Augustin Jean Fresnel | Encyclopedia.com

Complete Dictionary of Scientific Biography COPYRIGHT 2008 Charles Scribner's Sons
27-34 minutes

(*b*. Broglie, France, 10 May 1788; *d*. Ville-d'Avray, France, 14 July 1827)

optics.

Fresnel's father, Jacques, was a successful Norman architect and building contractor. In 1785, while directing improvements on the château of the maréchal de Broglie, he married Augustine Mérimée, the pious, well-educated daughter of the estate's overseer. Subsequently he was employed on the harbor construction project at Cherbourg; and when this work was interrupted by the Revolution in 1794, he retired with his family to Mathieu, north of Caen. Here Augustin spent the remainder of his childhood, deeply influenced by the home. In an atmosphere heavy with the values of a stern Jansenism his parents provided him with an elementary education. At twelve, undistinguished except for his practical ingenuity and mechanical talents, he entered the École Centrale in Caen. The school's progressive curriculum afforded Fresnel an introduction to science, and two of his masters made a lasting impression: F. J. Quesnot, the mathematics teacher, and P. F. T. Delarivière, the grammar instructor, whose course imparted the elements of *Idèologie*.

Intending a career in engineering, Fresnel was admitted to the École Polytechnique in Paris in 1804. For two years he benefited from the school's highlevel scientific instruction. After an additional three years of technical courses and practical engineering experience at the École des Ponts et Chaussées, he completed his formal training and entered government service as a civil engineer. The Corps des Ponts et Chaussées first assigned him to Vendée, where he worked on the roads linking the department with its new *chef-lieu* at La Roche-sur-Yon. About 1812 he was sent to Nyon, France, to assist with the imperial highway which was to connect Spain with Italy through the Alpine pass at Col Montgenèvre. In moments snatched from his professional duties Fresnel diverted himself with a series of philosophical, technical, and scientific concerns.

By mid-1814 Fresnel had turned to optics and had begun to consider the claims of the wave or pulse hypothesis of light. This inquiry, barely begun, was suddenly thrust aside the following year. Seeing Napoleon's return from Elba as "an attack on civilization," Fresnel deserted his post and offered his services to the Royalist forces. With the reestablishment of the empire he found himself suspended from his duties and put under police surveillance. Returning home to Mathieu, he devoted his enforced leisure to optics, undertaking experiments on diffraction. These confirmed his belief in the wave nature of light and started him on a decade of research aimed at developing his hypothesis into a comprehensive mathematical theory. With the Second Restoration, Fresnel was reactivated by the Corps des Ponts et Chaussées and thereafter was forced to restrict his investigations to periods of leave. Through the intervention of such influential friends as Francois Arago, these were not infrequent. From the spring of 1818 his scientific work was made easier by assignments in Paris, and intensive research over the next few years produced important results. After 1824 his efforts slackened. Work with the Lighthouse Commission, including the development of his new "echlon" lenses, put severe demands on his time, and faltering health sapped his energy.

Tuberculosis, the cause of his early death, cast a shadow over Fresnel's entire career. Plagued continually by ill health, he sought consolation in a religious faith which offered belief in Divine Providence and the hope of an afterlife. But this was no theology of resignation. Summoning the will to struggle against bodily suffering and fatigue, Fresnel threw himself into difficult tasks. Behind his remarkable determination was a severe Puritan, middle-class outlook which saw the highest merit in personal achievement, performance of duty, and service to society. Serious, intent, haunted by thoughts of an early grave, Fresnel bound himself closely to these ideals, shunning pleasures and amusements and working to the point of exhaustion. Despite the urgency of everything he attempted, Fresnel was always attentive to detail, systematic, and thorough. In science no less than in politics he held tenaciously to his convictions and defended them with courage and vigor. As a functionary he voiced outrage when the behavior of others fell short of his own high ethical standards. At times this approached a rankling self-righteousness, but generally his contemporaries saw him as reserved, gentle, and charitable.

