subject. His text was the first book written on anatomy during the Middle Ages that was based on the dissection of the human cadaver; his efforts consolidated anatomy as a part of the medical program at Bologna and encouraged further study. His book also dominated the teaching of anatomy, and no real improvements were made upon it until 1521, when Berengario da Carpi wrote his famous commentary on Mondino.

Although he is best known for his *Anatomia*, Mondino wrote at least nine *consilia* dealing with such ailments as catarrh, fevers, stone, melancholic humors, and so forth. He also wrote a number of commentaries on the collection of classical writings known as the *Ars medicinae* including *Super libro prognosticorum Hippocratis*, *Super Hippocratis de regimine acutorum*, *Annotata in Galeni de morbo et accidenti*, and perhaps others. His commentary *Lectura super primo, secundo et quarto de juvamentis* is on part of Galen's *De usu partium*. Another commentary on the *Canones* of Mesue the Younger includes material from his *Anatomia*. Mondino also wrote treatises on weights and measures, human viscera, prescriptions and drugs, medical practice, and fevers.

NOTES

1. Arturo Castiglioni, *A History of Medicine*, trans. by E. B. Krumbhaar (New York, 1947), 341.
2. Sarton, *Introduction to the History of Science*, III, 1, 842.
3. Singer, *The Evolution of Anatomy*, 75–76.
4. Moritz Roth, *Andreas Vesalius Bruxellensis*, 20.
5. Mondino dei Luzzi, *Anothomia*, in Joannes Ketham, *Fasciculo di medicina*, trans. by Charles Singer, I, 80–81.
6. Guy de Chauliac, *La grande chirurgie*, trans. by E. Nicaise (Paris, 1890), 30–31.

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The first printed edition of the *Anatomia* appeared at Padua in 1476. Other editions in Latin appeared at Pavia, Bologna, Leipzig, Venice, Strasbourg, Paris, Milan, Geneva, Rostock, Lyons, and Marburg. All told there are approximately forty printed editions in Latin and other languages. Only a few of the editions include woodcuts or illustrations, but one or more appear in the Leipzig (1493), Venice (1494), Strasbourg (1513), Rostock (1514), Bologna (1521), and Marburg (1541) editions. A modern facsimile of the 1478 Pavia edition was edited by Ernest Wickersheimer, *Anatomies de Mondino dei Luzzi et de Guido de Vigevano* (Paris, 1926).

There were at least two early French translations, one by Richard Roussat (Paris, 1532), and another by an unknown translator (Paris, 1541). This last was erroneously labeled as the first French translation by LeRoy Crummer, who discovered it and published several interesting woodcuts from it. See Crummer, "La première traduction française de l'*Anatomie* de Mondini," in *Aesculape*, **20** (1930), 204–207. An Italian translation by Sebastian M. Romano was included in Joannes Ketham, *Fasciculo di medicina* (1493), and this was translated into English by Charles Singer in the reprinting of *Fasciculo di medicina* (Florence, 1924 and 1925). Another fifteenth-century Italian translation, with a photographic reproduction of a fourteenth-century MS of the *Anatomia*, was printed in Lino Sighinolfi, ed., *Mondino de Liucci Anatomia, Riprodotta da un Codice Bolognese del secolo XIV^e; volgarizzata nel secolo XV* (Bologna, 1930).

Seven of Mondino's *consilia* were printed by Balduin Vonderlage in his dissertation, *Consilien des Mondino dei Luzzi aus Bologna* (Leipzig, 1922). Mondino's commentary on the *Canones* of Mesue, *Mesuë cum expositione Mondini super canones universales*, was printed at Venice in 1490, 1495, 1497, 1570, 1638, and Lyons in 1525. The following works have not been printed: *Practica de accidentibus morborum secundum Magistrum Mundinum de Liucius de Bononis; Tractatus de ponderibus secundum Magistrum Mundinum; De visceribus humani corporis; Super libro prognosticorum Hippocratis; Mundinus super Hippocratis de regimine acutorum; Annotata in Galeni de morbo et accidente; Super libro prognosticorum Hippocratis; Mundinus super Hippocratis de regimine acutorum; Annotata in Galeni de morbo et accidente; Super libro de pulsibus; Tractatus de dosis medicinae; De medicinis simplicibus; Practicae medicinae libri X; Consilia medicinalia; Consilium ad retentionem menstruorum*, and *De accidentibus febrium*.

