discipline of which the younger generation of investigators in physics have been deprived since that type of instrument has fallen into disuse. In the daytime artificial disturbances of the earth's magnetic field made measurements well nigh impossible and when observations were to be made at night auroral disturbances would frequently drive the spot of light furiously back and forth across the scale. Indeed the faintest gleam of northern lights was a signal for postponement.

From such experiences Nichols was led to consider the possibility of a new instrument for the study of radiation; a consideration which later was to result in the development of the special tool (the famous Nichols radiometer) which he was to use in the solution of all his problems and which will ever be associated with his name.

The Berlin Period (1894-96)

In 1892 Nichols went to Colgate University as Professor of Physics, an event that was to have a profound influence upon the remainder of his life, for there he met and (in 1894) married Miss Katherine West, a daughter of one of the foremost citizens of Hamilton. In the latter year he received leave of absence and went to Berlin with his young wife for further study.

The New Radiometer

The conditions for the study of radiation were altogether favorable in Berlin and Nichols was soon on the road to the realization of his concept, often mentioned during the Ithaca days, of a glorified and refined radiometer based upon the interesting but by no means sensitive device of Crookes. This task was brought to an eminently successful conclusion with the aid of some friendly suggestions from E. Pringsheim, who had already made some studies of the Crookes instrument.[1]

The results are described in the classical paper entitled "*A Method for Energy Measurements in the Infra Red Spectrum and the Properties of the Ordinary Ray in Quartz for Waves of Great Wave length.*"[2]

The radiometer developed in the course of these experiments

[1] Pringsheim: Wiedemann's Annalen 18, p. 32 (1883)
[2] Nichols; Physical Review (1), IV, 297 (1897).

took a form from which subsequent models varied only in so far as it was found desirable to adapt the vanes to each particular case. For work in the spectrum the vanes were long and narrow. When a star image was to be measured they became disks.

In general the conditions to be fulfilled were:

(1) Lightness of the moving parts—in the Berlin instrument the mass was reduced to seven milligrams.

(2) Reduction of the torsional moment—the arm was only two millimeters in length.

(3) Use of an exceedingly light suspension fibre of fused quartz.

(4) Determination of the gas pressure (.05 *mm.*) at which the sensitiveness was a maximum.

(5) Adjustment of the vanes to the most effective distance (2.5 *mm.*) from the mica window behind which they were suspended.

Under the above conditions the radiometer gave indications equivalent to a deflection of 2,100 scale divisions when exposed to a candle at a distance of one meter.

The first investigation of importance in which the new instrument was used was an exploration of the optical properties of quartz for the longer waves of the infra red. To determine the reflecting power, that of silver was first determined as far as 9.μ, at which wave length the fluorite prism of the spectrometer became opaque. Previous measurements by Rubens had extended only to 3.μ. Shortly beyond the latter wave length silver was found to be an almost perfect reflector, the values all ranging between 99% and 100%.

The reflection from the polished face of a prism of quartz, cut perpendicular to the optic axis, was then directly compared with that from the silver mirror and the transmission measured through a plate of quartz 18μ in thickness.

Thus were discovered the minimum of reflection (0.29%) at wave length 7.μ followed by the sudden transition to metallic reflection (74%) indicative of the presence of the great absorption bands between 8.μ and 9.μ. The same set of measurements served to disclose the hitherto unsuspected anomaly in the index refraction of quartz which had misled earlier observers as to wave lengths in these regions of the infra red spectrum.

The Residual Rays

An immediate and very important result of these experiments which were described before the Berlin Academy of Science in 1896[3] was the collaboration of Rubens and Nichols and the consequent development of the now classical method of residual rays for the exploration of the still unknown regions of the extreme infra red.

Given the existence in an optical medium of restricted regions of high reflecting power, such as had been shown to exist in the case of quartz, it became obvious that by several successive reflections from the surface of such a medium radiation could readily be obtained which would be approximately monochromatic; all other wave lengths than the one strongly reflected having disappeared by transmission through the substance. Furthermore, the location of these regions of approach to metallic reflection could be approximately estimated from the constants of the Helmholtz-Kettler formula for media the dispersion constants of which had been determined.

By three successive reflections from quartz of the radiation from a zircon disk it was found possible to isolate a bundle of rays corresponding to the band in the absorption spectrum of quartz which had been found in the course of the experiments which Nichols had just completed. To determine the wave lengths, since all material for prisms were under suspicion in these unexplored regions, recourse was had to a diffraction grating made of fine wires of gold strung side by side. This had the advantage over all ordinary gratings that the rays suffered neither reflection nor transmission by a medium other than the air. The third order spectra were readily found and the location was such as to corroborate the previous measurements. The agreement with the wave length predicted by means of the Helmholtz-Kettler formula was also as close as could be expected.

[3] Nichols: Berliner Berichte, Nov. 5, 1896; also Physical Review (1), IV, 297, 1897.

Earlier determinations by Paschen of the optical constants of fluorite afforded data by means of which it could be computed that residual rays obtained by reflection from that substance would have a wave length of about 30μ. The difficulty of confirming this prediction was really very serious. Only about one thousandth part of the initial energy remained after three reflections and to locate the diffraction spectra was a matter of the greatest delicacy.

The necessity of sending the radiation to be measured through a window into the vacuum chamber had seemed to invalidate the radiometer, since the best known transmitter of these infra red rays was fluorite itself which would be opaque to its own residual rays. A bolometer was therefore used with an armored galvanometer of high sensibility. The indications were barely perceptible, but a careful set of readings gave positive evidence of residual rays of the predicted wave length.

Here then was a promising method for the study of radiation in still more remote regions of the infra red. The previous limit of definite knowledge had been at about 9.μ. There was, however, indirect evidence of the existence of much longer waves obtained by comparing the absorption by various substances of the radiation from sources of high temperature and of low temperature.