For his scientific achievements Fresnel received several important honors. In 1823 the Acadèmie des Sciences elected him to membership by unanimous vote. He was a foreign associate of the Société de Physique et d'Histoire Naturelle of Geneva and a corresponding member of the Royal Society of London. In the last month of his life he received the Royal Society's Rumford Medal.

Confined almost exclusively to optics, Fresnel's scientific work shows an essential unity. Above all, his research found its motivation and direction in an attempt to demonstrate that light is undulatory and not corpuscular. Challenging the prevailing Newtonian view, he undertook a series of brilliant investigations which systematically elaborated the wave concept and established its conformity with experience. Fresnel brought to his research an ingenious mind, deft hands, and the discipline of an excellent scientific education. He was equally proficient in experiment and mathematics and effectively combined the two.

Characteristically, he initiated his investigations with experiments and proceeded, via analysis, to theory. He set as his goal mathematical theories from which precise consequences could be deduced and tested by further experiments. For Fresnel a true theory was one that predicts experience and rests on a simple conceptual basis, free of all auxiliary hypotheses. The simplicity requirement, which served Fresnel as a constant guide in his theoretical formulations, was grounded on a deep-seated belief that nature aims at the production of the most numerous and varied effects by the fewest and most general causes. This is the meaning of the epigram placed at the head of his prize essay on diffraction: "Natura simplex et fecunda." The idea of the underlying unity of natural processes doubtless found a guarantee in Fresnel's Providentialism. A consideration of his close relationship with Ampère and others in the circle of Maine de Biran might also disclose certain philosophical influences contributing to this viewpoint.

It was Fresnel's belief in the essential unity and simplicity of nature that conditioned his preference for a wave conception of light. His earliest statement in favor of light as a form of motion (in a letter of 5 July 1814) envisioned the possibility of referring heat, light, and electricity to the modifications of a single, universal fluid. Apparently, then, he regarded the whole Newtonian scheme of imponderables with its multiple fluids as suspect from the very start. But within this general scheme the corpuscular theory of light had its own special burden of complexity. Ignorant of the elaborations of the theory undertaken to accommodate polarization, Fresnel was not yet aware of how complex corpuscular optics had become. His determination to overhaul optical theory was sparked by a dissatisfaction with the caloric view of heat and an appreciation of the analogies between heat and light. But after he learned of Biot's work, he regularly assailed the corpuscular theory for its lack of unity and simplicity.

Rejecting corpuscular optics, Fresnel was poorly acquainted with earlier theories that conceived light as waves or pulses. In France, as elsewhere, the views of Huygens and Euler had no following and were hardly discussed. Physics textbooks of the period took note of the "Cartesian" hypothesis but dismissed it in a few lines. Apparently it was only with the most general knowledge of the work of his predecessors that Fresnel began to construct his theory. If he knew of Huygens' principle when he undertook his first investigations, he did not reveal it. From the start, however, he possessed another important concept, which made his theory, unlike, that of Huygens, a true wave theory. This was the idea that the pulses constituting light succeed one another at regular intervals. Fresnel may have taken the idea from Euler, but it is more probable that he hit upon it independently. Nor was he aided by the work of Thomas Young. He became familiar with Young's contributions to wave optics only after he was well into his own experiments.

Fresnel's first experimental investigation, a study of diffraction, gave him a firm foothold in undulatory optics and started him down a profitable path. By studying diffraction effects—the shadow and associated bands of color produced when a hair or other thin object is illuminated by a narrow beam—he hoped to counter objections to the wave hypothesis based on the apparent rectilinearity of the propagation of light and, if possible, to find positive support for the view of light as vibrations. The key to success was found in an application of the principle of interference, a concept drawn from acoustical theory. Attaching a slip of black paper to one edge of a diffracter, Fresnel observed that the bands of light within the shadow disappeared. By "a mere translation of the phenomenon" he concluded that the internal bands depend upon a crossing of rays inflected into the shadow from both edges of the diffracter. Since the bands outside the shadow on the side opposite the attached paper remained, the external bands appeared to arise from a crossing of rays proceeding directly from the light source and by reflection from one edge of the diffracter. Referred to the mechanical level, these effects seemed explicable only if light were undulatory. Bright bands would occur where the vibrations constituting light are in phase and reinforce one another. Intervening bands of darkness would correspond to places where the vibrations are out of phase by some odd number of half wavelengths and cancel one another.

