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(*b*. Dijon, France, 10 February 1785; *d*. Paris, France, 21 August 1836)

engineering, mechanics.

During the French Revolution, Navier's father was a lawyer to the Legislative Assembly at Paris and his mother's uncle, the engineer Emiland Gauthey, worked in the head office of the Corps des Ponts et Chaussées at Paris. After her husband's death in 1793, Navier's mother moved back to Chalon-sur-Saône and left her son in Paris, under the tutelage of her uncle. In 1802, after receiving preparation from his granduncle, Navier entered the École Polytechnique near the bottom of the list; but he did so well during his first year that he was one of ten students sent to work in the field at Boulogne instead of spending their second year in Paris. Navier's first year at the École Polytechnique had critical significance for the formation of his scientific style, which reflects that of Fourier because the latter was briefly his professor of analysis. He subsequently became Fourier's protégé and friend.

In 1804 Navier entered the École des Ponts et Chaussées, from which he graduated in 1806 near the top of his class. After spending a few months in the field, he was brought to Paris to edit the works of his granduncle, who had just died and who had become France's leading engineer. Navier, who seems to have been insecure financially, lived for the rest of his life in the St.-Germain-des-Prés quarter of Paris. His wife, Marie Charlot, whom he married around 1812, came from a family of small landowners in Burgundy.

Navier was a member of the Société Philomatique (1819) and of the Académic des Sciences (1824). In 1831 he became *Chevalier* of the Legion of Honor. From 1819 he taught and had complete charge of the courses in applied mechanics at the École des Ponts et Chaussées but did not become titular professor until 1830, when A.-J. Eisenmann died. In 1831 Navier replaced Cauchy at the École Polytechnique. Navier participated in Saint-Simonianism and the positivist movements. He had Auguste Comte appointed to be one of his assistants at the École Polytechnique and participated actively in Raucourt de Charleville's Institut de la Morale Universelle.

Navier sought to complete the publishing project of his granduncle Gauthey. The administration of the Corps des Ponts et Chaussées, which looked with favor on this project, had him brought back to Paris in 1807 to publish Gauthey's manuscripts. This convergence of interests turned Navier into a theoretician who wrote textbooks for practicing engineers. His taste for scholarship and his background of higher analysis at the École Polytechnique and of practical engineering learned from his granduncle gave him the ideal preparation to make significant contributions to engineering science. During the period 1807–1820 he made mathematical analysis a fundamental tool of the civil engineer and codified the nascent concept of mechanical work for the science of machines.

Navier contributed only a few notes, of little scientific interest, to the first volume of Gauthey's works, which appeared in 1809. But during the next three years (1809–1812) he did a great deal of research in analytical mechanics and its application to the strength of materials as preparation for the second volume of Gauthey's works and for the revised edition of Bélidor's *Science des ingénieurs,* both of which appeared in 1813. The traditional engineering approach as exemplified by Gauthey studied experimentally the materials used in construction. These materials—primarily stone and wood—possess poor resistance to bending and were used rigidly. They also have widely varying properties that depend on their type and origin. In the traditional approach the engineer designed to avoid rupture and gave no thought to bending. He used large safety factors to compensate for the widely varying properties of the materials, which he viewed as rigid bodies subjected only to extension and to compression. On the other hand, the analytical tradition, which belonged to mathematical physics and did not form part of an engineer's training until after the creation of the École Polytechnique, studied idealized flexible bodies that can vibrate, such as strings, thin bars, and thin columns. In the derivation of analytical expressions these bodies were assumed to be subjected uniquely to pure bending; compression and tension were, therefore, ignored.

Navier, who had received training in both traditions, united them when he considered iron, which was just beginning to be used for bridges. He used a sort of principle of superposition: two sets of independent forces developed when bodies were bent—those resisting compression and extension and those resisting bending. He drew on the traditional engineering approach for the study of the first set of forces and on the analytical one for the second set. The first set follows Hooke's law that stress is proportional to strain. For the second set Navier used the relationship that the resistance varies as the angle of contingency (one divided by the radius of curvature), for which he referred to Euler's *Methodus inveniendi lineas curvas maximi minimive proprietate gaudentes* (1744).