Rubens and Nichols proceeded at once to test a variety of optical media, but in addition to the residual rays from quartz and fluorite they succeeded in finding only those of rock salt and of mica, which latter substance showed two bands due to silica.

Rock salt was exceedingly difficult to work with. To increase the sensitiveness of the method beyond that attainable with the bolometer recourse was had once more to the radiometer, a change made possible by the discovery that silver chloride transmits these longest waves and that a thin plate of this material could be used instead of fluorite for a radiometer window. Five reflections were needed to separate out the residual rays and these were so feeble that their wave length could not be determined with certainty by means of the diffraction grating. It was shown, however, by a study of the refractive index that the residual rays from rock salt undoubtedly had a wave length of approximately 50μ. (Direct measurements in 1908 by Nichols and Day gave 52.3μ).[4] This was a very great extension, indeed, of the spectrum towards the longer wave lengths and a notable step beyond what Paschen and other workers in this field had thus far been able to reach.

A wave length of 50μ is one hundred times that of the green light in the middle of the spectrum. It is a distance, moreover, which lies within the realm of things directly appreciable by the unaided senses: a twentieth of a millimeter—the thickness of a sheet of paper!

In their relation to waves of these great lengths optical media might be expected to have properties quite different from those observed in the case of light waves and in the course of these researches it was noted that the metals increased in reflecting power and reached the limiting value of 100% for the residual rays of fluorite (23.7μ); also that lampblack was nearly transparent, whereas of substances transparent to the visible spectrum only three (silver chloride, sylvine and rock salt) transmitted a measurable amount of the residual rays of fluorite through a layer one millimeter in thickness.

Heat Waves and Electro-Magnetic Resonance

Having advanced the boundary of the infra red spectrum so far into the territory of electric waves the temptation to seek an electro-magnetic reaction to the residual rays was irresistible. Much time was therefore spent in the ruling of cross-hatched gratings on silvered glass, the purpose being to produce a system of resonators which might be expected to respond to rays of the wave length in question.

Righi, working with short electric waves, had obtained a maximum resonance with resonators corresponding to even multiples of quarter wave length. In making the minute rectangles of silver, therefore, the spacing of the cross-rulings was adjusted so as to give odd and even multiples of the quarter waves, respectively, on the gratings with which experiments were to be made.

[4] Nichols and Day; Physical Review (1), XXVII, p. 225.

Upon measuring the intensity of a polarized beam of the residual rays after reflection from these grids, the reflection was actually found to depend so definitely upon their dimensions, in agreement with the electro-magnetic theory of light, as to leave no doubt that the desired effect, i. e., the production of electric resonance through the action of the infra red radiation, had been successfully obtained. The authors expressed their obligation to Mr. Augustus Trowbridge, who assisted in the very difficult task of ruling the gratings.

This is a most significant experiment, second only to the demonstration of the *existence* of electric waves by Hertz. In all previous studies the attempt had been to build up a complete and convincing *parallel* between electric waves and heat waves, from which the identity of the two was to be inferred. Here, for the first time, that identity was established in a more direct and therefore a more impressive way—*by the successful substitution of heat waves for electric waves in the production of electro-magnetic effects.*

These observations did not "bridge the gap between electric waves and the infra red" in the sense of the production of electric waves shorter than the longest heat waves—or vice versa. (This was a problem to which Nichols returned many years later and which he solved.) They did, however, close the gap in another and even more important sense.

After two fruitful years in Germany Nichols returned to Colgate with his wife and a daughter born in Berlin, and resumed the teaching of physics. The results of the researches on the infra red were put into English, for publication in the *Physical Review,* and work required for the degree of D. Sc. at Cornell was completed. The examinations for the doctorate and the conferring of the degree occurred in 1897. In the meantime the radiometer, which had been found superior in delicacy to the bolometer, was being made ready for new and more trying experiments.

The Dartmouth Period (1898-1903)

Five happy and productive years in the life of E. F. Nichols began in 1898. In that year he was called from Colgate to the

Professorship in Physics at Dartmouth College and the same year saw the commencement of a particularly striking and successful investigation.

Heat from the Fixed Stars

This notable research was carried on in the heliostat room of the Yerkes Observatory, the use of which had been granted for this purpose by the director.

For these experiments the Nichols radiometer was given a slightly modified form. The vanes were circular and of a size to approximate as closely as practicable the star images of a reflecting telescope of 61 *c.m.* aperture and 233 *c.m.* focal length, the mirror of which had been figured and silvered by Ritchey especially for this work.

Thirteen years earlier C. V. Boys had exposed his radiomicrometer to radiation from the stars and so great was its delicacy that for the first time in the history of such endeavor there seemed to be a reasonable prospect of success. When the coil of the radiomicrometer was suspended in the focus of a sixteen-inch mirror a candle at a distance of 250 yards gave a deflection of 38 *m.m.* But for atmospheric absorption a considerable movement of the finely suspended thermo-element might therefore have been expected at a quarter of a mile, or possibly a discernible deflection from a candle a mile way! That no effect could be detected from any of the planets or fixed stars indicated quite clearly what the minimum sensibility of an instrument must be to give an unquestionable result. On the other hand, a doubtful motion observed when the image of Venus was thrown upon the thermo-junction of the radio-micrometer appeared to show that Boys had probably failed by a very narrow margin.

The various conditions upon which the sensitiveness of the radiometer is known to depend were therefore given especial consideration and, in spite of numerous troublesome disturbances greater than the effect itself, the first series of observations, made on August third, 1898, gave an unquestionable and positive result. In fact, it was found possible to estimate with reasonable accuracy the ratio of the brightness of Arcturus to that of Vega.