To put the concept of constructive and destructive interference to the test, Fresnel worked out simple algebraic formulas correlating the positions of the bands with factors determining the occurrence of interference—the path differences of the intersecting rays and the wavelength of the light. Performing the experiment with monochromatic red light and gauging the positions of the bands for various intervals between the light source, the diffracter, and the receiving screen (or plane of observation, since it proved equally effective and more convenient to dispense with the screen and view the bands directly with a lens), he found a close correspondence between actual values and those predicted by his formulas.

Although a paper of October 1815, embodying these results, won Arago to the cause of wave optics and made a favorable impression on the Institut de France, Fresnel was still far from a complete theory of diffraction. His indiscriminate use of the terms "rays," "vibrations," "inflection," and "diffraction" bespoke a residue of corpuscular influences and was symptomatic of a lack of precision in his formulation. The mirror experiment, demonstrating interference in circumstances where the attractive forces of inflection could not be invoked to explain its effects, marked an important step forward. In front of two mirrors arranged end to end at an angle slightly less than 180° Fresnel set a minute light source. After the necessary adjustments to obtain precisely the right conditions, he saw bands of color produced as the rays reflected from one of the mirrors intersected and interfered with rays reflected from the other. The interpretation of the bands in terms of interference seemed all the more certain since band positions corresponded to theoretical values obtained by adapting the diffraction formulas.

Although inflection was thus effectively discredited, Fresnel saw the need for further refinements. His formulas, positing rectilinear "rays" and referring path measurements to the very edge of the diffracter, predicted band positions only if it were assumed that the rays turned aside at the diffracter lost half a wavelength. Otherwise there was an inexplicable reversal, the bright bands occurring where dark ones were predicted and vice versa. Spurred by a desire to eliminate the ad hoc hypothesis, Fresnel undertook to reconstruct his theory on a new basis, a step carrying him, for the first time, beyond Young. Boldly he conceived the idea of combining Huygens' principle with the principle of interference. Applying the idea to diffraction, he supposed that elementary waves arise at every point along the arc of the wave front passing the diffracter and mutually interfere. The problem was to determine the resultant vibration produced by all the wavelets reaching any point behind the diffracter. The mathematical difficulties were formidable, and a solution was to require many months of effort. In the first attempt, fashioned around the concept of "efficacious rays," Fresnel succeeded in reducing the discrepancy between theory and fact by half, and in a paper of 15 July 1816 that reported the investigation, he begged critics at the Institut de France to treat with indulgence "his essays in such a difficult theory."

Not until the spring of 1818 was Fresnel able to reach his goal. Restored to active service in the Corps des Ponts et Chaussées and assigned to Rennes, he bore heavily the yoke of his engineering duties and continually badgered his superiors for leave. Whenever possible he returned to Paris to pick up the thread of his research. Throughout 1817 he concerned himself with polarization, but the need to cope with the periodic effects of chromatic polarization immediately reintroduced the basic mathematical problem carried over from the study of diffraction: that of "calculating the influence of any number of systems of luminous waves on one another." Fresnel took a decisive step toward the solution when, aided by an analogy between the oscillations of an ether molecule and those of a pendulum, he derived a general expression for the velocity of ether molecules put into motion by a wave.

