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(*b*. Angouleme, France, 14 June 1736; *d*. Paris, France, 23 August 1806)

physics, applied mechanics.

One of the major figures in the history of physics and engineering, Coulomb's main contributions were in the fields of electricity, magnetism, applied mechanics, friction studies, and torsion. His father, Henry, came from Montpellier, where the family was important in the legal and administrative history of Languedoc. His mother, Catherine Bajet, was related to the weathy de Sénac family. During Coulomb's youth the family moved from Angoulême to Paris, where he attended lectures at the Collège Mazarin and the college de France. An argument with his mother over career plans caused Coulomb to follow his father to Montpellier after the latter became penniless through financial speculations. Couloub joined the Société des Sciences de Montpellier as an adjoint member in March 1757 and read several papers in astronomy and mathematics there during the next two years.

He went to Paris in the autumn of 1758, seeking the tutoring necessary for him to enter the École du Genie at Mézières. After some months of study he passed the abbé Charles Camus's entrance examination and took up residence at Mézières in February 1760. At about this time he formed lasting friendships with Jean Charles Borda and with the abbé Charles Bossut, his teacher of mathematics at Mézières. Coulomb graduated in November 1761 with the rank of *lieutenant en premier* in the Corps du Génie. His first post was at Brest; but in February 1764 he was ordered suddenly to proceed to Martinique, where he remained until June 1772. Coulomb was put in charge of constructing Fort Bourbon, at a cost of six million livres. He directed several hundred laborers in all phases of the construction, and this experience was important as a foundation for some of his later memoirs in mechanics. Coulomb became seriously ill several times during his stay in Martinique, and these illnesses affected his health to the extent that he was never again a well man.

Following his return to France, Coulomb was posted to Bouchain, where he composed an important memoir in mechanics that earned him the title of Bossut's correspondent to the Paris Academy of Sciences (6 July 1774). Coulomb moved then to duty at Cherbourg, where he began work on a memoir on magnetic compasses that subsequently shared first prize in the Paris Academy's competition for 1777. The importance of this major physical studies: the quantitative study of magnetism, torsion and the torsion balance, friction and fluid resistance, and the germ of his theories of elasticity and of magnetism.

One other event during his stay at Cherbourg merits attention: his submission in 1776 of a plan for the reorganization of the Corps du Génie. The comte de St.-Germain became minister of war in October 1775, during the administration of Turgot. Coincident with Turgot's reform aims, St.-Germain called for memoirs on the reorganization of the Génie. Coulomb's unpublished "Mémoire sur le service des officiers du Corps du Génie" was organized around two principles, the individual and the state. He sought to define the maximum utility to be obtained for each and to show that the best use of the Génie brought the most to each individual.

Coulomb saw the opportunity for public works in time of peace and favored the establishment of review boards to judge the worth of proposed projects. Most of all, he saw the Corps du Génie and public service as a whole as a "corps a talent," that is, with appointment and advancement based on ability and accomplishment. He stressed not the evils of the state but the potential of the state and individual in balance.

Coulomb was posted to Rochefort in 1779 to aid the notorious marquis de Montalembert in constructing his controversial fort entirely of wood on the nearby Île d'Aix. During this period Coulomb found time to engage in a lengthy series of experiments on friction in the shipyards at Rochefort. The result of these researches won the double first prize at the Academy in Paris in 1781 and gained Coulomb election to the Academy as adjoint *mécanicien*. Membership in the Academy finally assured Coulomb of a Paris residence, after seven different field posts and twenty years' service in the Corps du Génie.

The year 1781 marked a decisive break in Coulomb's life and career. Permanently stationed in Paris, he could find a wife and raise a family. Henceforth, his engineering duties would be only as a consultant, and he was able to devote the major portion of his time to researches in physics. Coulomb the engineer became physicist and public servant. He read twenty-five scientific memoirs at the Academy (and at its successor, the Institut de France) from 1781 to 1806. His most famous memoirs were the series of seven memoirs on electricity and magnetism and the memoirs on torsion and the applications of the torsion balance. In addition to his physics research Coulomb participated in 310 committee reports to the Academy concerning machines, instruments, canals, and engineering and civic projects. In 1787 Coulomb and Jacques Rene Tenon were sent to England to investigate hospital conditions in London. In 1801 Coulob with whom Coulomb worked most closely were geometers, mechanicians, or astronomers (e.g., Bossut, Leroy, Borda, Prony, Laplace).