For further information see Howard B. Adelmann, *Marcello Malpighi and the Evolution of Embryology*, 5 vols., I (Ithaca, 1966), 74–84; Vern L. Bullough, *The Development of Medicine as a Profession* (Basel–New York, 1966); Giovanni Fantuzzi, *Notizie degli Scrittori Bolognese*, 9 vols., VI (Bologna, 1782–1790), 41–46; Giovanni Martinotti, "L'insegnamento del'Anatomia in Bologna prima del secolo XIX," in *Studi e memorie per la storia dell università di Bologna*, II (Bologna, 1911), 1–146; Moritz Roth, *Andreas Vesalius Bruxellensis* (Berlin, 1892); George Sarton, *Introduction to the History of Science*, 3 vols. in 5, III (Baltimore, 1927–1942), 1, 842–845; and Charles Singer, *The Evolution of Anatomy* (London, 1925), 75.

VERN L. BULLOUGH

MONGE, GASPARD (*b.* Beaune, France, 9 May 1746; *d.* Paris, France, 28 July 1818), *geometry, calculus, chemistry, theory of machines.*

Monge revived the study of certain branches of geometry, and his work was the starting point for the remarkable flowering of that subject during the nineteenth century. Beyond that, his investigations extended to other fields of mathematical analysis, in particular to the theory of partial differential equations, and to problems of physics, chemistry, and technology. A celebrated professor and peerless *chef d'école*, Monge assumed important administrative and political responsibilities during the Revolution and the Empire. He was thus one of the most original mathematicians of his age, while his civic activities represented the main concerns of the Revolution more fully than did those of any other among contemporary French scientists of comparable stature.

The elder son of Jacques Monge, a merchant originally of Haute-Savoie, and the former Jeanne Rousseaux, of Burgundian origin, Monge was a brilliant student at the Oratorian *collège* in Beaune. From 1762 to 1764 he completed his education at the Collège de la Trinité in Lyons, where he was placed in charge of a course in physics. After returning to Beaune in the summer of 1764, he sketched a plan of his native city. The high quality of his work attracted the attention of an officer at the École Royale du Génie at Mézières, and this event determined the course of his career.

Created in 1748, the École Royale du Génie at Mézières had great prestige, merited by the quality of the scientific and practical training that it offered. Admitted to the school at the beginning of 1765 in the very modest position of draftsman and technician, Monge was limited to preparing plans of fortifications and to making architectural models, tasks he found somewhat disappointing. But barely a year after his arrival he had an opportunity to display his mathematical abilities. The result was the start of a career worthy of his talents.

Monge was requested to solve a practical exercise in defilading—specifically, to establish a plan for a fortification capable of shielding a position from both the view and the firepower of the enemy no matter what his location. For the very complicated method previously employed he substituted a rapid graphical procedure inspired by the methods of what was soon to become descriptive geometry. This success led to his becoming *répétiteur* to the professor of mathematics, Charles Bossut. In January 1769 Monge succeeded the latter, even though he did not hold the rank of professor. The following year he succeeded the Abbé Nollet as instructor of experimental physics at the school. In this double assignment, devoted partially to practical ends, Monge showed himself to be an able mathematician and physicist, a talented draftsman, a skilled experimenter, and a first-class teacher. The influence he exerted until he left the school at the end of 1784 helped to initiate several brilliant careers of future engineering officers and to give the engineering corps as a whole a solid technical training and a marked appreciation for science. The administrators of the school recognized his ability and, after obtaining for him the official title of "royal professor of mathematics and physics" (1775), steadily increased his salary.

Parallel to this brilliant professional career, Monge very early commenced his personal work. His youthful investigations (1766–1772) were quite varied but exhibit several characteristics that marked his entire output: an acute sense of geometric reality; an interest in practical problems; great analytical ability; and the simultaneous examination of several aspects of a single problem: analytic, geometric, and practical.