Considering next the combined effect of multiple waves, Fresnel worked through to an important result. Just as a force can be resolved into perpendicular components, so the amplitude of the oscillations imparted by any wave can be reduced to the amplitudes of two concurring waves following one another at an interval of a quarter wavelength. To find the net effect of multiple waves, then, it was sufficient to reduce each to its two components, add like components, and recombine the sums. Temporarily setting polarization aside, Fresnel hastened to apply this result to diffraction. Urgency was called for, because the Acadèmie des Sciences had announced that diffraction would be the subject of its competition for 1819. Looking beyond the prize to the scientific "revolution" he hoped to effect, Fresnel was anxious to enter the contest. Not long before the closing date he put the final touches to his theory. Without any gratuitous hypotheses he could now calculate the light intensity at any point behind a diffracter.

In Figure 1 *P* is the point, *AG* the diffracter, *C* the light source, and *AMI* a partially intercepted wave.

front. One of the infinitesimally small arcs into which *AMI* may be divided is shown as *n'n*. From each of these elements a train of wavelets is assumed to arise, and the problem is to determine the composite effect of all the wavelets at *P*. The procedure takes the form indicated above, the wavelets being related to a wave emanating from the point *M* on the line *CP* and to another wave differing in phase by a quarter undulation. Considering the effect at *P* produced by a wavelet proceeding from *n'n*, Fresnel represents this small portion of the original wave front as *dz* and specifies its distance to *M* as *z*. The interval *nS* between the wave *AMI* and the tangent arc drawn around *P* is determined to be $1/2\ z^2(a+b/ab)$, *a* and *b* representing the distances *CA* and *AB*. Substituting into the appropriate expression supplied by his general mathematical investigation, Fresnel wrote the component of the wavelet relative to the wave emanating from *M* as

λ representing the wavelength. The other component relative to a wave separated from the first by a quarter wavelength is.

The sum of similar components of all the wavelets is then

These expressions later passed into the textbooks as "Fresnel's integrals." The square root of the sum of their squares gives the amplitude of the resultant vibration at *P*, while the sum of their squares measures the observable light intensity at the point. Tested and strikingly corroborated by experiment, the new theory served as Fresnel's entry to the competition and was awarded the prize. During the judging it received a dramatic and unexpected confirmation. One of the commissioners, Poisson, had perceived in Fresnel's mathematics the seemingly improbable consequence that the center of the shadow of a small disk used as a diffracter would be brightly illuminated. An experiment performed to test the calculation confirmed it exactly.

That light under certain circumstances displays an asymmetric aspect remained the most serious challenge for the undulatory conception of light. Particles might have "sides," but longitudinal waves could not. Understandably, Young experienced "a descent from conviction to hesitation" when informed of Malus' discovery of polarization by reflection. With Fresnel, however, it was otherwise. Undaunted, he set out early in his investigations to find an accommodation between the asymmetry of light and the wave hypothesis. For clues about the nature of polarization his first tack was to pursue a comparative approach in which the effects of polarized light would be juxtaposed against the known characteristics of ordinary light. Specifically, he decided to substitute polarized light for ordinary light under conditions producing interference. Initial experiments carried out jointly with Arago early in 1816 afforded no new insights. Polarized light gave the same effects as ordinary light. Fresnel questioned the adequacy of these hasty tests, and several months later undertook new experiments, obtaining results that were quite different. Aided further by Arago, he showed convincingly that in circumstances where ordinary light would interfere, rays polarized in mutually perpendicular planes have no effect on one another.

The theoretical implications were puzzling. In a note to a preliminary draft of the paper reporting the investigation, Fresnel offered two hypotheses accounting for his findings, one his own and the other elicited from Ampère. The noninterference of rays polarized in mutually perpendicular planes suggested that the vibrations constituting light are either transverse or a combination of longitudinal and transverse motions. Neither hypothesis appeared tenable. Transverse waves, the prevailing theory of elasticity held, are possible only in a solid medium; but an all-pervading solid ether could not be reconciled with the free, unimpeded movements of the planets demonstrated by astronomy. When he submitted his paper to the Acadèmie des Sciences, Fresnel deleted the note, and Arago's account of the investigation published in 1818 scrupulously avoided all theoretical considerations.