Navier found an expression for the static moment of the resistance of any given fiber and then integrated it to find the total resisting moment, which he equated with the total moment of the applied forces. He concluded that for simple cases the moment of elasticity varies as the thickness squared, which quantity measures the resistance to extension, and as the thickness cubed times the length, which measures the resistance to bending. In his later study on the bending of an elastic plane (1820), Navier used the same general approach, which, however, led to fourth-order partial differential equations that had already been set down by Lagrange and Poisson. He showed how these can be solved in certain cases by applying methods that Fourier had used in an unpublished study.

In the 1813 editions of Bélidor and of Gauthey, Navier added notes which drew on the research of Coulomb and on the experimental tradition of eighteenth-century physics that had given him data for tables of the strength of stone and of wood. He appealed for further experiments on the strength of materials so that they could be used well in construction.

Navier's success as editior of Bélidor's *Science des ingénieurs* and of Gauthey's works led their publisher, Firmin Didot, to invite him to prepare a revised edition of Bélidor's *Architecture hydraulique*. Navier sought to correct the errors found in this work and to give it a mathematical sophistication that would make it useful to the graduates of the École Polytechnique. One item needed particular attention—the study of machines, for which Navier sought a quantitative criterion that would facilitate the selection of the best machines and motors. Research on this topic, conducted during 1814–1818, led him to the concept of quantity of action, which Coriolis shortly afterward transformed into that of mechanical work. A body animated by a force, Navier argued, can produce an effect observable to our senses only if this body covers a distance and at the same time exerts a pressure against an obstacle. Thus, for any interval of time, we can measure the effect of an acting force by the integral of $F\,dx$, where F designates the acting force and x the distance through which it acts. Navier, who drew on Lazare Carnot, then equated this to half the *vis viva* (mv^2) acquired by the moving body during the same interval, less that lost through sudden changes of speed. Because he thought that the above relation applied only to cases for which the various parts of a system are linked by expressions independent of time, he did not achieve a full concept of the conservation of mechanical work as did G.-G. Coriolis. Navier called the action of a force over a distance "quantity of action," an expression taken from Coulomb, and related this to the quantity of work (in a nontechnical sense) used to run the machine. Citing Montgolfier, who said that it was the quantity of action which pays, Navier called the quantity of action a mechanical form of money. In Navier's writings the march of the argument leads to the concept of work, whereas in those of J.-V. Poncelet and of Coriolis it flows from this concept. It took an embryonic form in the writings of Lazare Carnot, found its birth in those of A.-T. Petit, Poncelet, and Navier, and achieved the status of a general principle of applied mechanics in those of Coriolis. In Navier's revision of *Architecture hydraulique,* the engineer found this concept so defined as to give a measure of the usefulness of motors and a criterion that permitted rational design of motors and machines.

Editing the works of Gauthey and Bélidor in the years between 1809 and 1819 led Navier to make significant contributions to engineering science and placed him in a position to institute a new era in the teaching of engineering. His courses, the style of which was influential for well over a half a century, built on the creative physics of his generation, liberally applied analytical mechanics, and thus gave to the civil engineer tools adapted to an industrializing age.

During the years 1820–1829 Navier's research moved in two directions. In practical engineering he designed a suspension bridge that spanned the Seine in front of the Invalides, where today the Pont Alexandre III stands. Just as his bridge was in the final stages of construction, a sewer broke and the resultant flooding caused the bridge to list. This accident, which, in the view of the Corps des Ponts et Chaussées, could have been easily repaired, gave to the Municipal Council of Paris, which had opposed Navier's project, the opportunity to put pressure on the government to order the bridge torn down, to Naviers great chagrin.

In theoretical science Navier studied the motion of solid and liquid bodies, deriving partial differential equations to which he applied Fourier' methods to find particular solutions. This theoretical research led him to formulate the well-known equation identified with his name and that of Stokes. Navier viewed bodies as made up of particles which are close to each other and which act on each other by means of two opposing forces—one of attraction and one of repulsion—which, when in a state of equilibrium, cancel each other out. The repelling force resulted from the caloric that a body possessed. When equilibrium is disturbed in a solid, a restoring force acts which is proportional to the change in distance between the particles. In a liquid this force becomes proportional to the difference in speed of the particles. For both cases Navier derived equations that proved to have the same mathematical form. Although he had no concept of shear and used a concept of intermolecular forces that is unacceptable today, he achieved results of which the expressions remain valid because he carefully summed moments of forces about orthogonal axes. This guaranteed that he did not overlook any forces that were acting even though he did not possess an efficient formulation for them.

