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(*b*. Estagel, France, 26 February 1786; *d*. Paris, France, 2 October 1853)

physics, astronomy.

Arago was the eldest son of Marie Roig and François Bonaventure Arago, a modest landowner of Catalonian origin who became mayor of Estagel in 1789. The family moved to Perpignan in 1795, when Arago's father was named cashier at the mint. There Arago completed the usual classical education and set his sights on a military career in the artillery. He prepared for admission to the École Polytechnique by mastering the works of Euler, Lagrange, and Laplace, and passed the entrance examination with great distinction in 1803. After two years at the head of his class, he was named secretary of the Bureau des Longitudes and sent to Spain with Biot on a geodetic expedition. After being held prisoner in Spain and Algeria, he returned in June 1809 to France, where he was welcomed into the Société d'Arcueil. He was elected to the Institut de France as an astronomer on 18 September 1809 and in that year also succeeded Monge as professor of descriptive geometry at the École Polytechnique, where he taught a variety of subjects until his resignation in 1830. At the request of the Bureau des Longitudes, which placed the Paris Observatory under his direction, Arago also taught astronomy to the general public at the observatory from 1813 to 1846. He was the main contributor to the *Annuaire du Bureau des Longitudes* for more than forty years and coeditor, with Gay-Lussac, of the *Annales de chimie et physique* from 1816 to 1840. He was a member of most of the important scientific societies, receiving the Royal Society's Copley Medal in 1825 and being elected perpetual secretary of the Académie des Sciences, replacing Fourier, on 7 June 1830.

Arago was at once volatile and warm-hearted in his personal relations. He either forged strong bonds with fellow scientists or engaged in sharp polemics that often were provoked by priority controversies. Among his closest friends were Alexander von Humboldt, with whom he shared a room in Paris from 1809 to 1811. Gay-Lussac, and Malus; and among his relatives, the physicist Alexis Petit and the astronomer Claude L. Mathieu. He had a stormy relationship with Biot, Thomas Young, and Brewster, but it did not blind him to their scientific merits. In both his writings and his public appearances, Arago conveyed a contagious sense of excitement that won him a large following. His personal style, which spilled over into his work habits, was that of a romantic—restless, inquisitive, volatile, and constantly bubbling with enthusiasm and optimism. Married in 1811, Arago had three sons and lived in an apartment at the observatory. In his later years he gradually lost his eyesight, went blind, and was reduced to dictating to his students.

Arago's most important original work in science was carried out before 1830, for his younger brothers, particularly Étienne, drew him into politics following the July Revolution of 1830. He was repeatedly elected deputy for his native department (Pyrénées-Orientales) and for Paris between 1830 and 1852, and sat on the left in the Chamber of Deputies, delivering influential speeches on educational reform, freedom of the press, and the application of scientific knowledge to technological progress, particularly concerning canals, steam engines, railroads, the electric telegraph, and photography. He also was twice named president of the Paris Municipal Council. The peak of Arago's political career came after the February Revolution of 1848, when he was made a member of the provisional government and was named, successively, minister of the navy and the army and president of the Executive Committee. As minister he signed decrees outlawing corporal punishment and improving the rations of sailors on the high seas, and abolishing slavery in the French colonies. His politics were those of a constitutional liberal, passionately concerned with social reform (he helped found *La réforme* in 1843), freedom of association, and education of the lower classes. He was, however, violently opposed to mob rule and to the socialistic programs espoused by Louis Blanqui, Alexandre Ledru-Rollin, and Louis Blanc. Arago's effective political career ended following his loss of control over the revolutionaries during the June days of 1848.

Arago's scientific life was dominated by a persistent interest in physical phenomena related to electricity, magnetism, and, above all, to light. His earliest investigations with Biot in 1805 and 1806 continued the work of Borda on the factors affecting the refraction of light passing through the atmosphere of the earth. They helped to verify the formulas given in Laplace's *Mécanique céleste*, which were based on the assumption that the atmosphere is composed of concentric rings of a mixture of oxygen and nitrogen, with density as a function of altitude. Biot and Arago showed experimentally that temperature and pressure were significant variables, whereas humidity and the traces of carbon dioxide in the atmosphere could be disregarded. But when Arago extended his investigations to refraction in liquids and solids—with Petiti in 1813 and Fresnel in 1815—he recognized the failure of the current theory of emission and particulate attraction to account for the empirical formulas he derived. After his return from the geodetic expedition to extend meridian triangulations from Barcelona to the Balearic Islands. Arago became a vocal critic of the Newtonian emission theory and, by 1816, an ardent supporter of the undulatory theory.

The original source of Arago's interest was Thomas Young's classic paper of 1801 on the color of thin glass plates and the discovery of polarization by Malus in 1808. Arago continued their independent investigations by passing beams of polarized light through a variety of gaseous and crystalline substances at various degrees of incidence to study the light's properties. His results, which suggested the usefulness of the undulatory theory, included the discovery of chromatic polarization by the use of thin mica plates (1811), rediscovered independently by Brewster; the elaboration of the conditions necessary to produce Newton's rings (1811); and the observation of special cases of rotary polarization (1812), which were shortly thereafter made a general law of optics by Biot.