Lacking any alternative hypotheses, Fresnel continued his inquiry. On the basis of the recent experimental findings he next worked out a detailed explanation of chromatic polarization. But, as with diffraction, the calculation of precise theoretical values and full confirmation had to await the "general law of the reciprocal influence of luminous waves," available only at the beginning of 1818. Although it extended the sway of interference as an explanatory concept, the study of chromatic polarization disclosed nothing new about the basis of polarization.

In search of further clues, Fresnel turned his attention to the influence of reflection on polarized light. His first efforts, summarized in a paper of November 1817, resulted in the discovery of an unusual modification of light, later designated "circular polarization." The novel light appeared to be symmetric about an axis drawn in the direction of its motion, but in other respects it behaved like polarized light. Fresnel determined that these characteristics would follow if the light were supposed to consist of two components with mutually perpendicular planes of polarization and a phase difference of a quarter undulation. Yet for the moment he saw no way to translate this into a satisfactory mechanical hypothesis. Another important investigation, completed in March 1818, showed that the rotation of the plane of polarization associated with the passage of light through quartz and certain liquids depends upon a weak double refraction and the superposition of two circularly polarized rays.

As he weighed the implications of these studies, Fresnel was gradually brought to the realization that the vibrations constituting light could only be transverse. Consistently the characteristics of polarized light testified to forces acting at right angles to the rays, and finally the conclusion became inescapable. In an article appearing in the *Annales de chimie et de physique in 1821*, Fresnel publicly committed himself to the view that light waves are exclusively transverse. Attempting a mechanical rationale, he offered a brief account of a hypothetical ether that would lend itself to transverse vibrations and yet retain the essential properties of a fluid. He then proceeded to an interpretation of polarization. Ostensibly, polarized light had its basis in ether vibrations executed in a definite, fixed plane at right angles to the direction of the wave. As for ordinary light, it could be considered "the union, or more exactly, the rapid succession, of systems of waves polarized in all directions." For Fresnel the major support for this conception of the nature of light was that it gave meaning and order to his empirical findings. His essay into ether mechanics was weak and was intended only as a demonstration of the physical possibility of transverse waves. The proof came from all the indications of experience, and a rigorous mechanical justification, however desirable, seemed unnecessary. Few among Fresnel's contemporaries agreed. Even Arago, who gave his faithful support in everything else, deserted him here.

Fresnel found an effective answer to his critics in a successful application of the concept of transverse waves to double refraction. A start was made in the article of 1821, when he suggested that the two rays of double refraction correspond to perpendicular components of the vibrations of the ray incident on the doubling crystal. From this simple idea he rapidly traversed an arduous course to a full-blown mathematical theory. As usual, his approach was to work back from experience. Availing himself of the law of refraction and Huygens' law of extraordinary refraction, he proceeded to develop a series of unified constructions specifying the velocities of both the rays of double refraction. Initially he found that the velocities could be accurately represented by the semiaxes of the intersection of the wave surface with an ellipsoid of revolution. This sufficed for double refraction in uniaxial crystals, but a more general construction was needed to provide for the refracting characteristics of biaxial crystals. By substituting an ellipsoid with three unequal axes for the ellipsoid of revolution, Fresnel had the solution, or at least a partial solution.

In one crucial respect the new construction fell short of full generality. It proved valid for most doubling crystals, which show weak double refraction, but it was not adequate for those like Iceland spar, in which the separation of the rays is considerable. The final construction, in the form of an equation of the fourth degree, followed only a week after the paper of 19 November 1821, which recounted the previous results. Although he now had a general law of double refraction meeting every test of experience, Fresnel pressed on. As in the study of polarization, he was reluctant to end his investigation without showing the mechanical plausibility of his results. In two supplements to the November memoir he concerned himself with this problem. When later he prepared an account of the investigation for publication, the mechanical considerations were emphasized, and the law of double refraction was represented as a deduction from the general properties of an elastic fluid. That this obscured the actual route of discovery is unimportant. Fresnel's treatment of double refraction was an impressive synthesis, and while transverse wave motion may not have been rendered more acceptable, successful applications of the new theory built around it soon made it indispensable.