This was the period in which Monge developed descriptive geometry. He systematized its basic principles and applied it to various graphical problems studied at the École du Génie—problems taken, for example, from fortification, architecture, and scaffolding. That Monge left only a few documents bearing on this work is not surprising, since he was essentially coordinating and rationalizing earlier knowledge, rather than producing really original material. Elements of descriptive geometry appeared very early in his teaching—to the degree that his familiarity with the graphical procedures currently in use and with the various branches of geometry allowed him to make the necessary synthesis. The documents from this period record the many investigations inspired by his readings in the rich collections of the library of the École du Génie. This research dealt with topics in infinitesimal calculus, infinitesimal geometry, analytic geometry, and the calculus of variations. His first important original work was "Mémoire sur les développées, les rayons de courbure et différents genres d'inflexions des courbes à double courbure." He published an extract from it in June 1769 in the *Journal encyclopédique*, and in October 1770 he finished a more complete version that he read before the Académie des Sciences in August 1771; the latter, however, was not published until 1785 (*Mémoires de mathématiques et de physique présentés à l'Académie . . . par divers sçavans . . .*, **10**, 511–550). By then some of the most important ideas in the memoir no longer seemed so original, because Monge had employed them in other works published in the intervening years. Nevertheless, this memoir is of exceptional interest, for it presents most of the new conceptions that Monge developed in his later works, as well as his very personal method of exposition, which combined pure geometry, analytic geometry, and infinitesimal calculus.

Wishing to make himself known and to have his work discussed, Monge sought out d'Alembert and Condorcet at the beginning of 1771. On the latter's advice, he later in the same year presented before the Paris Academy four memoirs corresponding to the main areas of his research. The first, which was not published, dealt with a problem to which he never returned: the extension of the calculus of variations to the study of extrema of double integrals. The second was the memoir on infinitesimal geometry mentioned above. The fourth treated a problem in combinatorial analysis related to a card trick.

In the third memoir Monge entered a field of study that was to hold his interest for many years: the theory of partial differential equations. In particular he undertook the parallel examination of certain equations of this type and of the families of corresponding surfaces. The geometric construction of a particular solution of the equations under consideration allowed him to determine the general nature of the arbitrary function involved in the solutions of a partial differential equation. Moreover, this finding enabled him to take a position on a question then being disputed by d'Alembert, Euler, and Daniel Bernoulli. Monge developed the ideas set forth in this memoir in two others sent to the Academy in 1772. The work presented in these papers was extended in four publications dating from 1776; two of these appeared in the *Mémoires* of the Academy of Turin and two in the *Mémoires* of the Paris Academy. In another paper (1774) Monge discussed the nature of the arbitrary functions involved in the integrals of finite difference equations. He also considered the equation of vibrating strings, a topic he later investigated more fully.

In May 1772 the Academy of Sciences elected Monge to be Bossut's correspondent. At this time he became friendly with Condorcet and Vandermonde. The latter's influence was probably responsible for two unpublished memoirs Monge wrote during this period, on the theory of determinants and on the knight's moves on a chessboard.

In 1775 Monge returned to infinitesimal geometry. Working on the theory of developable surfaces outlined by Euler in 1772, he applied it to the problem of shadows and penumbrae and treated several problems concerning ruled surfaces. A memoir composed in 1776 on Condorcet's prompting (and reworked in 1781 on the basis of a more thorough understanding) is of major importance, although not for its contributions to the practical problem of cuts and fills that served as its point of departure. Its great interest lies in its introduction of lines of curvature and congruences of straight lines.

Although in 1776 Monge was still interested in Lagrange's memoir on singular integrals, his predilection for mathematics was meanwhile slowly yielding to a preference for physics and chemistry. In 1774, while traveling in the Pyrenees, he had collaborated with the chemist Jean d'Arcet in making altitude measurements with the aid of a barometer. Having some instruments at his disposal in Mézières and working with Vandermonde and Lavoisier during his stays in Paris, Monge carried out experiments on expansion, solution, the effects of a vacuum, and other phenomena; acquired an extensive knowledge of contemporary physics; and participated in the elaboration of certain theories, including the theory of caloric and triboelectricity.

In 1777 Monge married Catherine Huart. They had three daughters, the two elder of whom married two former members of the National Convention, N.-J. Marey and J. Eschassériaux: the two present branches of Monge's descendants are their issue.

During the period 1777–1780 Monge was interested primarily in physics and chemistry and arranged for a well-equipped chemistry laboratory to be set up at the École du Génie. Moreover, having for some time been responsible for supervising the operation of a forge belonging to his wife, he had become interested in metallurgy.

His election to the Academy of Sciences as *adjoint géomètre* in June 1780 altered Monge's life, obliging him to stay in Paris on a regular basis. Thus for some years he divided his time between the capital and Mézières. In Paris he participated in the Academy's projects and presented memoirs on physics, chemistry, and mathematics. He also substituted for Bossut in the latter's course in hydrodynamics (created by A.-R.-J. Turgot in 1775) and in this capacity trained young disciples such as S. F. Lacroix and M. R. de Prony. At Mézières, where he arranged for a substitute to give some of his courses—although he kept his title and salary—Monge conducted research in chemistry. In June–July 1783 he synthesized water. He then turned his attention to collecting stores of hydrogen and to the outer coverings of balloons. Finally, with J. F. Clouet he succeeded in liquefying sulfur dioxide.