The following record of readings made on five nights will give an idea of the smallness of the quantities to be compared; the deflections caused by the heat received by Arcturus being of the order of one millimeter, those from Vega of half a millimeter.

Arcturus and Vega Compared

Date	Deflections		Ratio
August	Vega	Arcturus	Arcturus/Vega
4	0.31 m.m.	0.65 m.m.	2.1
8	0.64 "	1.30 "	2.0
9	0.33 "	0.98 "	3.0
11	0.60 "	1.36 "	2.3
13	0.68 "	0.68 "	1.0

The sensitiveness of the apparatus was such that a deflection of one millimeter represented about *one forty-nine millionth part* of the heat received from a candle at a meter's distance.

The situation of the Yerkes Observatory is particularly favorable for the determination of the effects of atmospheric absorption since the open and nearly level country stretches out to westward for many miles. For the estimation of this correction tents were erected at distances of 2,000 and 4,500 feet, respectively, and within these were candles which could be exposed or obscured in response to signals from the heliostat room of the observatory. Mr. C. E. St. John and Mr. A. L. Colton acted as assistants.

It was found that the intervening air would transmit 52.3% of the energy from a candle at a distance of 762.4 meters and from such measurements the absorbing effect of the atmosphere between a star and an observer at the surface of the earth could be computed. From these calibrations it was also found that the Nichols radiometer was twenty-six times as sensitive as the radiomicrometer used by Boys. By so narrow a margin was success separated from failure!

In August, 1900, observations were resumed. A cœlostat which had been constructed in May of that year for eclipse work now became available and with an increased sensitiveness of nearly fifty per cent measurements were made on Jupiter, Arcturus and Saturn. The final corrected values for relative intensities were as follows:

Vega	Arcturus	Jupiter	Saturn
0.51	1.14	2.38	0.37

The distinction between such comparisons as the above of the energy received from various stars and the indications obtained, for example by means of a photo-electric cell, is an important one. The photo-electric cell, first applied to stellar observations by Minchin in 1895, gives no direct measurement of the total heat output of a star; being even more highly selective than the retina or the photographic plate. It is photometric rather than radiometric and has therefore an entirely different function from any of the heat measuring devices. It has important applications in astronomy, but could not be used in estimating the climate of Mars or the moon, as has recently been done by Coblentz by a purely radiometric procedure.

Light-Pressure

This by-product of the electromagnetic theory was still in the class of effects mathematically established but not experimentally verified, twenty-five years after its statement by Maxwell in 1873. Nichols seems to have had it in mind, as a thing to be tried with his new radiometer, even in his Berlin days. It was then a subject of lively discussion among the younger men in the laboratory, with the general opinion rather against the practicability of an experimental demonstration unless, indeed, some superphysicist—a Paschen or a Lebedew—should make the trial. Now, at Dartmouth with the able and enthusiastic collaboration of Professor G. F. Hull the time was ripe for such an attempt.

The conditions to be met in the proposed experiments were, however, in some respects diametrically opposed to those of the radiometric process as applied to the determination of the energy of a beam of light.

In the measurement of heat, radiation reflected from the vane of the balance is lost—complete absorption is to be desired. In the measurement of light pressure radiation absorbed is only half as effective as radiation reflected. Perfect reflection is therefore the ideal condition.

In the measurement of heat, again, advantage is taken of the convection currents in the gas set up by the warmed surface of the vanes. This effect is a maximum for a certain pressure in the vacuum chamber within which the vanes hang and the best result is obtained when a certain very small distance is maintained between the vanes and window. In the measurement of light-pressure, adjustments were made with a view to reducing this so-called gas-action to a minimum and since gas-action is cumulative, whereas the response to light-pressure is immediate, a short period of vibration was evidently desirable. It was further decided that a ballistic throw should be used instead of a steady deflection.

To meet these new conditions a torsion balance with much larger vanes (12.5 *m.m.* in diameter) than those of the earlier forms of the radiometer was constructed. A considerable mass was added to the suspended system, with a magnetic needle and controlling magnet to secure a short and adjustable period of oscillation.

The vanes of microscope cover glass were silvered on one side, instead of being coated with an absorbing layer of oxide. By study of the variations in gas-action with the state of the vacuum a critical pressure (16 *m.m.* Hg.) was found at which the convection currents were scarcely appreciable. At this pressure the measurements were made.

It was the aim of this investigation to measure as accurately as possible the light-pressure resulting from exposure of the vane of the radiometer to a beam of known intensity for a given time and to compare the quantity thus obtained with that computed from the equations of Maxwell.

This comparison involved a knowledge of the moment of torsion of the radiometer which was determined by the method of vibrations. The time of exposure selected was six seconds, which was approximately a quarter of a period of the suspended system.

The intensity of the incident beam was measured, in the preliminary experiments, by means of an especially designed bolometer, but this was afterwards supplanted by a calorimetric device which was much more satisfactory. When the calorimeter was used the agreement between practice and theory was well within the experimental error.

Not only was the existence of light-pressure substantiated by this research, but the result of the Maxwellian analysis, *i. e.*, that the light-pressure is numerically equal to the energy contained in unit volume of the beam producing it, was quantitatively verified. A careful determination of the sources of error showed that the discrepancy between the observed and the computed effect was well within the probable error and that the latter was less than one per cent. It was further shown that in agreement with theory the effect is independent of the wave length of the pressure-producing ray.

A Question of Priority

The first announcement of the successful measurement of light-pressure by Nichols and Hull was made at the Denver meeting of the American Association for the Advancement of Science on the 29th of August, 1901. An abstract was printed in *Science* in October of that year and the full preliminary paper in the *Physical Review* for November. The *Astrophysical Journal* for January, 1902, also contained an abstract of the Denver paper and in the same number appeared an abstract of a paper by Lebedew of Moscow from the *Annalen der Physik* (VI, p. 433; Nov., 1901).