Coulomb's most celebrated engineering consulting task was in Brittany in 1783–1784. Here he became involved, against his will, in a commission to recommend canal and harbor improvements. The commission (which included Borda and the abbé Alexis Marie Rochon) submitted a critical report and Coulomb suffered as the scapegoat, being confined to prison for one week in November 1783. Coulomb's excellent reports to the Academy on canals and water supply systems led the comte d'Angiviller to nominate him in July 1784 as intendant of the royal waters and fountains. The task of intendant involved supervising the management of water systems in all royal properties, including a good part of the water supply of Paris. Most biographical sketches of Coulomb mention that he was appointed curator of the large collection of secret military relief maps of French cities and fortresses. Archival records, however, indicate this not to be so.

The Revolution of 1789 caused little outward change in Coulomb's activities. He was in the midst of his great series of memoirs on electricity and magnetism, and his committee reports to the Academy continued as usual. By 1791, however, the National Assembly had overturned or reorganized many of the institutions of the *ancien regime*, and such measures applied to the Corps du Génie led Coulomb to resign from the corps in April 1791. He retired with the rank of lieutenant, colonel, was holder of the Croix de St. Louis, and had thirty-one years' service in the corps. He obtained an annual pension of 2,240 livres, which was reduced by two-thirds after the Revolution. Coulomb continued active participation in the Academy until its abolition on 8 August 1793. About the same time he was removed from his position as intendant of waters. He continued work on a committee for standardization of weights and measures until it was "purged" in December 1793. At this time he and Borda retired to La Justinière, some property Coulomb owned near Blois. He returned to his research in Paris in December 1795, upon his election as member for *physique expérimentale* in the new Institut de France. His elder son, Charles Augustin II, was born in Paris on 26 February 1790 and his younger son, Henry Louis, was born there on 30 July 1797. Coulomb legitimized his marriage to Louise Françoise LeProust Desormeaux on 17 brumaire, an XI (1802).

Coulomb's last public service was as inspector general of public inspector general of public instrucion from 1802 until his death in 1806, in which office he played a significant role in supervising the establishment of the French system of *lycées*. Coulomb's health, weakened long before during his duty in Martinique, declined precipitously in the early summer of 1806, and he died on the morning of 23 August. Since he had been baptized in the Roman Catholic faith, his final services were held at the Abbaye de St.-Germain-des-Prés. There is little evidence, however, to indicate the extent of his religious convictions. Secondary accounts indicate that the Revolution took most of Coulomb's properties and that he died almost in poverty. Examination of the probate of his estate establishes, however, that Coulomb left over 40,000 francs. (This at a time when a physics professor at a good French university would receive perhaps 6,000 francs per year.) Two decades of field duty in the Corps du Génie must have accustomed Coulomb to a modest style of life. The probate description of his personal belongings accords with this. He was accomplished in history but not a man of letters; his library contained 307 books, 238 of which were volumes issued by the Academy. Coulomb is often referred to as "de Coulomb," implying nobility. He never signed himself as such, and there is no evidence to indicate that any of his family were ennobled.

Applied Mechanics. Generally speaking, Coulomb's studies in mechanics preceded his researches in physics. His mechanics included fundamental memoirs on structural mechanics, rupture of beams and masonry piers, soil mechanics, friction theory, and ergonomics. In these he can be considered one of the great engineers in eighteenth-century Europe. Like Monge, he seemed to apply his talents to whatever was at hand. He took advantage of the peculiarities of each military post and pursued his studies in mechanics accordingly. He was talented but not exceptionally gifted in mathematics, although he was one of the first to utilize the variational calculus in practical engineering problems. With the exception of his friction studies, most of Coulomb's mechanics memoirs were little known until utilized by Prony, Thomas Young, and others in the early nineteenth century.