In October 1783 Monge was named examiner of naval cadets, replacing Bézout. He attempted to reconcile his existing obligations with the long absences required by this new post, but it proved to be impossible. In December 1784 he had to give up his professorship at Mézières, thus leaving the school at which he had spent twenty of the most fruitful years of his career. From 1784 to 1792 Monge divided his time between his tours of inspection of naval schools and his stays in Paris, where he continued to participate in the activities of the Academy and to conduct research in mathematics, physics, and chemistry. A list of the subjects of his communications to the Academy attests to their variety: the composition of nitrous acid, the generation of curved surfaces, finite difference equations, and partial differential equations (1785); double refraction and the structure of Iceland spar, the composition of iron, steel, and cast iron, and the action of electric sparks on carbon dioxide gas (1786); capillary phenomena (1787); and the causes of certain meteorological phenomena; and a study in physiological optics (1789).

Meanwhile, with other members of the Academy, Monge assisted Lavoisier in certain experiments. For example, in February 1785 he participated in the analysis and synthesis of water. In fact, he was one of the first to accept Lavoisier's new chemical theory. After having collaborated with Vandermonde and Berthollet on a memoir on "iron considered in its different metallurgical states" (1786), he participated in several investigations of metallurgy in France. In 1788 he joined in the refutation, instigated by Lavoisier, of a treatise by the Irish chemist Kirwan, who was a partisan of the phlogiston theory. That Monge was among the founders of the *Annales de chimie* testifies to his standing in chemistry. During this period Monge's position as naval examiner obliged him to write a course in mathematics to replace Bézout's. Only one volume was published, *Traité élémentaire de statique* (1788).

When the Revolution began in 1789, Monge was among the most widely known of French scientists. A very active member of the Academy of Sciences, he had established a reputation in mathematics, physics, and chemistry. As an examiner of naval cadets he directed a branch of France's military schools, which were then virtually the only institutions offering a scientific education of any merit. This position also placed him in contact, in each port he visited, with bureaucracy that was soon to come under his administration. It also enabled him to visit iron mines, foundries, and factories, and thus to become an expert on metallurgical and technological questions. Furthermore, the important reform of teaching in the naval schools that he had effected in 1786 prepared him for the efforts to renew scientific and technical education that he undertook during the Revolution.

Although Monge was a resolute supporter of the Revolution from the outset, his political role remained discreet until August 1792. He joined several revolutionary societies and clubs but devoted most of his time to tours of inspection as examiner of naval cadets and to his functions as a member of the Academy, particularly to the work of the Academy's Commission on Weights and Measures.

After the fall of the monarchy on 10 August 1792, a government was created to carry on the very difficult struggle imposed on the young republic by adherents of the *ancien régime*. On the designation of the Legislative Assembly, Monge accepted the post of minister of the navy, which he held for eight months. Although not outstanding, his work showed his desire to coordinate all efforts to assure the nation's survival and independence. His politics, however, were judged by some to be too moderate; and attacked from several sides and exhausted by the incessant struggle he had to wage, he resigned on 10 April 1793. Henceforth he never played more than a minor political role. A confirmed republican, he associated with Jacobins such as Pache and Hassenfratz; but he never allied himself with any faction or participated in any concrete political action. On the other hand, he was an ardent patriot, who placed all his energy, talent, and experience in the service of the nation, and he played a very important role in developing the manufacture of arms and munitions, and in establishing a new system of scientific and technical education.

Monge resumed his former activities for a short time; but after the suppression of the Academy of Sciences on 8 August 1793 his work came under the direct control of the political authorities, especially of the Committee of Public Safety. From the beginning of September 1793 until October 1794, he took part in the work of the Committee on Arms. He wrote, with Vandermonde and Berthollet, a work on the manufacture of forge and case-hardened steels, drew up numerous orders concerning arms manufacture for Lazare Carnot and C. L. Prieur, supervised Paris arms workshops, assembled technical literature on the making of cannons, gave "revolutionary courses" on this latter subject (February–March 1794), and wrote an important work on it. He also was involved in the extracting and refining of saltpeter and the construction and operation of the great powderworks of Paris. In addition, he participated in the development of military balloons.