By a coincidence, then, the first complete reports of these two researches appeared simultaneously, *i. e.*, in the November numbers of the *Annalen* and of the *Review*. The two pieces of work were clearly wholly independent. Nichols and Hull, as stated above, had read a paper giving specific data in August and so it appeared for the moment that priority of publication, an unimportant distinction in such a case as this, should go to them.

In fact, however, Lebedew, quite without the knowledge of the American investigators, had made a report of progress at the International Congress of Physics which met in Paris in the summer of 1900. In this he reported that his experiments up to that time had been such as to indicate the existence of an effect equal to the values computed by Maxwell and by Bartoli. No specific numerical data were given at that time. Priority in the announcement of the *general character* of the results obtained should therefore undoubtedly be accorded to Lebedew. Nichols and Hull in experiments subsequent to the publication of their paper of November, 1901, obtained experimentally the theoretical value of light pressure with an accuracy far exceeding that of Lebedew's measurements, *i. e.,* within a fraction of one per cent.[5] Lebedew's probable error would seem to have been of the order of twenty per cent.

Comets' Tails

The establishment of light pressure upon a firm experimental basis led inevitably to a revival of interest in the application of that effect to cometary theory. Arrhenius in his then recent volume on Cosmic Physics and Lebedew in a paper published in 1902 had shown that for otherwise similar spheres the ratio of radiation pressure to gravitation is inversely as the density.

In a paper in the *Astrophysical Journal* of June, 1903 (XVII, p. 352; June, 1903), Nichols and Hull considered at some length the phenomena occurring in comets on their approach to the sun. After pointing out the doubtless very complicated conditions existing in the heads and nuclei of comets they estimated that the ratio of radiation pressure to gravitation may reasonably be supposed to reach the value of 20 : 1, whereas the ratio necessary to the production of comets' tails may be taken as about 18 : 1. The production of triple tails could be explained, as they pointed out, by supposing a sifting or sorting of the fine material to take place within the comet. Radiation pressure, then, is a sufficient explanation of the behavior of comets, but there is every reason to suppose this action to be accompanied by various other effects. Small bodies

[5] Nichols and Hull; Physical Review (1), XVII, p. 26 and 91; also Astrophysical Journal, XVII, p. 315, and Proc. Am. Acad. Arts and Sciences for 1903.

when warmed on one side, for example, are strongly repelled by a sort of gas action, while a porous substance may be driven over various complicated courses by the back thrust of out-rushing particles.

To show the deflection of a stream of particles by lateral illumination, mixtures of a very light lycopodium powder and powdered emery were poured through a contraction in a glass vacuum tube, very much as in an ordinary hourglass. When a beam of light was focussed upon the stream a strong deflection of the lighter particles occurred, while the denser bits of emery passed down through the tube essentially unaffected.

As an ocular demonstration this experiment was striking, but in spite of extraordinary precautions to maintain a high vacuum the out-rush of gases from the heated surfaces of these light particles, on the sides exposed to radiation furnished a driving force several times greater than that due to light pressure itself and in the same direction.

To what extent this gas effect which Nichols and Hull picturesquely designated as "rocket action" is actually added to the light pressure in the driving away from the sun of the materials composing comets' tails is, of course, not readily to be estimated.

At Columbia (1903-1909)

After five years at Dartmouth, Nichols accepted a call to a professorship in Columbia University, which position he held until 1909. The winter of 1904-5 was spent, on leave, at the University of Cambridge, concerning which delightful sojourn Sir Joseph Larmor writes:

"I have vivid recollection of his arrival here now long ago, I think simultaneously with H. A. Bumstead, now also gone. They had the advantage of being accompanied by their families then in tender years. Although they belonged primarily to the Cavendish Laboratory and so were rather outside my own sphere, they fitted into all sides of Cambridge life at once, created the impression that they belonged to it essentially, though at the same time bringing the experience and attitude of a larger world. Especially Nichols brought with him an established reputation in physical experiment from both America and Berlin: and his efficiency and helpfulness were aided by a modesty which was, as often, a main source of influence and authority. These pioneers were followed soon by Hull and Zeleny and many others, and the stream has not ceased. Wherever their careers took them in after life we felt that there Cambridge had a footing and that a plane of intimacy and mutual appreciation would persist."

In New York after a considerable period of readjustment to the conditions, never particularly favorable to scientific endeavor, of the city, a new attack was made upon the problem of residual rays. In Berlin the question as to the existence of the absorption bands upon which such rays depend had been left unanswered save in the case of fluorite and rock salt, and the wave length of the rays in the case of the latter substance was but roughly estimated. It was now found possible to determine the position (at 52.3μ) for rock salt with precision and to add to the list of the substances investigated ammonium chloride (51.4μ), barium carbonate (46.0μ), and strontium carbonate (43.2μ).

This addition to our knowledge was made by the use of a group of Nernst filaments as a source of light, by such refinements in the construction of the radiometer as were suggested by the previous extended experience with that instrument and particularly by the careful removal and exclusion of water vapor from the atmosphere through which the rays passed on their way from the source to the vanes of the radiometer. Aside from the isolation and determination of the wave length of these new residual rays the research brought out a relation between the wave length and the atomic weight of the bases in the salts used as reflectors, *i. e.*, that the wave length of the residual rays increases with atomic weight of the base. Dr. W. S. Day was the co-worker in these experiments.