His most important memoir on mechanics was also his first, "Sur une application des règles de *maximis et minimis* à quelques problèmes de statique, relatifs à l'architecture" (1773). (The dates given herein for Coulomb's memoirs, unless otherwise indicated, are those dates when he formally presented the memoirs before the Paris Academy of Sciences. The actual dates of publication may be obtained from the bibliography.) The purpose of this memoir, he said, was "to determine, as far as a combination of mathematics and physics will permit, the influence of friction and of cohesion in some problems of statics." Coulomb's statics problems might seem disconnected to the modern reader, but they were at the heart of eighteenth-century engineering mechanics. If one examines the standard early eighteenth century work (e.g., Bernad Forest de Bélidor's *Science ds ingénieurs*, or Amédée François Frezier's *Traité de stereotomie*), one finds the main engineering topics to be the strength of masonry materials, the design of retaining walls, and the design of arches. These are precisely the problems that Coulomb attacked.

In the beginning of the 1773 essay, Coulomb introduced three propositions relating to equilibrium and resolution of forces. Following this, he considered friction and cohesion, and gave virtually a theory of the flexure of beams and rupture and shear of brittle materials. Coulomb utilized Amonton's law that frictional resistance is proportional to the normal force acting on the surface rather than to the area of the surface in contact. He noted, however, that this law is not strictly observed in practice and that the coefficient of friction varies with the materials involved. Following this, he considered cohesion. Friction was seen as resulting from tangential contact between bodies, but cohesion was supposedly due to the effect of close-acting central forces. Cohesion in materials was considered by Coulomb as a mixture of what would today be called shear and tensile strengths. According to him, cohesion is measured by the resistance that solid bodies oppose to direct "disunion" of their parts. In a homogeneous body each part resists rupture with the same degree of resistance. Therefore, total cohesion is proportional to the number of parts to be separated, and thus to the surface area of rupture. Experimenting with stone, mortar, and brick sections, Coulomb found values for ultimate strength under tension and shear. Although his experimentally.

determined values varied slightly, he assumed that shear and tensile coefficients were the same.

Having presented these basic propositions and experiments, Coulomb proceeded to a discussion of the flexing of a beam and correctly determined, for the first time, the neutral surface of a beam. Considering a rectangular cantilever beam (Fig. 1) of cross section *AD*, he concluded that the upper portion *AC* will be under tension and the lower portion *CD* under compression. Resolving the forces into horizontal and vertical components, he showed that the sum of horizontal forces along *AD* must equal zero and the sum of vertical forces must equal the load ϕ. Finally, the moment of the load ϕ about axis *C* must equal the sums of the internal moments of the beam. Note that although Coulomb took a perfectly elastic beam as an example, he realized the distribution of forces along *BCe* could be *any* sort of curve; and in Figure 1 he drew it as some sort of parabola. In addition, Coulomb recognized that shearing forces could be neglected in long, narrow beams. Following this, he extended his analysis to the rigid, inelastic case.

In this one memoir of 1773 there is almost an embarrassment of riches, for Coulomb proceeded to discuss the theory of compressive rupture of masonry piers, the design of vaulted arches, and the theory of earth pressure. In the latter he developed a generalized sliding wedge theory of soil mechanics that remains in use today in basic engineering practice. A reason, perhaps, for the relative neglect of this portion of Coulomb's work was that he sought to demonstrate the use of variational calculus in formulating methods of approach to fundamental problems in structural mechanics rather than to give numerical solutions to specific problems. It required that group of *Polytechniciens*, teachers and students, in the early nineteenth century to appreciate the importance of this work in the context of the new engineering mechanics. The eighteenth-century engineer preferred to use empirical design tables, such as those compiled by Jean Rudolph Perronet and Antoine de Chézy.

Coulomb's most celebrated study, one that brought him immediate acclaim, was "Théorie des machines simples," his prize-winning friction study of 1781. He investigated both static and dynamic friction of sliding surfaces and friction in bending of cords and in rolling. From examination of many physical parameters, he developed a series of two-term equations, the first term a constant and the second term varying with time, normal force, velocity, or other parameters. In agreement with Amontons's work of 1699, Coulomb showed that in general there is an approximately linear relationship between friction and normal force; but he extended the investigation considerably to show complex effects due to difference in load, materials, time of repose, lubrication, velocity, and other considerations. Coulomb's work in friction remained a standard of theory and experiment for a century and a half, until the advent of molecular studies of friction in the twentieth century. To quote Kragelsky and Schedrov's recent monograph (p. 52) on the history of friction: "Coulomb's contributions to the science of friction were exceptionally great. Without exaggeration, one can say that he created this science."

