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## CENTENNIAL OF THE UNDULATORY THEORY OF LIGHT[1]

A hundred years ago physical science received one of the greatest contributions ever made by a single man. This achievement was the establishment of the undulatory theory of light by the Frenchman, Augustin Fresnel. The work of this extraordinary man put the theory of optics on an entirely new foundation and inaugurated a steady evolution of this discipline which continues up to the present time. Beyond this, it had a stimulating and inspiring influence on other branches of physics having no apparent connection with the theory of light. It would be an interesting problem to look back on a century of scientific work and to analyze what concepts are due to Fresnel and how these concepts have stood the test of a hundred years. However, our present intention is a different one. A retrospective glance at the time of Augustin Fresnel and the scientific atmosphere in which he lived has still another purely human interest. It gives us an opportunity to trace step by step the resistance which a new and revolutionary idea finds in its way and to see how this resistance is gradually overcome. The fate of new concepts defying tradition is always the same: In the beginning they meet with a strong opposition rejecting them sometimes with cold disdain, sometimes with passionate irritability. Slowly and gradually the new theory obtains a reluctant acceptance. The contemporaries raised in different views finally resign themselves to it and only the following generation is in a position to admire and praise it without inhibitions.

The history of the undulatory theory is a classical example of this process. A hundred years ago the scientific public opinion was not such a complicated and widely ramified structure as to-day. Essentially it was represented by the opinion of five or six specialists associated with the Academy of Sciences of Paris. A discovery was accepted when its author had succeeded in convincing this handful of men. There are still numerous documents extant which give us all the necessary information about the attitude of the leading savants towards Fresnel's new theory. Science outside of France is almost of no avail for our problem. In Germany the experimental and theoretical study of nature was taken up a generation later and the conditions were similar in this country. In England there were several natural

[1] Read in a public session of the Astronomy and Physics Club of Pasadena, California.

philosophers of importance, but they were not interested in optics. An isolated figure was Thomas Young; as we shall bring out later, he anticipated some of Fresnel's first discoveries. But Young as a physician by profession was himself an outsider and not taken seriously by specialists. His influence was not sufficient to ease Fresnel's task appreciably.

Early science was guided in the explanation of the phenomena of light and vision by two analogies in the regions of better investigated sense perceptions. On the one hand, the phenomena of olfaction have their cause in material particles emanating from the fragrant body, which enter our organ of smell and produce in it the well-known sensations. On the other hand, the cause of sound is a wavelike or undulating motion of the air. Accordingly, two different views about the nature of light had from the very dawn of science their supporters among the philosophers. The emission hypothesis contended that a luminous body projects into space tiny particles which enter and affect our eyes. The undulatory hypothesis regarded light as a wavelike motion of a hypothetical medium which was supposed to fill all space and to penetrate all transparent bodies. This medium was named the *light ether*. Each hypothesis had had in the course of centuries a number of famous exponents. We find the emission hypothesis stated by Empedokles and among its supporters were Kepler, Newton and Laplace. On the other hand the undulatory hypothesis was preferred by Aristotle, Descartes, Hooke, Huyghens and Euler.