The study of double refraction was Fresnel's last major contribution to wave optics. Thereafter his responsibilities on the Lighthouse Commission absorbed the bulk of his energies. To the problems encountered here—the improvement of lenses and the design, construction, and location of the lighthouses—he brought the same inventiveness, concentration, and perseverance previously manifest in his scientific work. Yet science was not entirely forgotten in these later years. Fresnel found the time to carry out an investigation of partial reflection, to make a beginning toward a mathematical theory of dispersion, and to act as chief propagandist for the wave theory. In occasional notes and academic reports he addressed himself to topics outside of optics. Most noteworthy was his contribution to Ampère's electrodynamic molecular model. It is tempting to think that, given more time, he might have pursued further his youthful vision of restoring heat, light, and electricity to a common basis in the motions of a universal ether.

As it was, Fresnel succeeded fully in attaining his explicit goal, the establishment of the wave conception of light. Not long after his death scientific opinion definitely shifted in favor of waves and opened up the pathway leading to the deeper insights of Maxwell. In broad context Fresnel's work can be viewed as the first successful assault on the theory of imponderables and a major influence on the development of nineteenth-century energetics.

BIBLIOGRAPHY

I. Original Works. Fresnel's writings were collected in Oeuvres complètes d'Augustin Fresnel, Henri de Senaramont, Émile Verdet, and Léonor Fresnel, eds., 3 vols. (Paris, 1866–1870). Provided with a detailed analytical table of contents, this comprehensive edition lacks only the important notes on electrodynamics addressed to Ampère. For these, see *Mémoirse sur l'électrodynamique*, Société Française de Physique, ed., 2 vols. (Paris, 1885–1887), I. 141–147.

II. Secondry Literature. The details of Fresnel's life are poorly known, and no full-length biography has been published. The most detailed account is François Arago's "Éloge historique," in Fresnel's *Oeuvres complètes*. III, 475–526. Other contemporary sources are A. J. C. Duleau, *Notice sur A. Fresnel* (Paris, 1827); an anonymous account in Vielh de Boisjoslin, ed., *Biographie universelle et portative des contemporains*, 4 vols. (Paris, 1830), II, 1770–1175; A. Marc *Notice sur A. J. Fresnel* (Caen, 1845); and Léon Puiseux, "Fresnel," in *Notice sur Matherbe, La Place, Varignon, Rouelle, Vauquelin, Descotils, Fresnel et Dumont-d'Urville* (Caen, 1847).

Among recent accounts with biographical interest the most noteworthy are Charles Fabry, "La vie et l'oeuvre scientifique d'Augustin Fresnel," in *Revue internationale de l'enseignement*, **47** (1927), 321–345; G. A. Boutry, "Augustin Fresnel: His Time, Life and Work, 1788–1827," in *Science progress*, **36** (1948), 587–604; and Pierre Speziali, "Augustin Fresnel et les savants genevois," in *Revue d'histoire des sciences et de leurs applications*, **10** (1957), 225–259.

The *Revue d'optique*, **6** (1927), is a centennial issue devoted entirely to Fresnel. The best starting point for an assessment of his scientific work is Verdet's introduction to the *Ocuvres complètes*. Brief but authoritative is the discussion in Vasco Ronchi, *Histoire de la lumiere* (Paris 1956), pp.242–261. Fresnel's investigations leading to the recognition of transverse wave motion are analyzed in detail in André Chappert, "L'introduction de l'hypothese des vibrations transversales dans l'oeuvre de Freshel," an unpublished study done for the Diplôme d'Érudes Supérieures de philosophie at the University of Paris. See also R. Silliman, "Augustin Fresnel (1788–1827) and the Establishment of the Wave Theory of Light" (thesis, Princeton University, 1968).

Robert H. Silliman