Another subject of much interest to Coulomb was the question of efficiency and output in work, and in this field (ergonomics) he made one of the most significant contributions before the studies of F. W. Taylor, a century later. Coulomb began this work in Martinique and read the first of several memoirs on the subject to the Academy in 1778. It was finally published in 1799 as "Résultats de plusieure expériences destinées à déterminer la quantité d'action que les hommes peuvent fournir par leur travail journalier, suivant les différent manières dont ils employent leurs forces." Earlier studies tested men or animals only for very brief periods, thus obtaining exaggerated results of productivity. Coulomb investigated various work parameters very realistically and with considerable psychological insight; and he distinguished between useful work and fatigue in work from living "machines," solving to make the ratio of effect to fatigue a maximum. In this he produced the first real study of the practical aspects of labor allocation. Among his findings were that frequent rest periods during certain tasks produce higher overall output, and that maximum daily human work results from seven to eight hours' labor for heavy tasks and ten hours' labor for light tasks. He utilized similar isoperimetric methods to investigate the theory and design of windmills.

Physics. Coulomb's election to the Paris Academy in 1781 and his acquisition of a permanent post in Paris allowed his research generally to turn from applied mechanics to physics. His physics work, however, is integrally tied to his earlier work in mechanics. His concern with friction and cohesion and his emphasis upon the importance of shear in structural mechanics are continued in his studies of torsion, in his ideas of "coercive force" in electrostatics and magnetism, and in his final studies in magnetism and the properties of matter.

Coulomb's first writings on torsion were presented in his Academy prize-winning memoir of 1777, "Recherches sur la meilleure maniere de fabriquer les aiguilles aimantées." He never attacked the general problems of elasticity (these were developed by Navier, Poisson, and Cauchy in the first decades of the nineteenth century), but his simple, elegant solution to the problem of torsion in cylinders and his use of the torsion balance in physical applications were important to numerous physicists in succeeding years. In chapter 3, Coulomb developed the theory of torsion in thin silk and hair threads. Here he was the first to show how the torsion suspension could provide physicists with a method of accurately measuring extremely small forces. He showed that within certain angular limits, torsional oscillation consisted of simple harmonic motion. He examined the parameters relating the angle of twist to the length, diameter, and elastic properties of the torsion thread. In the range of simple harmonic oscillation Coulomb demonstrated that the force of torsion was proportional to the angle of twist. He used this principle in measuring small magnetic forces and also called attention to its use in measuring other forces, notably those of fluids in motion. Eventually he was able to measure forces of less than 9×10^{-4} dynes.

This 1777 memoir contained the design of a torsion suspension declination compass. Adoption of this compass by the Paris Observatory in 1780 and the observatory's subsequent request for a solution to seemingly unresolvable problems in magnetic measurement led Coulomb to undertake a further series of experiments on torsion. His major memoir on torsion, presented 9 September 1784 ("Recherches theoriques et expérimentales sur la force de torsion et sur l'élasticité des fils de métal"), emerged from this latter investigation. This in turn provided him with a means to investigate and determine quantitatively the force relationships in varied physical fields. The torsion balance invented by Coulomb (see note) and the theory of torsion aided him in constructing theories concerning the molecular interaction within fluids and solids and, as is widely known, provided the instrumental foundation for his work in electricity and magnetism.

In his 1784 memoir Coulomb sought (1) to discover the laws of torsion and to determine possible applications of torsion and (2) to investigate the laws of coherence and elasticity of bodies by means of torsion. That is, as he noted, his study was in two regions of the torsion spectrum: the linear and nonlinear regions. Within the first he proposed to determine the linear relationship of force to torsion and to propose practical applications of this phenomenon for use in measuring various small forces. In the nonlinear region he proposed to investigate the mechanism of torsion itself, "in order to determine the laws of coherence and elasticity of metals and of all solid bodies." Coulomb developed both theoretically and experimentally the fundamental equation for torque in thin cylinders to be:

where M equals the torque, μ equals a constant rigidity coefficient, B is the angle of twist, and D and L are the cylinder diameter and length, respectively. In doing so, he corrected an error of his 1777 memoir (where he supposed the dependence on the diameter to be D^3).