Sufficient experimental data for a mathematical theory of light were accumulated only about the end of the seventeenth century, mainly by Newton's discoveries. As we have mentioned, this great philosopher decided himself for the hypothesis of emission. Applying the principles of mechanics which he had recently discovered to the motion of the hypothetical light particles, he created the emission theory of optics. The idea of wave motion had to stand back for a whole century. In part this was due to the enormous authority of Newton's name, in part to some real advantages of his theory. This theory was clearly formulated and seemed fit to give precise answers to a few concrete questions, while the concepts of the undulatory hypothesis were somewhat vague and did not appear to offer points of attack for special applications. It is true that a famous Dutchman, Christiaan Huyghens, had laid some foundations for a future theoretical treatment of wave motions by enunciating a principle bearing his name. The gist of his contentions was that one can regard every point of a light wave, progressing through the ether, as an independent source of light. Huyghens's principle proved to be a wonderful tool in the hands of his successors with which they achieved almost miraculous results. However, the applications to which Huyghens himself put his method seemed to suffer from grave inner contradictions. Especially the rectilinear propagation of a light ray remained an inexplicable enigma to this point of view. Even a hundred years later in Fresnel's time his partisan Young wrote in a private letter: "If a ray of light has constantly such a tendency to diverge into the path of neighbouring rays as Huyghens assumes, then I don't see how, even in the most transparent medium, it can travel a way, howsoever short, without being completely extinguished." Therefore, the philosophers of the eighteenth century had serious, well-analyzed reasons for rejecting this doctrine. Only the great Swiss mathematician, Leonhard Euler, expressed himself in favor of the undulatory hypothesis, without, however, adding anything of importance to its theory. Thomas Young was the first to whom some progress beyond Huyghens's teachings is due. But the gigantic task of solving all the contradictions and of erecting a finished undulatory theory on the foundations laid by Huyghens required a genius like Fresnel's.

Augustin Jean Fresnel was born in the year 1788 in the small French town of Broglie as the son of an architect. He received a careful education under the guidance of his intellectual mother, but his delicate physique retarded his early development. He could scarcely read at the age of eight and his teachers were rather discouraged about his future. His playmates, however, had a more correct view of his personality, since to them he was known under the nickname "the genius." He owed this distinction to his technical ingenuity, which enabled him greatly to improve upon the construction of little cannons of elder wood. In fact, he brought this weapon to such a formidable perfection that its use had to be prohibited by a parents' meeting especially called for this purpose.

At the age of sixteen Augustin passed a brilliant examination into the École Polytechnique at Paris, and choosing civil engineering as his specialty received his technical training in the "Corps des Ponts et Chaussées." Having graduated after a five years' course, he was employed by the government in building state roads and had to spend several years in a complete rural solitude. To have a recreation and to divert his mind from the worries and frictions of his profession, he began to devote his spare time to research. In the beginning he was occupied by religious and philosophical problems. It was not until the year 1814 that at the age of twenty-six his attention returned to the difficulties which optics had presented to him during the time of his studies at the École Polytechnique. And soon he was absorbed in the endeavor to replace the theory of optics which then prevailed by a better one.

It is doubtful whether his trying professional work would have left him the time to succeed. But political events that interrupted his engineering career for several months gave him the leisure to devote himself completely to science during that period. Napoleon, who had been prisoner on the Island of Elba, suddenly returned to France, and Fresnel joined as a volunteer the little army that tried to stop the emperor's progress. Being a state official he was suspended by Napoleon's ephemeral government, the so-called government of the hundred days. He was, however, permitted to choose as his temporary residence the village in which his mother lived in retirement. On his journey to this place he had the opportunity of spending a few days in Paris and of consulting several scientists, especially the astronomer and physicist Arago. It does not seem that Arago's advice was of any immediate assistance to him. Nevertheless he derived some encouragement from the friendly reception this savant gave him. Later the connection of these two men became highly beneficial for themselves and for the progress of science.

In the seclusion of his mother's country place Fresnel devoted himself to the investigation of the phenomena of *refraction.* He possessed neither a heliostat nor a micrometer, and had to improvise his apparatus of wire and cardboard with his own hands. But even with such crude facilities he succeeded by means of patience and good judgment in making measurements of sufficient accuracy to establish a few laws which these phenomena obey. The results of this work were two comprehensive papers which he caused to be presented to the Academy of Sciences in short succession. As we have mentioned, Huyghens and Euler had realized that light consisted of a periodic succession of waves. However, it did not occur to them that the effects of different waves could influence each other. Thomas Young was the first to point out that in certain points the effects of two waves could destroy each other, namely, when the crest of one wave is superposed on the trough of the other. This mutual action is known at present as the principle of interference. Young tried an experiment which has become famous; he proved by it the influence of two neighboring sunbeams upon each other, and gave also an adequate theoretical discussion of this phenomenon. He was equally successful in applying his principle of interference to explaining the colors of thin films which had been thoroughly studied and described by Newton.