Monge also engaged in tasks of a different sort. After the suppression of the Academy he joined the Société Philomatique; participated in the work of the Temporary Commission on Weights and Measures, which continued the projects of the Academy's commission; and took part in the activities of the Commission on the Arts, which was responsible for preserving the nation's artistic and cultural heritage. He was also active in the projects for educational reform then under discussion. His experience at the École de Mézières and in the naval schools explains the special interest that the renewal of scientific and technical instruction held for him. At the elementary level, he prepared for the department of Paris a plan for schools for artisans and workers that the Convention adopted on 15 September 1793 but rejected the next day. At a more advanced level, he was convinced of the value of creating a single national school for training civil and military engineers. Consequently, when he was appointed by the Convention (11 March 1794) to the commission responsible for establishing an École Centrale des Travaux Publics, he played an active role in its work. The memoir that Fourcroy prepared in September 1794 to guide the first steps of the future establishment ("Développements sur l'enseignement . . .") shows the influence of Monge's thinking, which derived from his experience at Mézières. Appointed instructor of descriptive geometry on 9 November 1794, Monge supervised the operation of the training school of the future *chefs de brigade*, or foremen, taught descriptive geometry in "revolutionary courses" designed to complete the training of the future students, and was one of the most active members of the governing council. After a two-month delay caused by political difficulties, the school—soon to be called the École Polytechnique—began to function normally in June 1795. Monge's lectures, devoted to the principles and applications of infinitesimal geometry, were printed on unbound sheets; these constituted a preliminary edition of his *Application de l'analyse à la géométrie*.

Monge was also one of the professors at the ephemeral École Normale de l'An III. From 20 January to 20 May 1795 this school brought together in Paris 1,200 students, who were to be trained to teach in the secondary schools then being planned. The lectures he gave, assisted by his former student S.-F. Lacroix and by J. Fournier, constituted the first public course in descriptive geometry. Like those of the other professors, the lectures were taken down by stenographers and published in installments in the *Journal des séances des écoles normales*.

Monge, who regretted the suppression of the Academy of Sciences, actively participated in the meetings held from December 1795 to March 1796 to prepare its rebirth as the first section of the Institut National, created by the Convention on 26 October 1795. But just when Monge's activities seemed to be returning to normal, events intervened that prevented this from happening.

Monge was named, along with his friend Berthollet, one of the six members of the Commission des Sciences et des Arts en Italie, set up by the Directory to select the paintings, sculptures, manuscripts, and valuable objects that the victorious army was to bring back. He left Paris on 23 May 1796. His mission took him to many cities in northern and central Italy, including Rome, and allowed him to become friendly with Bonaparte. At the end of October 1797 Monge returned to Paris, officially designated, with General Louis Berthier, to transmit to the Directory the text of the Treaty of Campoformio.

Immediately after returning, Monge resumed his former posts, as well as a new one, that of director of the École Polytechnique. But his stay in Paris was brief; at the beginning of February 1798 the Directory sent him back to Rome to conduct a political inquiry. While there, Monge took an active interest in the organization of the short-lived Republic of Rome. The following month, at the request of Bonaparte, he took part in the preparations for the Egyptian expedition. Although reluctant at first, he finally agreed to join the expedition. His boat left Italy on 26 May 1798, joining Bonaparte's squadron two weeks later. Monge arrived in Cairo on 21 July and was assigned various administrative and technical tasks. As president of the Institut d'Égypte, created on 21 August, he played an important role in the many scientific and technical projects undertaken by this body. He accompanied Bonaparte on a brief trip in the Suez region, on the disastrous Syrian expedition (February–June 1799), and, after another brief stay in Cairo, on his return voyage to France (17 August–16 October). During this period of three and a half years, in which he was for almost the whole time away from France, Monge's correspondence and communications to the Institut d'Égypte show that he was working on new chapters of his *Application de l'analyse à la géométrie*. Moreover, the observation of certain natural phenomena, such as mirages, and the study of certain techniques, including metallurgy and the cultivation of the vine, provided him with fruitful sources for thought. Meanwhile, at the request of his wife and without his knowledge, his *Géométrie descriptive* was published in 1799 by his friend and disciple J. N. Hachette, who limited himself to collecting Monge's École Normale lectures previously published in the *Séances*.