Working with brass and iron wires, Coulomb found that the elasticity limit could be changed by work-hardening. Although the limit of elasticity could be changed, he found that the elasticity itself remained unchanged. This indicated to him the basic dissimilarity of the concepts of cohesion and of elasticity. Above a certain angle of torsion a thin cylinder, for example, either becomes noticeably inelastic or the range of elastic behavior may be shifted (permanent set). Here Coulomb gave the theory that *intramolecular* strains are elastically restored up to a certain limit. Beyond this limit the stresses become great enough to rupture the *intermolecular* bonds, and thus the material fractures or flows along a roughly planar section. After strain beyond the elastic limit but below rupture, the material is rearranged but the *intramolecular* elasticity remains the same. As Coulomb expressed it the *molécules intégrantes* change shape under stress without relative change of place. But when the force of torsion is greater than the force of cohesion, the molecules must separate or slide one over another. Through a certain range the sliding increases the area of mutual contact between the molecules and, therefore, the range of elasticity is increased. Coulomb posited that, within limits, the molecules have a definite shape, and thus there is a maximum possible area of mutual contact between the sides of the molecules. Beyond this point the sliding stops, and outright rupture occurs. His further experiments with regard to magnetism and the various possible mechanical states of iron wires seemed to confirm this idea.

Coulomb's physical theory of torsion here was influenced by his earlier theories concering soil mechanics and compressive rupture of masonry piers. In harmony with his earlier work he saw permanent set as an *inter*molecular sliding. And, since he believed cohesion to be a positive force acting between bodies, he supposed the molecules would tend to increase their areas of mutual contact. J. T. Desaguliers and others had attributed friction phenomena to a cohesion effect proportional to the surface area of the materials in contact. Similarly, Coulomb attributed the range of permanent set to this sliding or realignment because it gave him definite points for the start of permanent set and of final rupture.

Coulomb's torsion balance was used for many of his quantitative studies in electricity and magnetism. After the French Revolution he continued with his studies of elastic and cohesive properties of matter, particularly with regard to low-velocity fluid motion.

Coulomb's major memoirs in electricity and magnetism are his 1777 memoir on magnetic compasses, the famous series of seven electricity and magnetism memoirs read at the Academy from 1785 to 1791, and several magnetism memoirs prepared after the French Revolution. In his electrical studies Coulomb determined the quantitative force law, gave the notion of electrical mass, and studied charge leakage and the surface distribution of charge on conducting bodies. In magnetism he determined the quantitative force law, created a theory of magnetism based on molecular polarization, and introduced the idea of demagnetization (basically, that combinations of magnetic poles can "cancel" each other).

In the broadest sense Coulomb participated in the articulation and extension of the Newtonian theory of forces to the disciplines of electricity and magnetism. With regard to electricity and magnetism he said, "One must necessarily resort to attractive and repulsive forces of the nature of those which one is obliged to use in order to explain the weight of bodies and celestial physics." And to do this, it would be necessary to obtain exact quantifications of these laws. Particularly in his early writings, Coulomb stressed the importance of destroying the Cartesian notion of vortices, which had again gained favor through an Academy competition of 1746 (in which the winning entries of Leonhard Euler, Daniel and Johann II Bernoulli, and François Dutour had supported the idea of magnetic vortices). It is the attack on these ideas, begun by Franz Aepinus and John Michell and continued by Coulomb, that turned theories of electricity and magnetism toward the idea of action at a distance. Once the boundary conditions could be set for the physical extent of the electric and magnetic "fluids"; once these fluids could be assumed to act as point sources; then regardless of whether one employed the one-fluid or the two-fluid system, the mechanics of the Newtonian system of action at a distance could be applied to electricity and magnetism.