Absence of Long Waves in the Solar Spectrum

To this period likewise belongs the very ingenious and beautiful demonstration of the complete absence in sunlight, even at the height of the Mt. Wilson Observatory, of waves of the order of 51μ. In the summer of 1906 Nichols set up on Mt. Wilson a series of five reflecting surfaces of rock salt, and showed that a beam of sunlight after successive reflection from these produced not the slightest effect upon the vane of the radiometer. All wave lengths outside the absorption band would disappear, since the reflecting power of rock salt is about three per cent and $.03^5 = .000,000,024,3$; whereas, within the band the reflection is ninety-seven per cent, and the intensity after five reflections would be $.97^5 = .858$. So complete is obviously the separation of the residual rays from the entire remainder of the spectrum in an extreme case like this that the demonstration is conclusive.

The Presidency of Dartmouth College

In 1909 the presidency of Dartmouth College fell vacant and Nichols was sought to fill the post. That he was considered after being absent from Hanover for six years, during which time he had not concerned himself in any direct way with the affairs of the college nor shown an interest by speech or written word in pedagogy, bears witness to the profound impression upon the college community at Hanover which he had made as a man of character and ability. The same qualities which throughout his life drew others strongly to him were doubtless decisive in this instance.

That he accepted the call, although he knew that his action involved the relinquishment of research for many years to come, must be interpreted to mean that in him after all the man of science was not paramount; that the call to human service, at whatever sacrifice, would not be denied. Not all of his friends were willing to accede without question the wisdom of his decision nor the necessity for the sacrifice. One speaker at the supper held the day of his inauguration was bold enough to voice this dissent; essentially in these words:

"Men of Dartmouth: You have chosen a man to be your head who is undoubtedly capable of the highest type of service possible to a college president, but do you realize the price? You have called from his laboratory a man whose labors in the domain of Physics are immortal and through whom during his stay with you lustre and glory shone upon these college walls.

"There may be, there doubtless are, a thousand men qualified to do thoroughly well what a college president has to do. Where will you find another to measure the pressure of light or determine the heat from the fixed stars? These are prob-

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lems that had baffled all who came before, and he had solved them. Do you realize, moreover, that upon such work as that and upon it only, the lasting and true fame of an institution of learning rests?

"If by some cataclysm Dartmouth College, proud as it stands today, and justly proud, were to be swept from the face of the earth, it would be utterly forgotten in a single century; save that it might be recalled that here in the opening years of the twentieth century Nichols and Hull carried on their imperishable researches. But you have called and he has come to you and laid aside his work, which none but he could do, to be the servant of Dartmouth for years to come. May you realize what a sacrifice has been made in your behalf and give to him sympathy and loyalty and support unstinted!"

And so for seven years Ernest Fox Nichols went up and down the land, as college presidents must, talking to Dartmouth alumni and friends, pleading for loyalty and fanning the flames of love for Alma Mater. And Dartmouth flourished and waxed greater. It was an important position, worthily filled, but the work had to be done, as is ever the case, at the cost of a total abeyance of all scientific productiveness. At last in 1916 it became possible to lay down this burden and to become again a simple man of science, to which good end Yale opened her hospitable doors and offered him a professorship in physics.

When America entered the World War the call for service was, of course, imperative and not to be denied. Many months were given to the investigation of the numerous schemes proposed to the government for protection against the menace of the submarine; countless conferences and consultations were held under a pressure that was inexorable. Everything—whether scientific, social or personal—had to give way to the great questions of national defense. Thus the seven years given over to the work of the Dartmouth presidency were stretched into ten before it became possible to get into harness again for research.

In 1920 came an offer of the directorship of the work in pure science at the Nela Park Laboratory in Cleveland, an opening which seemed more favorable to uninterrupted scientific activity than the professorship at Yale; and this was followed a few months later by an unlooked for call from the Massachusetts Institute of Technology.

The death of President McLaurin had left that institution without an executive head, and its friends discerned in Nichols the man preeminently fitted to deal with its problems; in particular with that of the proper relation of applied to pure science in the education of the engineer. The idealism that characterized his inaugural address, in which the human aspects of engineering were especially emphasized, attracted much favorable comment; but all hopes of his taking an active part in the realization of the vision unfolded on that occasion were thwarted by a most serious illness with which he was stricken almost immediately and which compelled many months of complete rest and relaxation. All thoughts of further administrative work were definitely abandoned and upon his resumption of a relatively active life it was to Cleveland and the scientific work of the laboratory and not to Boston that he turned.

His letter of resignation addressed to the trustees of the Institute of Technology expresses in so fine a form the noble spirit of the man that although it has already appeared in an article by his cousin, Professor Philip Fox,[6] it is reproduced below.

"A sufficient time has now elapsed since the onset of a severe illness, which followed immediately upon my inauguration, to enable my physicians to estimate consequences. They assure me certain physical limitations, some of them probably permanent, have resulted. These, they agree, make it decidedly inadvisable for the Institute or for me that I should attempt to discharge the manifold duties of president. Indeed, they hold it would be especially unwise for me to assume the grave responsibilities, to attempt to withstand the inevitable stresses and strains of office, or to take on that share in the open discussion of matters of public interest and concern inseparable from the broader activities of educational leadership.

"As my recuperation is still in progress I have contended earnestly with my doctors for a lighter judgment. I feel more than willing to take a personal risk, but they know better than I, and they stand firm in their conclusions.

"The success of the Institute is of such profound importance to our national welfare, to the advancement of science and the useful arts, that no insufficient or inadequate leadership is sufferable. Personal hopes and wishes must stand aside.

[6]Astrophysical Journal, LXI, p. 1, 1925.

"It is therefore with deep personal regret, but with the conviction that it is best for all concerned, that I tender you my resignation of the presidency of the Institute and urge you to accept it without hesitation.

"To you who have shown me such staunch and generous friendship it is pleasant to add that in the judgment of my physicians the physical disqualifications for the exigencies of educational administration are such as need not restrict my activities in the simpler, untroubled, methodical life of scientific investigation to which I was bred. It is to the research laboratory, therefore, that I ask your leave to return."