Young's beautiful researches had remained unknown to Fresnel. His first work practically amounted to the independent rediscovery of the principle of interference and hardly contained anything going beyond Young's contributions. This English physician had been called by Helmholtz "the most penetrating mind that ever lived." Outside of his optical investigations we are indebted to him for the generally accepted physiological theory of color vision and for a decisive step in the deciphering of the Egyptian Hieroglyphics. It is characteristic of young Fresnel's talent that he recognized the principle of interference at first sight and passed through the whole optical life work of the great Englishman and beyond it at the first onset.

The Academy of Sciences charged Arago with the examination of the two papers presented by Fresnel. The first thing Arago did was to obtain for Fresnel a leave of absence, so that he could spend a few months in Paris and repeat his experiments with better facilities, in part in collaboration with Arago. Francois Arago, who has played such an important part in the history of optics by this intervention on behalf of Fresnel and by his subsequent association with him, was himself one of the most interesting figures of scientific France. The academy accepted him as one of its members at the unusually early age of twenty-three to indemnify him for the hardships, sacrifices and danger of life he had gone through on the occasion of the famous French-Spanish meridian measurement which was undertaken for determining the length of the meter. At the same time the emperor appointed him professor at the École Polytechnique. Neither the academy nor the government had to regret their choice, for Arago developed into the most famous and popular wizard of France. If we look over his scientific work to-day, we must admit that it is not quite sufficient to account for his unprecedented popularity. A large part of his reputation was based on the clearness of his delivery and on the art of humanizing science which he possessed to an unusual extent. It is said that in his lecture courses the scholar of note sat beside the layman without any preparation and each went home with profit and satisfaction. Indeed, it is a great merit to have made science generally accessible at a time when most of the specialists were inclined to enshroud it in a nimbus in order to hide it from the crowd. In the evening of Arago's life the people of France received their opportunity of proving to him their gratitude and respect: After the revolution of 1848 they elected him by acclamation into the provisional government and entrusted him with the departments of war and of the navy.

But even pure science was more indebted to Arago than appears from his collected papers. Having a quick comprehension, many-sided interests and an active, progressive mind, he entered into correspondence and personal contact with many leading men of science. His sterling character, free from jealousy and envy, favored the change of these relations into lasting friendships which joined him, not only with

French, but also with German and English scholars. He was, therefore, the very man to clear the way for an exchange of opinions between slower and more reserved minds who would not have found and enriched each other without him. Figuratively speaking, he was a ferment or catalyzer accelerating the process of scientific evolution.

When Arago was charged with the report on Fresnel's work he was thirty and had just founded in company with his intimate friend, the chemist Gay-Lussac, a new magazine, the *Annales de Chimie et de Physique,* which is still thriving at the present day. No sooner had he recognized Fresnel's unusual talent than he began to ease matters for him as energetically as he could. In the beginning of the year 1816 that young man arrived in Paris to repeat and extend his experiments with improved apparatus. With the help of the more accurate data so obtained, he recast the contents of his two papers into a new form which appeared as his first publication in March, 1816, in Arago's magazine. He sent a reprint to old Thomas Young, but it seems that Fresnel's work made no particular impression on this veteran of science. "Neither myself," he wrote to Arago, "nor the very few who are acquainted with my writings can find in it a single new fact of any importance." This sentence was unjust: there was in Fresnel's paper a brief reasoning by which he showed that light is reflected from a mirror only in one direction. This argument needed only to be combined with Huyghens's principle to solve immediately the enigma of rectilinear propagation of light. This step was carried out by Fresnel in his next publication, and then Young changed his opinion of the importance of the young scholar and expressed to him his appreciation in a flattering letter.