Coulomb worked in both electricity and magnetism throughout the 1780's. Of his seven memoirs in electricity and magnetism the first six are concerned with electricity, and it is to these that we now turn. In the first memoir (1785), Coulomb presented the details of his torsion balance as adapted for electrical studies and demonstrated the inverse-square law of forces for the case of two bodies of opposite electrical charge. This was established statically, using the torsion balance. There were good reasons for Coulomb to limit his early presentation to the case of repulsive forces. The major reason is that the force varies as the inverse square of the distance, while torsion varies as the simple distance. This presents a situation of unstable equilibrium in the use of the torsion balance; and in most instances the charged pith balls under test and in most instances the charged pith balls under test quickly come together and discharge, nullifying any results.

In the second memoir (1787) Coulomb extended these investigations to the proof of the inverse-square law for electricity and magnetism for the cases of both repulsive and attractive forces. Although he actually succeeded in using the static deflection approach to measure attractive forces, in general Coulomb utilized a dynamic oscillation method to demonstrate the inverse-square law for them. A magnetic needle or charged pith ball was suspended from the torsion balance at a certain distance from another needle or pith ball fixed upon a stand. The method was to deflect the torsion arm and then time the period of the resulting oscillations, repeating this procedure for varying distances between the fixed and the oscillating bodies. This dynamic method requires the assumptions (1) that the electrical or magnetic forces act as if concentrated at a point and (2) that the line of action between the two bodies is along the axis joining their centers, and that the field lines can be considered parallel and equal (that is, the dimensions of the bodies measured must be small compared with the distance between them). If these assumptions hold, the forces responsible for motion will be proportional to the inverse square of the period, and the period will vary directly as the distance between the bodies.

Although Coulomb proved directly by experiment that the electric and magnetic force laws vary inversely as the square of the distance, he never specifically demonstrated that they are also proportional to the product of the respective charges or pole strengths. He simply stated this to be so. That is, Coulomb had demonstrated that $F \alpha$ (I/r2), but only implied that $F \alpha q_1q_2$ or $F \alpha m_1m_2$. He later introduced the proof plane device. His use of this device and his experiments on magnetizing iron wires show that he indirectly demonstrated the effect of the product of the charges, or pole strengths. Similarly, Coulomb defined "electric mass" and "magnetic density," but only in relative terms. He never defined a unit magnetic pole strength or (unlike Henry Cavendish) a unit electric charge.

In his third to sixth memoirs (1787–1790), Coulomb examined losses due to leakage of electric charge and investigated the distribution of charge on conducting bodies. He determined that charge loss is proportional to the charge, or:

where δ and *-dδ* are charge and charge loss, respectively; *dt* is an element of time; and *m* is a constant dependent upon humidity and other factors. Coulomb saw charge leakage as taking place by direct contact on a molecular level, through charge-sharing either with adjacent air molecules or across the small *idio-électrique* interval he believed to exist around each molecule in a dielectric. The resistance opposed by each interval recalls his engineering experience with friction and strength of materials, for here is a coercive or passive force that must be overcome.

Experiments with charge leakage and Coulomb's conceptions of material behavior led him to the theory that in electricity there are two classes of substance: perfect conductors and dielectrics. Conduction could then occur in two ways: either through perfect conductors, such as certain metals, gases, and liquids, or through dielectric breakdown. Coulomb believed that in nature there is probably no perfect dielectric; that is, all bodies have a limit above which they cannot resist the passage of electricity. In perfect conductors the electricity can flow freely over the surface of bodies. In dielectrics conduction is resisted by the nature of the dielectric; but if there are "conducting molecules… within the imperfect dielectric, or distributed along its surface," then the electricity may flow over the dielectric, provided the electric intensity is sufficient to overcome the coercive force opposed by each *idio-électrique* interval within the dielectric.

Further, Coulomb showed that charge distribution does not depend on chemical affinity or elective attraction, but that it depends "uniquely" on the mutual repulsion of charge of like sign and on the geometry and positioning of the bodies, and that static charge distribution is limited to the surface (and not the interior) of conducting bodies, regardless of the material constituents or geometries of these bodies. He believed that charge could exist within dielectrics as well as on their surfaces, and he proposed to examine this; but the project never materialized. This study of the modes of charge distribution was undertaken partially as a means of preparing for a quantitative study of the effect of body geometry upon the distribution of charge. This became the subject of his fifth (1788) and sixth (1790) memoirs, an experimental investigation of charge distribution between conducting bodies of differing sizes and shapes, both in contact and after separation. These studies made large use of his proof plane to determine the charge density at each point on the charged body.