In his subsequent and what were to be his last researches, Nichols now reverted to his favorite problem of earlier years, *i. e.*, to the bridging of the gap between electro-magnetic waves and the infra red. With the collaboration of Dr. J. D. Tear two papers were published. In the first of these the boundary of the electric spectrum toward the infra red was advanced very materially by the production of Hertzian waves, which were much shorter than any previously known.

This result could be attained only by the construction of a Hertzian oscillator capable of setting up such waves and of a receiver adapted to them. The oscillator had an adjustable spark gap in kerosene oil between minute tungsten cylinders. The spark length was of the order of .01 *m.m.* The receiver was a sort of super-radiometer, the vanes of which were of tungsten or in some of the experiments of very thin mica bearing a light film of platinum. The weight of the suspended parts was reduced to about half a milligram.

This type of instrument was a result of ideas developed by Nichols nearly twenty years earlier and discussed by him in a paper before the International Electrical Congress in St. Louis in 1904. The radiometer vanes bore resonators consisting of suitable lengths of platinum wire, 1μ in diameter, mounted in front of mica shields, or of resonating rectangles of platinum film deposited on thin mica. These excessively minute elements of the receiver absorbed waves to which they were in resonance and becoming heated gave a deflecting moment to the suspended system of which they formed a part. The deflection was proportional to the incident energy. Such a radiometer, in which the heating effect is due to resonance is selective and reacts only to waves with which it is in tune.

The gap in the spectrum at the time these measurements were begun was from 0.4 *m.m.* (the longest heat wave recorded by Rubens and von Bayer in 1915) to 7.0 *m.m.*, the shortest electric wave (Mobius, 1920).

Ignoring the overtone of wave length 0.8 *m.m.* the boundary was thus extended by over two octaves at the time of the completion of the paper described above. In reality, since there is no good reason for rejecting the overtone the extension towards the red was more than three octaves.

A few months later, in time for the spring meeting of the National Academy in 1924, the authors were in position to announce the complete filling of the gap.[7]

Using an oscillating doublet in which the tungsten cylinders were only a tenth of a millimeter long and a tenth of a millimeter in diameter, fundamental waves of .9 *m.m.* were obtained. Adjustment of the conditions of vibration made it possible to suppress the fundamental and enhance a chosen overtone. In this way electric waves *down to .22 m.m.* were produced.

It only remained to establish, independently of other observers, an overlapping boundary of the infra red spectrum to which end advantage was taken of the existence, already known, of very long waves in the radiation from the mercury arc. Filtration through eight millimeters of fused quartz and from sheets of black paper removed the shorter rays from this source and a beam was thus isolated in which *those of .42 m.m. predominated.*

Wave lengths of both electric and infra red rays were determined with a Fabry and Perot interferometer and an especially designed echelon.

The gap between the two spectra was thus definitely and effectively closed, with an overlap of nearly two millimeters.

The presentation of this final paper took place in the beautiful new hall of the Academy of Sciences, which had been opened and dedicated with imposing ceremonies the day before and

[7]Nichols and Tear; Astrophysical Journal, Jan., 1925.

was in use for scientific deliberations for the first time that morning. The assemblage was one of unusual eminence, the occasion an impressive one, with no suggestion about it of impending tragedy. The speaker with his story half told was in the midst of a lucid statement, quite in the happy manner usual to his presentations, when his heart stopped. His sentence remained unfinished and in an instant in the midst, as it were, of friends and colleagues, his earthly career had its sudden ending. The spirit of Ernest Fox Nichols had passed on into the other world. What more fitting departure could a man of science desire?

The Ending of the Day's Work

Some of the most significant comments of the daily and the technical press were gathered into a leaflet and printed under the above title. They are so sympathetic in tone and they voice so well the feelings of the scientific world that it has seemed fitting to reproduce and thus preserve them as an addendum to the present biographical notice.

From the *New York Times,* April 30

(Abridged)

Washington, April 29.—Dr. Ernest Fox Nichols, one of the leading members of the National Academy of Sciences, dropped dead shortly after noon today while addressing the great audience of scientists at the three-day meeting of the National Academy of Sciences and National Research Council.

Just as he was concluding an important address in the new $5,000,000 endowment building of the National Academy which President Coolidge assisted in dedicating yesterday, Dr. Nichols collapsed, but as he did not fall, the academicians present did not at first grasp the full import of the tragedy that had just occurred before them.

Dr. Nichols stood on a semi-circular marble platform of Grecian design from which President Coolidge and eminent scientists have spoken during the past two days, and near the end of the address uttered the worlds: "I must—" at the beginning of a sentence which he never completed. Then he moved back toward the center of the platform, leaned over toward the right, until the weight of his body was resting against the marble stand.

Some present thought he was merely resting, as it was known his heart was not in good condition. Others, in view of the fact that Dr. Nichols' talk related to new radiometric electric wave receivers, thought he was leaning over to test some instrument. However, when he failed to move, scientists rushed to the platform, and observed at a glance that he was dying.

C. M. Jackson, head of the Medical Division of the National Research Council, was called to the platform. An ambulance was summoned from the Emergency Hospital, but had some difficulty in finding the building, which was only opened for the first time yesterday. Major General George O. Squier, former head of the Army Signal Corps, summoned an Army ambulance. Before either ambulance arrived the eminent scientist had expired.

The scientists formed a double line through which the body was borne from the building. The flag on the Academy was half-masted.

From the *Springfield* (Mass.) *Republican*

(Abridged)

News of the sudden death of Dr. Ernest Fox Nichols will come as a shock to a host of men who knew him as college teacher and president. As President of Dartmouth seven years and of Massachusetts Institute of Technology eight months, and as professor at Colgate, Dartmouth, Columbia and Yale, he has been a guide and counselor to nearly a generation of students.