If Fresnel's first publication did not meet with the unreserved approval even of his partisan, Thomas Young, it is clear that it must have had still much less success with the opponents of the undulatory hypothesis, who held the majority in the Paris Academy of Sciences. President of this famous corporation was at that time the great Laplace, whom we have already mentioned as a distinguished adherent of the emission theory. Also Edouard Biot, the discoverer of the optical activity of liquids and of an electro-dynamical law bearing his name, had rigidly committed himself to the Newtonian theory by publishing a book in two big volumes in which the phenomena of polarization of light were treated from this point of view. Two more physicists of international reputation who belonged to the Academy, Ampère and Fourier, did not take a conspicuous part in the controversy, whilst the mathematician, Poisson, turned out to be a most exasperated adversary of Fresnel's contentions and of the undulatory theory.

Laplace and Biot were not in the least shaken in their convictions by the work of Young and of Fresnel. They regarded it as sure that a really exhaustive study of interference and diffraction could only lead to new triumphs of the emission theory so dear to their hearts. Therefore, when the question of the competition for the grand prize in mathematical sciences came up, they did not hesitate to propose for this competition the following problem: "A theoretical and experimental investigation of the phenomena of diffraction and interference." The prize problem was announced in March, 1817, and August 1 of the following year was appointed as date for turning in the competitive essays. The wording of this announcement clearly shows that its authors were prejudiced in favor of the emission theory and had no idea of the truth.

These circumstances were not encouraging for Fresnel's taking part in the competition. Only reluctantly he made up his mind to join it at the urgent instances of Arago and Ampère. His leave of absence in Paris had long since expired. During it he had shown an extraordinary productivity in ideas and experiments. But now he was detained in the city of Rennes by trying official duties which deprived him of the possibility of scientific work for a whole year. Not until the fall of 1817 was he granted a second leave of absence. Half a year later it was followed by a complete transfer to Paris, and this made scientific facilities permanently available to him. He finished and delivered in time his competitive paper. Only a small part of it was occupied by direct answers to the questions proposed by the academy. The bulk was devoted to a systematical summary of the theory of diffraction which we regard to-day as the classical presentation of this subject. Following Huyghens he divides a spherical wave into infinitesimal elements and regards each of them as a separate source of light. If we concentrate our attention on a point outside of this wave, it can be shown that this point is reached only by light coming from a minute part of the sphere which lies in the straight line connecting the center of the sphere with the point under consideration. The elements covering the rest of the sphere cancel each other in their action by interference. By this reasoning the enigma of rectilinear propagation of light is solved and the apparent contradiction in Huyghens's principle removed. The same type of argument remains valid when a part of the wave surface is screened off by opaque objects, and easily explains the formation of fringes at the border of the geometrical shadow. Fresnel carried through the numerical calculations in a few special cases and proved by experiments tried for this purpose the splendid agreement between theory and experience.

On the board of judges appointed by the academy three influential adherents of the old theory were opposed to Arago, the only representative of the new ideas. The chemist, Gay-Lussac, who also was on the board, was completely non-partisan. Through his personal relations to the judges, Fresnel was kept informed about his chances, and by the letters he wrote to his brother we can follow the oscillations of the scales. A short time after turning in his paper he complains of Laplace's negative attitude, and then goes on as follows:

In a conversation which I recently had with Poisson he admitted to me that the many disconnected hypotheses occurring in the Newtonian theory had diminished his confidence in it to a considerable extent. I hope that the perusal of my paper will bring him on the side of the undulatory theory. Mr. Biot, who did read this paper and who knows the difficulties of the emission system better than anybody else, is the one whose conversion seems to me the nearest. It is a pity that because of his book he finds himself in a position so strongly biassing his ambition in favor of that theory. As to *Arago*, he is much satisfied with my theory of diffraction, and I believe that *Gay-Lussac's* opinion of it is about the same.

Unfortunately the favorable impressions which Fresnel had of his chances was due to the optimism of his youth, and his faith in scientific conversions turned out to be premature.