Following the measurement of charge distributions, Coulomb attempted, with moderate success, to develop analytical support for his results, using various approximative formulations. It was mostly from data presented in these two memoirs that Poisson composed his beautiful theory of electrostatics in 1811.

In the last of his seven memoirs in electricity and magnetism (1791), Coulomb sought to determine the magnetic momenta of magnetic needles and the magnetic intensity at each point as a function of their dimensional parameters. Also in this memoir he presented his fully developed theory of magnetism. In his 1777 memoir on magnetic compasses, Coulomb had leaned to Aepinus' one-fluid theory of magnetism. Although he steadfastly held that the one-fluid and the two-fluid systems were mathematically the same, experimental facts led him to question the basically macroscopic view of a magnet as having an excess of fluid near one pole and a deficiency at the other, or as having positive fluid at one pole and negative fluid at the other. He knew that the magnetic "fluid" could not be physically transferred from one magnet to another. He later discovered that bundles of magnetized wires could produce a more powerful magnet than a single bar of equal weight. The fact that a magnet could be broken into any number of pieces and produce smaller magnets led Coulomb to discard the macroscopic fluid theory and hypothesize that each magnetized particle was in fact a polarized *molécule aimantaire*.

Coulomb's molecular polarization model was amenable to those of both the one-fluid and the two-fluid schools, although he personally preferred the two-fluid model. The molecular model received general approval through the textbooks of René Just Haüy and Jean Baptiste Biot, and it was conceptually important to Biot and Poisson. It was important also to Ampère, although he altered the magnetic polarization idea and suggested that magnetism consisted of molecular electric currents flowing normal to the axis of the molecule. This final memoir in Coulomb's celebrated series of seven was presented just two years before the Academy was dissolved. After the Revolution, Coulomb's studies centered on the magnetic properties of materials as a function of their elastic and thermal history, and on the extent of magnetic properties in all matter.

Coulomb's fundamental researches in electricity and magnetism well represent the extension of Newtonian mechanics to new areas of physics. At the same time they illustrate the emergence of the "empirical" areas of physics from within traditional natural philosophy to positions of sophisticated disciplines in physics.

It may be fitting, finally, to present three statements that define Coulomb's approach to his work. First, both in his view of the Corps du Génie and in public service, he said men should be judged on their abilities and that a public service body was a "corps à talent." Second, in his work in applied mechanics Coulomb called for the use of rational analysis coupled with reality in experiment; for the conduct of research in engineering through use of a "combination of mathematics *(calcul)* and physics." Third, this use of rational analysis and engineering reality, coupled in the pursuit of *physique expérimentale*, led to Coulomb's work in physics and the evaluation of Biot that "It is to Borda and to Coulomb that one owes the renaissance of true physics in France, not a verbose and hypothetical physics, but that ingenious and exact physics which observes and compares all with rigor."

NOTE

Coulomb first mentioned the torsion balance in his 1777 magnetism essay (written 1776, published 1780), both for measuring magnetic declination and in connection with the measurement of fluid resistance. His major memoir on torsion was read at the Academy 9 September 1784 (published 1787). Coulomb claimed to have no knowledge of any predecessors in this work.

Numerous secondary sources, however, cite John Michell as the inventor of the torsion balance. *In no known published* memoir or volume of Michell's is there any mention of a torsion balance. Henry Cavendish ("Experiments to Determine the Density of the Earth," in *Philosophical Transactions*, **88** (1798), 469–70) is usually said to have established Michell's claims, but Cavendish actually says nothing except that Michell privately mentioned his idea of a torsion balance before the publication of Coulomb's experiments. Michell, says Cavendish, did not construct such a balance until a short time before his death (in 1793). Apparently there may have been some fuss about the matter before Coulomb's death in 1806, for at Coulomb's funeral J. J. Lalande, speaking of Coulomb's lack of jealousy, said that "An Englishman seized his idea on the suspension of (magnetic) needles, but Coulomb never bothered to complain."

For a detailed discussion of the invention of the torsion balance, see Gillmor, *Charles Augustin Coulomb*.