Dr. Nichols' success as an educational administrator was testified to in the most cordial terms by the trustees of Dartmouth in their letter accepting his resignation, "with the greatest reluctance," in 1915. He had, they said, brought to bear upon the processes of readjustment at the college "a high order of administrative ability, enriched with a large tolerance, an exhaustless patience, a noble dignity and generosity"; "by unremitting labor," he had "accomplished a monumental task"; he had brought to his task "trained powers of analysis, coupled with the loftiest ideals of scholarship," and it had been their "hope that Dartmouth College might long continue to enjoy" his leadership. That his reputation in the educational field was excellent is further evidenced by his choice later as President of "Tech," a position which ill health compelled him to resign after a brief service.

But notwithstanding Dr. Nichols' constructive interest in educational problems and his recognized success in meeting them, it was as a scientist that his greatest work was done and his greatest reputation acquired. In resigning from the presidency of Dartmouth to take the chair of physics at Yale, he recalled that he had accepted it reluctantly, his work as teacher and student of physics having gratified his "every ambition"; he also felt he had "already done" his best work for the college. In a statement at the time he further said that he felt "like one who has been loaned by one profession to the other" and that the "time for payment" had arrived.

As a physicist his rank is with the best that America has produced. His experiments, discoveries and inventions in the branch of the science dealing with heat and light rays and with optics gave him an international reputation. His taking off while still in possession of a keen mind and eager enthusiasm is a great loss to human knowledge.

Editorial, *Electrical World,* May 10

A tragedy of great impressiveness occurred at the new and handsome hall of the National Academy of Sciences in Washington on the morning of April 29th. It was the first session of the Academy in the new building, following the dedicatory exercises of the preceding day. Several interesting papers were read according to schedule, and about 11 a. m., Dr. E. F. Nichols, the widely known physicist, went on the platform to read a paper on "Joining the Infra-Red and Electric Wave Spectra." He had been for a long time in poor health, but did not show any signs of weakness as he went up to speak to the academicians in their fine central auditorium. With clear voice and fine delivery he presented his subject, which was of great interest to all electrical men. His paper was illustrated by slides, and he spoke freely without notes.

His first slide showed a long vertically drawn column spectrum of electromagnetic waves. On the top of the column were the shortest known X-ray waves, of length 2 tenth-centimeters (2×10^{-10} cm.). At the bottom of the column was the approximately longest radio wave of 3 centimeter-sixes (3×10^{6} cm.), or 30 km., corresponding to a frequency of 10 kilocycles per second. This range of 1.5×10^{16} in ratio, or some 54 octaves, showed only about one octave of visible spectrum, near the fourth-centimeter point (1 micron). He showed that in all this long pathway of 54 octaves there had been left one gap of unexplored frequencies, having wave lengths a few centimeters long, where the infra-red joined on to the Hertzian short electromagnetic waves. He described how his work, still in progress, with a collaborator, J. D. Tear, closed that gap and made the whole series a continuously explored spectrum.

Very clearly and beautifully he described the stereopticon pictures, showing the methods and apparatus he used, with little Hertzian cylinders and with radiometers, to produce, detect and measure these little electromagnetic waves. He showed a most interesting picture of an echelon grating, composed of successive brass slabs, forming a doll's stairway, backed by an inclined glass sheet. He remarked as he pointed these out on the screen, "I think this will interest our president, Dr. Michelson," who sat on the platform opposite to him. He turned to the next slide, which showed two curves, one according to theory and the other to observation, concerning the behavior of this echelon. Without change in voice or bearing and without premonitory symptom, he said as the slide changed, "I shall—" and sat on the rear bench of the platform, laying down his head on it, with the pointer still in his hand. So quietly was this said that even the president, on the platform near him, supposed that he had merely bent over for a few moments. For fifteen seconds the hall was perfectly still.

Then the president went over and touched him gently. A physician was called for. When the physician went up Dr. Nichols was pulseless and showed no signs of life. The session immediately adjourned.

There was something very fine in this tragic close of an active career. A great scientist went to his rest, without suffering and suddenly, while narrating his victory over the unknown to his fellow academicians, with his wife and friends by his side. The triumph exceeded the calamity of his death. He closed the gap as he departed.

From *Science,* May 9, 1924

Surrounded by friends and associates and addressing, as one of the leaders in his own field of science, a distinguished audience of fellow scientists, Ernest Fox Nichols died suddenly April 29, in the auditorium of the building of the National Academy of Sciences at Washington.

Were it possible to be unmindful of the added shock and sorrow to his family which such sudden death brings, his friends could have wished for him no more fitting ending of his life, devoted as it was to the advancement of scientific knowledge, than to die in full mental vigor, in physical health as it seemed, and to the very last instant taking the part of a leader in his profession.

Ernest Nichols was born fifty-four years ago and received his collegiate training in his native State, Kansas. As a graduate student in physics he began his career at Cornell University from which institution he received the doctorate of science in 1897 after having spent two years at Berlin, where he completed his first important piece of experimental work. Unlike the majority of foreign students in Berlin in those days, Nichols worked on a problem of his own devising. He appeared older and more experienced than most of his fellow students in the laboratory, though he was not yet twenty-five years old, and his assiduity and his patience in overcoming great experimental difficulties was amply rewarded by his producing a very fine piece of work. This first important research of his was the study of the optical properties of quartz in the infra-red region of the spectrum and the results which he obtained led directly to the perfection of the so-called method of residual rays which has been used with conspicuous success by Rubens and his fellow workers in investigating the extensive infra-red spectrum. Before he left Berlin at the end of his second year, Nichols had published important papers in collaboration with Rubens and he was regarded both in Europe and America as an experimental physicist of extraordinary ability. In the course of the next ten years he held successively the positions of professor of physics at Colgate, Dartmouth and Columbia, and during this period his research work was largely directed towards the experimental verification of certain predictions of the dominant electro-magnetic theory of light. One of these predictions, that a beam of light should exert a minute pressure on an object in its path, had been looked for without success until Nichols, in collaboration with Hull, in America, and Lebedew in Russia, independently discovered and measured this minute effect and found it to be in accord with the theory.

