he built perhaps two hundred small steam engines. His major contributions were in instrumentation, however, and the most important single innovation was his "metallic manometer," which in his patent of 18 June 1849 was described as a "pressure gauge without mercury." This gauge is by far the most widely used for indicating pressures in the range of 15 to 100,000 pounds per square inch. The sensing element, or transducer, of the gauge was and is the Bourdon tube, which is a metal tube with an elliptical cross section. This tube, bent into a C, a helix, or a spiral, or simply twisted about its central axis (all except the spiral were used by Bourdon in 1851), tends to straighten out when pressure is applied to a fluid within it. When one end of the tube is fixed, the movement of the other end will indicate variation of pressure. Obituary notices repeat the story that Bourdon was led to the principle of the Bourdon tube by observing the action of a lead cooling coil under internal pressure. Judging from his painstaking attention to detail, this explanation is not unreasonable. Important aspects of the design of Bourdon tubes are still based upon empirical evidence rather than mathematical analysis.

In 1851, as a result of the success of his gauges at the London International Exhibition, Bourdon was awarded the Legion of Honor.

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EUGENE S. FERGUSON

BOURNON, JACQUES-LOUIS, COMTE DE (*b.* Metz, France, 21 January 1751; *d.* Versailles, France, 24 August 1825), *mineralogy.*

Bournon was an early and ardent supporter of the Abbé Haüy's theories of crystal structure. In approximately twenty scientific memoirs he followed Haüy's procedure in identifying the integrant molecules of various mineralogical species, but he did not hesitate to criticize Haüy's judgment when he considered it erroneous. His major work was the handsomely illustrated three-volume *Traité complet de la chaux carbonatée et de l'arragonite* (1808), in which he described minutely all of the currently known crystal variations of calcite and aragonite.

Bournon's father, the owner of the Château de Fabert, near Metz, had formed a large mineralogical collection that stimulated Bournon's early and lasting interest in mineralogy. Bournon pursued a military career, becoming a lieutenant of the marshals of France. In 1791 he emigrated to the Rhineland and fought in the army of the princes in the campaign of 1792, after which he went to England. He was well received in scientific circles there, owing to his *Essai sur la lithographie de St. Étienne-en-Forez et sur l'origine de ses charbons de pierre* (1785).

In England, Bournon lectured frequently on mineralogy and organized the large mineralogical collections of Lord Grenville, Sir Abraham Hume, and Sir John St. Aubyn. He was elected a fellow of the Royal Society in 1802 and helped to found the Geological Society, of which he was the first foreign secretary, from 1811 to 1814. He returned to France after the restoration of the Bourbons and became the director general of the mineralogical cabinet of Louis XVIII. The mineral bournonite, a sulfantimonite of lead and copper characterized by beautifully shaped crystals that are often twinned, was named after Bournon, who first described it completely in 1804.

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Bournon's important works are *Essai sur la lithographie de St. Étienne-en-Forez et sur l'origine de ses charbons de pierre* (Paris, 1785); *Traité complet de la chaux carbonatée et de l'arragonite,* 3 vols. (London, 1808); *Traité de minéralogie,* 3 vols. (London, 1808); *Catalogue de la collection minéralogique du Comte de Bournon* (London, 1813); and *Catalogue de la collection minéralogique particulière du roi,* 2 vols. (Paris, 1817). His mineralogical memoirs were published principally in the *Philosophical Transactions of the Royal Society,* London, the *Journal des mines,* and *Transactions of the Geological Society.*

JOHN G. BURKE

BOUSSINESQ, JOSEPH VALENTIN (*b.* St.-André-de-Sangonis, Hérault, France, 15 March 1842; *d.* Paris, France, 19 February 1929), *mechanics, theoretical physics.*

Boussinesq came from a family of small farmers, and his first lessons were given by the village schoolteacher and by his uncle, a priest. He then attended the small seminary at Montpellier. After receiving the *baccalauréat,* he became an assistant master in a private school but was not responsible for teaching the children. When he obtained his *licence ès sciences* in 1851, Boussinesq went on to teach at the Collège d'Agde, then at Le Vigan, and later at Gap. Self-taught in scientific matters, he nevertheless was able, in 1865, to present a report on capillarity to the Académie des Sciences. In 1867 his thesis on the spreading of heat won him his *docteur ès sciences* as well as the goodwill of the academician and mathematician Barré de Saint-Venant. Boussinesq then became a professor at the Faculté des Sciences in Lille in 1873, and later he was assigned the chair of physical and experimental mechanics in Paris, followed by those of mathematical physics and of the calculus of probabilities. He was elected to the Académie des Sciences in January 1866 and eventually became its dean; at his death he was its oldest member.

Boussinesq led a simple, secluded life dedicated entirely to science and meditation on philosophical and religious problems, particularly on the conciliation of determinism and free will. He humbly admitted "the smallness of the ensemble of our unclouded knowledge lost in an ocean of darkness."

Faithful to mechanistic thought, which seeks kinematic representations, Boussinesq started with the principle of the conservation of energy and the principle that the accelerations of the points in an isolated system depend solely upon its static state and not on the velocities. He combined a great imaginative boldness with submission to experimental results. One of his conclusions was that simplicity is indispensable in scientific organization and that intuition is a valuable guide. Boussinesq loathed the introduction of such monsters as continuous functions without derivatives and of non-Euclidean space. Hostile to relativist innovations, he remained loyal to classical mechanics and sure of the reality of the ether. He did, however, make important contributions to all branches of mathematical physics except that of electromagnetism.

Boussinesq brought the theoretical study of ether closer to the study of experimental hydrodynamics in his researches on light waves and the theory of heat. His work on hydraulics was considerable; and with extraordinary insight he was able to use a method of legitimate approximation that made it possible to carry out intricate calculations concerning the study of whirlpools, liquid waves, the flow of fluids, the mechanics of pulverulent masses, the resistance of a fluid against a solid body, and the cooling effect of a liquid flow.

Although Boussinesq approached mathematics only in order to apply it practically, he was led to some interesting analyses in seeking the solution of particular problems. In the field of elasticity he obtained some intuitive results when considering certain potentials (logarithmic potentials with three variables, spherical potentials with four variables). In 1880 Boussinesq came upon nonanalytic integrals of hydrodynamic equations. He also found some asymptotic solutions of differential equations corresponding to cases of physical indetermination.

Boussinesq left a considerable amount of work. Besides the hundred or more papers he submitted to learned societies, he published several scholarly and abstruse books, full of original ideas but unorganized and often obscure. By virtue of the spirit of his research he can be considered one of the last figures of classical science in the nineteenth century.

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LUCIENNE FÉLIX

BOUSSINGAULT, JEAN BAPTISTE JOSEPH DIEUDONNÉ (*b.* Paris, France, 2 February 1802; *d.* Paris, 11 May 1887), *agricultural chemistry.*

Boussingault's education, although not extensive, was influenced by Thénard, Gay-Lussac, Georges Cuvier, and Haüy; he also studied engineering. His South American geological and meteorological research in 1821–1832, recommended by Alexander von Humboldt, earned him recognition as a scientist and election to the Académie des Sciences in 1839.

From 1834 to 1876, Boussingault applied organic analysis in field and laboratory research on his farm at Bechelbronn, Alsace, to problems of soil fertility, crop rotation, plant and soil fixation of nitrogen, ammonia in rainwater, and nitrification, in order to