BIBLIOGRAPHY

I. Original Works. Nearly all of Coulomb's published memoirs appear in the publications of the Académic des Sciences (Paris), either in the *Mémoires de I Académie royale des sciences* (vols. published 1785–1797) and the continuation of these, the *Mémoires de l'Institut national des sciences et arts—Sciences mathématiques et physiques* (vols. published 1799–1806), or in the supplementary series for memoirs of nonmembers, *Mémoires de mathématique et de physique présentés à l'Académie royale des sciences, par divers savans* (vols. published 1776–1785). Extracts of his later memoirs were often published by others in various physical journals; sometimes these bear Coulomb's name, sometimes the name of the reporter who wrote the extract. One paper, "Recherches sur les moyens d'exécuter sous l'eau toutes sortes de travaux hydrauliques sans employer aucun épuisement," was published separately under slightly varying title by C. A. Jombert (Paris, 1779), Du Pont (Paris, 1797), and Bachelier (Paris, 1819, 1846).

There exist collections of Coulomb's major memoirs. The collection of his mechanics memoirs, *Théorie des machines simples* (Paris, 1809, 1821), is rather rare. The collection of his memoirs in electricity and magnetism is more easily located, *Mémoires de Coulomb*, A. Potter, ed., vol. I of *Collection des mémoires relatifs à la physique, publiés par la Société française de Physique*, 5 vols. (Paris, 1884–1891). Potier's edition of the memoirs omits certain important passages and should be checked against the original memoirs as published by the Academy. *Vier Abhandlungen über die Elektricität and den Magnetismus…. Uehersetzt and herausgegeben von Walter König* (Leipzig, 1890), no. 13 in Ostwald's Klassiker der Exakten Wissenschaften, is a German translation of Coulomb's first four memoirs on electricity and magnetism.

Archival material concerning Coulomb has been located in numerous repositories in France. For a full listing of archival and published sources written by and concerning Coulomb, see Gillmor (below). Most of the extant Coulomb MS material concerns his work in the Corps du Génie and his committee reports to the Academy. Without exception, the location of MS copies of his scientific memoirs is unknown. J. B. J. Delambre and J. B. Biot had a portion of these manuscripts at one time shortly after Coulomb's death. Two MS notebooks compiled by Coulomb shortly before his death are in the Bibliothéque de l'Institut de France, MS1581–82. His unpublished memoir on the reorganization of the Corps du Génie (1776) is in Archives de l'Inspection du Génie, 39, rue de Bellechasse, Paris 7^e: art. 3, sect. 10, carton 2, no. 5a.

II. Secondary Literature. C. Stewart Gillmor, *Charles Augustin Coulomb: Physics and Engineering in Eighteenth Century France* (in press), presents a full account of Coulomb's life and works; the volume also includes an extensive bibliography. Contemporary short éloges of Coulomb are J. B. J. Delambre, "Éloge historique de M. Coulomb," in *Mémoires de l'Institut national des sciences et arts—Sciences mathématiques et physiques*, **7** (1806), "Histoire," 206–223; and J. B. Biot, "Coulomb," in *Mélanges scientifiques et littéraires de Biot*, 3 vols.(Paris, 1858), III, 99–104. For a discussion of Coulomb's contributions to physics see Edmond Bauer, *L'electro-magnétisme—hier et aujourd'hui* (Paris, 1949), pp. 213–235. Coulomb's work in applied mechanics and engineering is discussed in S. B. Hamilton, "Charles Auguste [*sic*] de Coulomb," in *Transactions of the Newcomen Society* (London), **17** (1938), 27–49; and Stephen P. Timoshenko, *History of Strength of Materials* (New York, 1953), pp. 47–54, 61–62, 64–66. For Coulomb's friction studies see. V. Kragelsky and V. S. Schedrov, *Razvitia nauki o trend—Sookoi Trenia* ("Development of the Science of Friction—Dry Friction"; Moscow, 1956), pp. 51–69. Hugh Q. Golder, "The History of Earth Pressure Theory," in *Archives internationales d'histoire des sciences*, **32** (1953), 209–219, discusses Coulomb's earth pressure theory.

C. Stewart Gillmor