In 1909 he gave up for a period of seven years his chosen field of work to become President of Dartmouth College. Throughout this period, embracing as it did the best years of his professional life, he cherished the hope that he might return to the life of productive scholarship which he had had to abandon in assuming heavy administrative duties. In 1916 he went to Yale as professor of physics, but his hopes of leisure for research in pure science were not to be fulfilled, as the approaching entry of America into the World War made it necessary to organize the scientists of the country for research and invention along lines having immediate practical value in war. Dr. Nichols was among the first to offer his services to the government through the National Research Council, which he had helped to organize, and he was an active member of the group engaged in the study of antisubmarine defense in the early part of the war and was connected with the department of Naval Ordnance during the entire period of America's participation in the war.

In 1920 he became the director of research in pure science in the laboratory of the National Lamp Works in Cleveland, a position which, but for a short period of time, he occupied until the time of his death. In 1921 he was inaugurated President of the Massachusetts Institute of Technology, but owing to serious ill health was unable to continue in office for more than a few months.

Of the thirty years between the publication of his first important paper and his death, about one-third was devoted to purely administrative work and this period was that during which discoveries of the most far-reaching importance to physics were being made. When Nichols returned to experimental investigation, he felt that he had almost to learn his own subject over again, and he told many of his friends that it seemed to him that he should never regain a firm grasp of it. He did this, however, in spite of delicate health, and in the end was contributing regularly to the physical journals and reading papers before the American Physical Society and the National Academy of Sciences. His modesty with regard to his own place in American science was so great that one wishes he might have known what was to happen at his death: that the most distinguished gathering of his fellow scientists of America were to stand uncovered, bowed and sorrowful, at the tragic loss of an honored colleague as his dead body was borne through their ranks.

AUGUSTUS TROWBRIDGE.

PRINCETON UNIVERSITY.

From *Light,* June, 1924

The tragically sudden death of Doctor Ernest Fox Nichols while delivering an address before the National Academy of Sciences in Washington, brought profound sorrow to a great company of his friends and followers in all walks of life and in every part of the country. The entire body of his National co-workers join in expressing to Mrs. Nichols and Miss Nichols our sincere sympathy in the sorrow which has fallen upon their hearts and home.

Among the leaders in the Nela family he held a place of peculiar honor and affection. In the world of science he was a recognized authority, taking rank among the greatest. As a citizen, he stood for those high ideals and values which constitute the great constructive energies in our national history.

Doctor Nichols was great as a scientist but greater as a man. His scientific knowledge was warmed by a beautiful human sympathy. In his nature there occurred the unusual combination of a powerful and penetrating intellect and a rare and delicate affection for folks. His keen sense of humor expressed itself in kindly judgments of men and events, invariably marked by tolerance and charity. His eyes were ever toward the light and in spite of physical weakness he faced the future with undaunted courage and hope. Conscious of the infinite mystery which enwraps the world, he held firmly to those eternal verities which, when knowledge fails, reveal themselves to faith. Of him it can be said in simple truth, "He did justly and walked humbly before his God."

The academic distinctions and achievements of Doctor Nichols were many and varied. Born in Leavenworth, Kansas, June 1st, 1869, he took his B. Sc. degree from the Kansas Agricultural College when he was nineteen. Later he pursued his studies in physics, receiving various degrees in Cornell, Berlin and Cambridge Universities. At the early age of twenty-three, he was appointed professor of physics at Colgate. From 1898 to 1903, he was on the teaching staff at Dartmouth. In 1903 he went to Columbia as professor of experimental physics. From 1909 to 1916 he was President of Dartmouth College. After a four-years' term as professor of physics at Yale, in 1920, he became director of the pure science department of the Nela Research Laboratories, Cleveland.

In 1921 Doctor Nichols was elected President of Massachusetts Institute of Technology. His inauguration brought together an unique assemblage representing the best in our academic, industrial and political life. On that occasion Governor Channing Cox of Massachusetts, a former student of Doctor Nichols, paid his old friend and teacher a remarkable tribute in a speech of extraordinary charm and feeling.

In his inaugural address, Doctor Nichols developed ideals for the engineering and scientific professions which caught the instant attention of the country. His thesis was that the engineer who dominates the present age must give the same attention to the problems of human relations and human engineering that he does to the technical problems of his profession.

A few days later Doctor Nichols was stricken with serious illness. Finding it impossible to take up the duties of administration, he resigned and set himself to the task of recovering his health. Although far from complete recovery, after a year of rest he was welcomed back to the Nela Research Laboratories, where, little by little, he resumed the work of original research in which he always delighted. And it was during this period that, with his colleague, Doctor J. D. Tear, Doctor Nichols was able to bridge the gap between radio waves and light waves, thus helping towards a final answer to the question "What is Light?" which for several hundred years has furnished men of science with a theme for investigation and discussion.

Was it prophetic of the last great Adventure, so near at hand, that our friend should have given the closing days of his distinguished career to solving the question "What is Light?" As with reverent mind he sought his way amid the mysteries and wonders of physical light, who can doubt that this gallant soldier of the Truth was being fitted to behold that "Light which is the life of men?"

CHARLES A. EATON.

NELA PARK, CLEVELAND.

Nothing is here for tears, nothing to wail
Or knock the breast, no weakness, no contempt,
Dispraise or blame, nothing but well and fair
And what may quiet us in a death so noble.
—*Samson Agonistes.*

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