Following the July Revolution, Navier became an active technical consultant to the state. He reported on the policy that should be adopted for policing the road transportation of heavy loads, for bidding to obtain government contracts, for constructing roads, and for laying out a national railway system. His reports exhibit Navier's high engineering ability and his continuing commitment to the Saint-Simonian and positivist movements.

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II. Secondary Literature. A. Barré de Saint-Venant, op cit., pp. xxxix–liv, lists obituaries by P. S. Girard, by C. H. Emmery de Sept-Fontaines, and by G. C. Prony, who errs in Navier's date of birth; in the library of the École des Ponts et Chaussées a MS biography of Navier contains obituaries by Coriolis and by Raucourt, the latter from *Éducateur, journal de l'Institut de la morale universelle …,***1,** no. 5 (Sept.-Oct. 1836), 38–39; there is also a notice by Fayolle in Biographic universelle, LXXV (Paris, 1844), 314–317. Navier's standing as a student at the École des Ponts et Chaussées is detailed in Archives nationales, Paris, F142148, F1411054, F1411055 (which also contains remarks about Navier's course).

A. Barré de Saint-Venant, op. cit., op. xc–cccxi, gives a comprehensive history of the strength of materials and locates Navier's work within it; S. Timoshenko, in *History of Strength of Materials* (New York, 1953), 70–80; and I. Todhunter, in *A History of the Theory of Elasticity and of the Strength of Materials*, I (repr. New York, 1960), 133–146, cover the same ground. F. Stüssi, "Baustatik vor 100 Jahren—die Baustatik Naviers," in *Schweizerische Bauzeitung,***116** , no. 18 (2 Nov. 1940), 201–205, discusses Navier's ill-fated bridge and the correctness of his research on the strength of materials.

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The official *Moniteur universel* (24 Feb. 1828), 251–252, defends Navier's bridge, which Balzac ridicules in his *Oeuvres*, M. Boutreron and H. Longnon, eds., XXV (Paris, 1922), 196, and notes on 299–302. G. Le Franc, "The French Railroads 1823–1842," in *Journal of Economic and Business History*, **2** (1929–1930), 299–333, gives the background that enables one to situate Navier's writings on railway systems.

Navier's association with positivism may be traced through *Journal du genie civil …, Éducateurf, journal de I'lnstitut de la morale universelle* (Bibliothèque Nationale, Paris, cote R7368), and through the archives of the École Polytechnique, Paris, "Registres du Conseil d'instruction," **7bis** , 30 Oct. 1833 and 31 Oct. 1834.

At the archives of the École Polytechnique, the "Registre matricule des élèves" describes Navier; the cartons for 1802 and for 1803 give Navier's standing; that for 1831 contains the letter appointing Navier professor; the "Registre du Conseil d'instruction," **7bis** , 18 Dec. 1830 and 29 Jan., 18 Feb., 4 Mar., and 18 Mar. 1831, details Navier's election to his professorship at the École Polytechnique; the same vol. reveals the conflict between Navier and Poisson concerning the teaching of Fourier's theory of heat (see 20 July 1831, 29 May 1832); on this conflict also see the "Registre du Conseil de perfectionnement," **6** , 54.

Also consult the following works by R. McKeon: "A Study in the History of Nineteenth Century Science and Technology: Engineering Science in the Works of Navier," in *Proceedings of the XIIIth International Congress of the History of Science, section 11, history of technology*; "Profile chronologique de Navier," deposited at the Centre Alexandre Koyré, Paris, on 23 Nov. 1970; and "Navier éditeur de l'Architecture hydraulique de Bélidor," unpublished report read at the Congrès de l'Association française pour l'avancement des sciences, Chambéry, France, 8 July 1971, of which an extract is in *Sciences*, **3** (1972), 256–257.

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