It was this series of disparate experiments that caused Fresnel to write to Arago in 1815 to announce his theory of stellar aberration and the explanation of diffraction phenomena by undulatory principles. Although Fresnel's "discoveries" had retraced the work of Bradley and Thomas Young, Arago urged him to pursue his investigations and agreed to collaborate with the young engineer. Together they published a series of papers advocating the undulatory theory of light, answering one by one the criticisms of the partisans of emission theory, especially Arago's colleagues and former friends, Laplace and Biot. In this collaborative enterprise Fresnel supplied the crucial mathematical analyses and the seminal concept of transverse waves, while Arago contributed his encyclopedic command of the current literature in optics, his critical powers, and a significant number of experimental insights and actual experiments.

Above all, Arago functioned as a catalytic agent and public defender of the new theory, and eventually as its major historian. In 1824 he wrote an important article on polarization, translated by Young for the *Encyclopaedia Britannica*, and later wrote detailed and moving biographical notices of Fresnel (1830), Young (1832), and Malus (1853), sprinkled with personal anecdotes of great significance. It was Arago who, in 1838, borrowing and amplifying the idea and apparatus from Wheatstone's experiments for measuring the speed of electricity, suggested the "crucial experiment" to decide between the corpuscular and undulatory theories of light by comparing the speed of light in water and in air. The experiment, which vindicated the undulatory position, was carried out by Foucault in 1850 and announced to the Academy in Arago's presence.

Arago was also concerned with optical instruments that proved useful for a variety of purposes, in physics and meteorology as well as in astronomy, for which they were mainly devised. In 1811 he invented the polariscope to determine the degree of polarization of light rays by passing them successively through a mica or rock-crystal polarizer and an Iceland spar analyzer. With the addition of a series of properly graduated plates that could be inclined at will with reference to the incident ray, Arago transformed his polariscope into a polarimeter, which he used to verify one of the few mathematically expressed laws he discovered; the cosine-squared law for calculating the intensity of the ordinary ray in double refraction. In 1833 he derived from it the ratio of the amount of polarized light to neutral light: cos $2i$ for the ordinary ray and $2 \sin^2 i$ for the extraordinary ray, where i is the angle between the rock-crystal polarizer and the plane of polarization of the incident ray. With the polarimeter, he was able to differentiate between light emanating from solid and liquid surfaces, polarized by reflection and from incandescent gases, and to determine that the edge of the sun is gaseous. The polarimeter also suggested to him ways to determine polarization of the corona during total eclipses, to determine that rays from the sun's halo are refracted but not reflected, to observe the nature of a comet's tail, and to calculate the height of isolated clouds.

In 1815 Arago built a primitive cyanometer to measure the degree of blueness of the atmosphere, which was later adapted for use in hydrographical determinations of the depth of the sea. In 1833 he proposed a photometer to measure comparative intensities of stellar light; his student Paul Ernest Laugier later employed it. He also perfected an ocular micrometer for measuring small angles, which was erroneously attributed to William Pearson. The workings of all these instruments, based upon polarization phenomena, were expounded with great clarity and enthusiasm in Arago's public lectures at the observatory, published posthumously as *Astronomie populaire*.

As a young astronomer and member of the Bureau des Longitudes, Arago made numerous observations and important theoretical proposals. Among them were the explanation of the scintillation of stars by the use of interference phenomena and the realization of the asymmetry of the layers of atmosphere with reference to the observer. In his later years he made some important remarks on solar appendages noticed during the 1842 eclipse, which he observed with Laugier and Mauvais. But it was even more by the stimulus he gave younger astronomers—including Paul Laugier, Félix Mauvais, Jean Goujon, Jules Jamin. Hervée Faye, and Charles Mathieu—that Arago made made his reputation as an astronomer. It also was Arago who urged Leverrier, his successor as director of the observatory, to take up Bouvard's work on the tables of Uranus. These investigations eventually led to the prediction of the existence and position of Neptune. Arago was also attentive to instrument makers, being responsible for promoting the precision work of Henri Gambey and Louis Bréguet. He was proud that during his tenure at the observatory most of its late eighteenth-century, English-made instruments were gradually replaced by better, French apparatus.

In 1820 Arago interrupted his optical work to play a significant role in the elaboration of electrodynamic and electromagnetic theories. Invited to the La Rive laboratory in Geneva to witness the verification of Oersted's experiments linking electricity to magnetism, he immediately acquired a passionate interest in the subject, displaying what Humboldt characterized as "the intolerance of a new convert." Arago repeated the Geneva experiments at the Paris Academy on 11 September 1820, thereby inspiring Ampère to elaborate his electrodynamic theory of electricity and magnetism. Although the two scientists did not write joint papers, they were in constant and friendly communication, often working in each other's laboratories. Just as Arago had been the champion of Fresnel's theories in 1815, so now did he propa- gandize Ampére's new theory and vehemently support his novel views. Because of his loyalty to Ampére, Arago was never fully able to appreciate or accept the rival theory of Faraday.