The deliberations of the board were progressing slowly. As Fresnel quite correctly remarked, not only the award of a prize, but a complete scientific revolution was at stake. We shall be able to estimate what formidable resistance had to be overcome if we occupy ourselves with the personality of the most influential of the judges. Peter Simon Marquess de Laplace had already reached the age of seventy when he came into contact with Fresnel. Having risen from small beginnings to the highest offices and honors, and become the pride of France, he watched his fame with jealousy and did not like being eclipsed by anybody else. As president of the Academy of Sciences, member of the French Academy, honorary member of almost every academy and scientific society of Europe and America, the great man could not complain of being too little appreciated. After Lagrange's death there was no mathematician in the whole world who could come anywhere near him in reputation and authority, and nevertheless he was susceptible in a surprising degree to the feeling of rivalry and scientific jealousy. Characteristic for this is an episode from Arago's recollections, who for a short time was Laplace's assistant at the observatory and therefore a frequent guest in his house. "The son of Mr. de Laplace," related Arago, "was preparing himself for the examinations at the École Polytechnique, and he often would call on me at the observatory. On the occasion of one of these visits I explained to him the method of continuous fractions by means of which Mr. Lagrange finds the roots of numerical equations. The young man talked with admiration about this to his father. Never shall I forget the rage into which the latter was put by his son's words, nor the bitterness of the reproaches he addressed to me for having advocated that method, which as everybody knows, is beyond criticism as to elegance and rigor. Never had prejudice shown itself less disguised and in a harsher form. 'Alas,' I said to myself, 'how right were the ancients attributing failings even to him who shook Olympus with his frown'."

It is, therefore, easy to understand that the academic honors and distinctions heaped upon Laplace could soothe his vanity as little as the shower of decorations descending upon him. His ambitious nature was craving for political power. The opportunism and complete lack of principles which he showed in this pursuit were blamed by many contemporaries. A republican at the time of the first republic, he became after the revolution of the 18 Brumaire home secretary or minister for the interior of the first consul. In this capacity he proved a complete failure. Napoleon used to say that "he carries the spirit of the infinitesimal into politics," and dismissed him after six weeks. However, he filled, during the consulate and empire, other important offices, having been made president of the Senate and Grand Officer of the Legion of Honor, and created a count. This did not prevent Laplace from turning an archreactionary after the restoration and becoming a marquess and a peer of France.

The influence of Laplace's mentality on his attitude toward Fresnel and the undulatory theory is obvious. Laplace was almost as great a physicist as mathematician. Among other things he had paid a great deal of attention to optics, and believed that he had explained a number of new facts from the point of view of the emission theory. If it is hard for every man to relinquish at an advanced age the convictions of long years, and to turn over a new leaf, this applied to Laplace in an increased measure. He had acquired a certain right to regard his own opinions as more valuable than those of other people and was confirmed in this by his vanity. Therefore, he felt little desire to enter into ideas foreign to him, least of all into those of such a young man and scientific beginner as Fresnel. After a conversation with Laplace the latter wrote to his brother, "I understand that M. de Laplace does not pay any attention to what one says to him," and in another letter: "M. de Laplace, who reads very little, had not the patience for reading through my thick paper from end to end. He requested Arago to prepare an abstract of it for him."

It is hard to say what the decision of the judges would have been if an unforeseen event had not given a new aspect to the matter. From the form of the integrals by which Fresnel had expressed the distribution of light in the geometric shadow, Poisson had recognized that the middle of the shadow cast by an opaque circular screen should be just as bright as if there were no screen at all. Fresnel was summoned and invited to account for this. He tested this point experimentally and the experiment gave a striking confirmation of the paradoxical conclusion from his theory. Including this success, the new doctrine could boast of so many cases of agreement with experiment that it could no longer be ignored. Though the judges were very far from sharing Fresnel's views, they made up their minds to award the prize to Fresnel, especially as there was no other competitor of merit. It is hardly necessary to say that history has ratified this decision. We regard at present Fresnel's winning essay as a classic. Its study can be highly recommended, being not only enjoyable but also profitable and stimulating even in our days. It is possible that Laplace, the only mind among the judges equal to Fresnel's, had a suspicion of the historical significance of this episode. It seems that in the dilemma of conquering his vanity or of impairing his reputation in the eyes of posterity, he consciously chose the first course.