On his return to Paris, Monge resumed his duties as director of the École Polytechnique but relinquished them two months later when, following the *coup d'état* of 18 Brumaire, Bonaparte named him senator for life. By accepting this position Monge publicly attached himself to the Consulate. Although this decision may seem to contradict his republican convictions and revolutionary faith, it can be explained by his esteem for and admiration of Bonaparte and by his dissatisfaction with the defects and incompetence of the preceding regime. Dazzled by Napoleon, Monge later rallied to the Empire with the same facility and accepted all the honors and gifts the emperor bestowed upon him: grand officer of the

Legion of Honor in 1804, president of the Senate in 1806, count of Péluse in 1808, among others.

Monge had to divide his time among his family, his teaching of infinitesimal geometry at the École Polytechnique, and his obligations as a member of the Academy of Sciences and of the Conseil de Perfectionnement of the École Polytechnique, and his duties as a senator. Further tasks were soon added. He was founder of the Société d'Encouragement pour l'Industrie Nationale and vice-president of the commission responsible for supervising the preparation and publication of the material gathered on the Egyptian expedition, *Description de l'Égypte*. Even though his duties as senator took him away on several occasions from his courses at the École Polytechnique, he maintained his intense concern for the school. He kept careful watch over the progress of the students, followed their research, and paid close attention to the curriculum and the teaching.

Most of Monge's publications in this period were written for the students of the École Polytechnique. The wide success of the *Géométrie descriptive* was responsible for the rapid spread of this new branch of geometry both in France and abroad. It was reprinted several times; the edition of 1811 contained a supplement by Hachette; and the fourth, posthumous edition, published in 1820 by Barnabé Brisson, included four previously unpublished lectures on perspective and the theory of shadows.

In 1801 Monge published *Feuilles d'analyse appliquée à la géométrie*, an expanded version of his lectures on infinitesimal geometry of 1795. In 1802, working with Hachette, he prepared a brief exposition of analytic geometry that was designed to replace the few remarks on the subject contained in the *Feuilles*. Entitled *Application de l'algèbre à l'analyse*, it was published separately in 1805; in 1807 it became the first part of the final version of *Feuilles d'analyse*, now entitled *Application de l'analyse à la géométrie*. This larger work was republished in 1809 and again in 1850 by J. Liouville, who appended important supplements.

Aside from new editions of the *Traité élémentaire de statique*, revised by Hachette beginning with the fifth edition (1810), and some physical and technical observations made in Italy and Egypt and published in 1799, Monge's other publications during this period dealt almost exclusively with infinitesimal and analytic geometry. For the most part they were gradually incorporated into successive editions of his books. His production of original scientific work began to decline in 1805.

A decline likewise occurred in Monge's other activities. Suffering from arthritis, he stopped teaching at the École Polytechnique in 1809, arranging for Arago to substitute for him and then to replace him. Although he wrote a few more notes on mathematics and several official technical reports, his creative period had virtually come to an end. In November 1812, overwhelmed by the defeat of the Grande Armée, he suffered a first attack of apoplexy, from which he slowly recovered. At the end of 1813 he was sent to his senatorial district of Liège to organize its defenses but fled a few weeks later before the advancing allied armies. Absent from Paris at the moment of surrender, he did not participate in the session of 3 April 1814, in which the Senate voted the emperor's dethronement. He returned shortly afterward and resumed a more or less normal life. In 1815, during the Hundred Days, he renewed his contacts with Napoleon and even saw him several times after Waterloo and the abdication. In October 1815, fearing for his freedom, Monge left France for several months. A few days after his return to Paris, in March 1816, he was expelled from the Institut de France and harassed politically in other ways. Increasingly exhausted physically, spiritually, and intellectually, he found his last two years especially painful. Upon his death, despite government opposition, many current and former students at the École Polytechnique paid him tribute. Throughout the nineteenth century mathematicians acknowledged themselves as his disciples or heirs.

Scientific Work. Monge's scientific work encompasses mathematics (various branches of geometry and mathematical analysis), physics, mechanics, and the theory of machines. His principal contributions to these different fields will be discussed in succession, even though his mathematical work constitutes a coherent ensemble in which analytic developments were closely joined with material drawn from pure, descriptive, analytic, and infinitesimal geometry, and even though his investigations in physics, mechanics, and the theory of machines were also intimately linked.