Arago also made several important contributions to electromagnetism on his own. On 20 September 1820 he announced the discovery of the temporary magnetization of soft iron by an electric current, which suggested to Ampère a theory about the nature of magnetic "currents" and provided the technological key to the electric telegraph. Ampère calculated that the magnetic power could be multiplied by twisting the current-carrying wire into a helix, and with Arago he carried out the first experiments on primitive solenoids. In his historical articles Arago was always careful to credit Ampère with the major share of this discovery, which ultimately depended upon Ampère's mathematical theory. In 1822, while he and Humboldt were magneic intensity of a hill at Greenwich, Arago casually noticed the dampening effect that metallic substances had on the oscillations of the compass needle. After a delay of several years, during which he worked on the speed of sound and the crystalline anture of ice, and wrote up his observation on the chemical and thermal effects of light, Arago recognized the importance of his original observation at Greenwich. He announced that the rotation of nonmagnetic metallic substances (especially copper)created a magnetic effect on a magnetized needle. Known as Arago's "disc" or "wheel," it was the discovery of this effect that won him the Copley Medal in 1825 John Herschel and Babbage attempted to explain the phenomenon on the basis of Ampère's theory, but it was Faraday who in 1831 explained it by his theory of induction. By this time Arago had abandoned electrical research and had turned to other, more eclectic concerns.

In 1824 Arago was a member of an academic commission to study steam pressure, with the aim of reducing the dangers of explosion in steam engines. He and Dulong prepared elaborate apparatus for measuring pressure under high temperatures, verifying Boyle's law for values up to 24 atmospheres. Through his long-standing friendship with Humboldt, Arago was led to write popular articles on meteorology and physical geography, which ranged from discussions of the temperature of the earth, the seas, and the atmosphere to earthquakes and magnetic variations on the earth. He was particularly influential in propagating Humboldt's concept of isothermal lines and in setting down the purposes of and data required from scientific expeditions. In 1839 Arago took a personal interest in announcing and popularizing the inventions of Niepce and Daguerre, who were awarded government pensions as a result of Arago's recognition of their inventions' potential significance.

In his last years, while his sight was failing him, Arago continued to discharge his duties as perpetual secretary of the Academy by summarizing the achievements of other scientists and by suggesting new experiments that he himself could not carry out. Surrounded by a group of devoted younger scientists who wrote, observed, and experimented for him, Arago never lost his mental energies and his ability to stimulate his colleagues and excite the public about the progress of science.

BIBLIOGRAPHY

I. Original Works. Arago published no single scientific treatise of major significance during his lifetime. After the June days of 1848 he began arranging his papers in preparation for a complete edition. It was published posthumously as *Oeuvres de François Arago*, J. A. Barral, ed., 17 vols. (Paris, 1854–1862; 2nd ed., 1865), with an introductionh by Humboldt. It contains most of his published articles (somewhat edited) and reports, the revised portions of his lectures *(Astronomie populaire)*, and many previously unpublished notes. Missing is the *Recueil d'observations géodésiques, astronomiques et physiques en Espagne, en France, en Angleterre et en Ecosse, pour déterminer la variation de la pesanteur et des degrés terrestres sur le prolongemeni du méridien de Paris* (Paris, 1821), written with Biot, and a number of reports prepared for the Academy, which are printed in the *Procés-verbaux des séances de l'Académie*, 10 vols. (Hendaye, 1910–1922), for the period until 1835 and unpublished in the archives of the Academy thereafter. Arago also collaborated with Bouvard, Mathieu, and Nicollet in preparing *Observations astronomiques, faites à l'Observatoire royal de Paris*, 2 vols. (Paris, 1825–1838). He annotated and edited Alexandre Bertrand, *Lettres sur les révolutions du globe* (5th ed., Paris, 1839); Jacques Etienne Victor Arago, *Souvenirs d'un aveugle*, 2 vols. (Paris, 1842–1843); and Condorcet, *Oeuvres*, 12 vols. (Paris, 1847–1849).

Of Arago's voluminous correspondence, only a small portion has been published: *Correspondance d'Alexandre de Humboldt avec François Arago (1809–1853)*, E. T. Harpy, ed. (Paris, 1908). The library of the Paris Observatory has over 50 unpublished letters (B4 9–12) and most of his MS notes and observations related to astronomy (C6 8–11, E1 19, E3 4–13). An important correspondence with Thomas Young is at the British Museum (Add. MSS 34613) and at the Royal Society Library.

II. Secondary Literature. The best biography is still Maurice Daumas, *Arago* (Paris, 1943), despite its meager scholarly apparatus. In addition to the works cited in Daumas's bibliographical essay, pp. 273–275, and in Horace Chauvet, *François Arago et son temps* (Perpignan, 1954), consult Maurice Crosland, *The Society of Arcueil* (London, 1967), *passim*.

Roger Hahn