This view is suggested by the fact that during the second period of Fresnel's scientific activity, his way was smoothed by Laplace in every possible respect. The researches of this second period were devoted to the phenomena of polarization and are based on an additional hypothesis by which Fresnel had completed and extended the undulatory theory, namely, on the assumption that the vibrations of light are not taking place in the direction of the ray, but at right angles to it, that they are *transverse,* as Fresnel put it. His previous results were not affected by this assumption. Both Huyghens's principle and the idea of interference which formed the bases of the earlier conclusions require only the *existence* of vibrations; in this connection their orientation is quite immaterial.

The concept of transversality on which Fresnel had ingeniously erected the whole structure of crystal optics was regarded as a mechanical impossibility by his contemporaries and met with strong opposition. Arago, who in August, 1822, reported to the academy about Fresnel's most important paper, dwelt with much approval on its experimental side, but passed over the theoretical part in silence. After Arago had finished, Laplace addressed the assembly; he congratulated the author on his beautiful results achieved by perseverance and sagacity, and declared that he esteemed these investigations above everything that had been presented to the academy for many years.

The patronage of Laplace and the friendship of Arago opened to Fresnel the access to the highest honor which the academy had to award. On May 12, 1823, he was unanimously elected a member of that body. Because of failing health his scientific productivity declined after his election. His last paper on optics was published in the beginning of 1826; it marks the completion of his life work and seems, therefore, the appropriate date from which to count the establishment of the undulatory theory.

However, it would be a mistake to assume that this theory was established in the minds of his contemporaries. Fresnel's election to the academy was due to his numerous experimental discoveries whose importance nobody could deny, while the theoretical views that had led him to these discoveries were still the subject of passionate controversy. Even his most friendly colleagues did not get beyond the stage of indulgence in their relation to the undulatory theory and were very far from becoming its warm-hearted supporters. I should like to recall to you Fresnel's letter from the time of the prize competition in which he speaks about Laplace, Arago, Poisson and Biot and expects their rapid conversion. What were the actual opinions of these men? We have already suggested that Fresnel's work must have shaken Laplace's faith in the Newtonian theory. However, Laplace never made a public or private statement to this effect. In the fourth edition of 1813 of his book "Exposition du système du monde" a whole chapter was devoted to a summary of the Newtonian theory of light. From the fifth edition of 1824 this chapter had simply vanished. Instead we read in the preface: "In the last edition I had presented the main results of the analytical theory of optics. As this field has since considerably increased I intend to treat it in a separate book." This book never appeared. Arago, whom we know as Fresnel's most faithful supporter during the first period of his work, did not, to the very end of his life, become reconciled with the idea of transverse vibrations. Even in 1852, twenty-five years after the death of his great friend, he wrote: "From the moment when Fresnel introduced transverse vibrations I refused to follow him." The most passionate opponent of the hypothesis of transversality was, however, Poisson. He resisted it with all his might, as well by word of mouth in the Philomathic Society of Paris, as in print in the *Annales de Chimie et de Physique.* The description of Poisson that has been handed down to us is not quite free of contradictions. On the one hand, he is represented to us as a stout gentleman with a rosy, benevolently smiling face. The chair on which he sat and the desk at which he wrote were his whole world. Only once in all his life could his family prevail upon him to make a journey. Every day he repeated his motto: "There are only two fine things in life: studying mathematics and teaching mathematics." On the other hand, we see him occasionally in a state of irritability and bad temper. His rivalry with Fourier sometimes assumed an undesirable form and in his polemic with Fresnel he was also often harsh and unjust. We can understand that the insufficient mechanical arguments by which Fresnel had tried to support his hypothesis could have offended him as a mathematician. But it is strange that he had no eye for the physical proofs produced in hundreds of experiments. However, the close study of Fresnel's ideas had a very strong influence on Poisson's later work, though he never admitted this. In his paper of 1830 on the propagation of sound in elastic bodies he pays equal attention to the transverse and to the longitudinal waves.