Descriptive and Modern Geometry. Elaborated during the period 1766–1775, Monge's important contribution is known from his *Géométrie descriptive*, the text of his courses at the École Normale de l'An III (1795), and from the manuscript of his lectures given that year at the École Polytechnique. Before him various practitioners, artists, and geometers, including Albrecht Dürer, had applied certain aspects of this technique. Yet Monge should be considered the true creator of descriptive geometry, for it was he who elegantly and methodically converted the group of graphical procedures used by practitioners into a general uniform technique based on simple and rigorous geometric reasoning and methods. Within a few years this new discipline was being taught in French scientific and technical schools and had spread to several other Continental countries.

Monge viewed descriptive geometry as a powerful tool for discovery and demonstration in various branches of pure and infinitesimal geometry. His persuasive example rehabilitated the study and use of pure geometry, which had been partially abandoned because of the success of Cartesian geometry. Monge's systematic use of cylindrical projection and, more discreetly, that of central projection, opened the way to the parallel creation of projective and modern geometry, which was to be the work of his disciples, particularly J.-V. Poncelet. The definition of the orientation of plane areas and volumes, the use of the transformation by reciprocal polars, and the discreet introduction in certain of his writings of imaginary elements and of elements at infinity confirms the importance of his role in the genesis of modern geometry.

Analytic and Infinitesimal Geometry. Analytic and infinitesimal geometry overlap so closely in Monge's work that it is sometimes difficult to separate them. Whereas from 1771 to 1809 he wrote numerous memoirs on the infinitesimal geometry of space, it was not until 1795, in his lectures at the École Polytechnique, that he specifically developed analytic geometry.

Nevertheless, even in his earliest works, Monge sought to remedy the chief weaknesses of analytic geometry, although this discipline was then for him only an auxiliary of infinitesimal geometry. Rejecting the restrictive Cartesian point of view that was still dominant, he considered analytic geometry as an autonomous branch of mathematics, parallel to pure geometry and independent of it. Consonant with this approach, as early as 1772 and at the same time as Lagrange, Monge systematically introduced into the subject the elements defined by first-degree equations (straight lines and planes) that had previously not been part of it. He also solved the basic problems posed by this extension. Parallel with this endeavor, he sought, following Clairaut and Euler, to make up for the long delay in the development of three-dimensional analytic geometry. In addition Monge introduced an absolute symmetry into the use of the coordinate axes. He showed great analytic virtuosity in his calculations, some of which display, except for the symbolism, a skillful handling of determinants and of certain algorithms of vector calculus. His ability in this regard very early allowed him to establish the foundations of the geometry of the straight line (in Plücker's sense), which he systematized in 1795.

The first two editions (1795 and 1801) of Monge's course in "analysis applied to geometry" at the École Polytechnique contain as an introduction a brief statement of the principles and fundamental problems of this renewed analytic geometry, which was soon taught in upper-level French schools. With his disciple J. N. Hachette, Monge published in 1802 an important memoir, "Application de l'algèbre à la géométrie," which completed the preceding study, notably regarding the theory of change of coordinates and the theory of quadrics. In 1805 Monge collected these various contributions to analytic geometry in a booklet entitled *Application de l'algèbre à la géométrie*, which in 1807 became the first part of his great treatise *Application de l'analyse à la géométrie*. The many articles that Monge and his students devoted to individual problems of analytic geometry (change of coordinates, theory of conics and quadratics, among others) in the *Journal de l'École polytechnique* and in the *Correspondance sur l'École polytechnique* attest to the interest stimulated by the discipline's new orientation.

Throughout his career infinitesimal geometry remained Monge's favorite subject. Here his investigations were directed toward two main topics: families of surfaces defined by their mode of generation, which he examined in connection with the corresponding partial differential equations, and the direct study of the properties of surfaces and space curves. Since the first topic is discussed below, only the principal research relating to the second topic will be presented here. In 1769 Monge defined the evolutes of a space curve and showed that these curves are the geodesics of the developable envelope of the family of planes normal to the given curve. In 1774, after having returned to this question in a memoir presented in 1771, Monge completed the study of developable surfaces outlined by Euler. Concurrently utilizing geometric considerations and analytic arguments, he established the distinction between ruled surfaces and developable surfaces; gave simple criteria for judging, from its equation, whether a given surface is developable; applied these results to the theory of shadows and penumbrae; and solved various problems concerning surfaces. In particular, he determined by means of descriptive geometry the ruled surface passing through three given space curves. Still more important is the memoir on cuts and fills, of which Monge made two drafts (1776 and 1781). The point of departure was a technical problem: to move a certain quantity of earth, determining the trajectory of each molecule in such a way that the total work done is a minimum. Through repeated schematizations he derived the formulation of a question concerning the theory of surfaces that he examined very generally, introducing such important notions as the congruence of straight lines, line of curvature, normal, and focal surface. This memoir served as a starting point for several of Monge's later works, as well as for important investigations by Malus in geometrical optics and by Dupin in infinitesimal geometry.