More than anybody else Biot had identified himself with the views of the emission theory, and its extension for the phenomena of polarization was essentially his work. Like Poisson, he started a polemic with Fresnel which, however, did not present much of interest. Nevertheless, Biot was the only one of the group who in later years, long after Fresnel's death, succeeded in a complete acceptance and assimilation of his theory. In 1846 Fresnel's brother, who was preparing for print an edition of Augustin's collected writings, had to examine some posthumous manuscripts in collaboration with Biot. In this connection he relates the following episode:

> Mr. Biot, after having expressed in warm words his high appreciation of Augustin's personality and his regret of not having come in closer social contact with him, dwelt with much emphasis on his scientific work. After a few moments' hesitation he proceeded with more animation as if moved by overwhelming thoughts: "What a marvelous power of intuition did your brother show in his fruitful concept of transverse vibrations!" One can imagine my surprise and emotion at this exclamation of the famous old man whom I had always regarded as one of the greatest fanatics of the Newtonian theory.

In the later development of optics it became known through the work of Maxwell and Hertz that the vibrations of light are not of a mechanical, but of an electromagnetic nature. Fresnel's theory was not affected by this as it implies only the existence of vibrations and their transverse character. Another crisis in our ideas of the nature of light is taking place at present, but under the name of the principle of correspondence we are still using and will continue to use the whole body of Fresnel's analysis. Again, as in Maxwell's time, the mathematical theory remains practically unchanged and only its physical interpretation is under discussion.

There is not much to say about the outer circumstances of Fresnel's life. As a governmental engineer he was assigned to the department of lighthouses in view of his optical propensities. These duties were not a sinecure. Important progress in the construction of searchlights is due to Fresnel, and his writings on this subject fill one of the three volumes of his collected papers. Taking into account that he acted at the same time as examiner at the École Polytechnique, it is astonishing how he could afford the necessary energy and time for his enormous scientific work. His health, always delicate, could not resist this strain. In the last years of his life frequent indispositions did not leave him time enough to divide it between science and official obligations. Devoted to his duty he decided in 1824 with a heavy heart to give up the main part of his scientific work. In the beginning of 1827 he was obliged to petition also for relief in his office by allowing him an assistant in the person of his brother. But it was too late: four months later he expired at the age of thirty-nine in the arms of his mother.

Fresnel's contemporaries did justice to his personality and to his scientific fervor. They were not able to appreciate the greatness of his work, which became apparent only to posterity, as the relative height of mountains can be judged only from a distance. I thought to-day a good opportunity to let pass before your eyes Fresnel's life and the fight he had to lead for his ideas a hundred years ago.

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## THE CONDITION AND NEEDS OF SYSTEMATIC MYCOLOGY

THE subject of mycology is of such vital concern not only in connection with its many practical and important relations to human industry and activity, but also in the fundamental problems of biology, as to deserve much greater and more careful attention from student and teacher, as well as from the general scientist, than it receives at present.

Interpreted in its broader sense as including the study of bacteria and yeasts, as well as the multitude of parasitic and saprophytic fungi, mycology is of vast economic and scientific significance. The bacteria in relation to plant and animal diseases, the yeasts in connection with important industrial processes and the parasitic fungi in their relation to agriculture by the destruction of growing crops, stored food and other products, merely constitute a few of the important practical aspects of the subject. With respect to purely biological problems, such as phylogeny and evolution, the fungi offer especially favorable material for research, as various aspects and