Several memoirs written between 1783 and 1787 contain numerous studies of families of surfaces and some new results relating to the general theory of surfaces and to the properties of certain space curves.

In *Feuilles d'analyse appliquée à la géométrie* (1795 and 1801) Monge assembled, along with general considerations regarding the theory of surfaces and the geometric interpretation of partial differential equations, monographs on about twenty families of surfaces defined by their mode of generation. *Application de l'analyse à la géométrie* (1807) includes some supplementary material, notably attempts to find families of surfaces when one of the nappes of their focal surface is known. The manuscript of Monge's course for 1805–1806 also contains important additional findings (transformations by reciprocal polars, conoids, etc.). The richness and originality in Monge's lectures, qualities evident in this manuscript and confirmed by the testimony of former students, explain why so many French mathematicians can be considered his direct followers. Among them we may cite Tinseau and Meusnier at the École de Mézières, Lacroix, Fourier, and Hachette at the École Normale, and Lancret, Dupin, Livet, Brianchon, Malus, Poncelet, Chasles, Lamé, and still others at the École Polytechnique. Certain aspects of their writings show the direct influence of Monge, who thus emerges as a true *chef d'école.*

Mathematical Analysis. The theory of partial differential equations and that of ordinary differential equations occupies—often in close connection with infinitesimal geometry—an important place in Monge's work. Yet, despite his great mastery of the techniques of analysis and the importance and originality of certain of the new methods he introduced, his writings in this area are sometimes burdened by an excessive number of examples and are blemished by insufficiently rigorous argumentation.

As early as 1771 the memoirs presented to the Academy and the letters to Condorcet reflect two of the guiding ideas of Monge's work: the geometric determination of the arbitrary function involved in the general solution of a partial differential equation, and the equivalence established between the classification of families of surfaces according to their mode of generation and according to their partial differential equation. He returned to these questions several times between 1771 and 1774, developing many examples and extending his study to finite difference equations. Also, in the memoir of 1775 on developable surfaces he discussed the partial differential equation of developable surfaces and that of ruled surfaces.

From 1773 to 1786 Monge carried out new research in this area. In seven memoirs of varying importance he presented flawlessly demonstrated results, and a progressively elaborated outline of very fruitful new methods. His essentially geometric inspiration drew upon the ideas of his earliest papers and on the division, introduced by Lagrange, of the integral surfaces of a first-order partial differential equation into a complete integral, a general integral, and a singular integral. By means of his theory of characteristics Monge gave a geometric interpretation of the method of the variation of parameters. In addition he introduced such basic notions as characteristic curve, integral curve, characteristic developable, trajectory of characteristics, and characteristic cone. Monge was also interested in second-order partial differential equations.

In particular he created the theory of "Monge equations"—equations of the type

$$Ar + Bs + Ct + D = 0,$$

where A, B, C, D are functions of x, y, z, p, q, and where p, q, r, s, and t have the classical meanings—and solved the equation of minimal surfaces. Investigating the theory of partial differential equations from various points of view, Monge—despite some errors and a somewhat disorganized and insufficiently rigorous presentation—contributed exceptionally fruitful methods of approaching this topic. For example, he demonstrated the geometric significance of the total differential equations that do not satisfy the condition of integrability, thus anticipating J. F. Pfaff's treatment of the question in 1814–1815. Monge also introduced contact transformations, the use of which was generalized by Lie a century later. In addition he determined the partial differential equations of many families of surfaces and perfected methods of solving and studying various types of partial differential equations.

Monge resumed his research in this area in 1795–1796 and in 1803–1807, when he completed his courses in infinitesimal geometry at the École Polytechnique, with a view toward their publication. He perfected the theories sketched in 1783–1786, corrected or made certain arguments more precise, and studied the area of their application.

Mechanics, Theory of Machines, and Technology. From the time he came to Mézières, Monge was interested in the structure, functioning, and effects of machines; in the technical and industrial problems of fortification and construction; and in local industry, particularly metallurgy. He held that technical progress is a key factor governing the happiness of humanity and depends essentially on the rational application of theoretical science. His interest in physics, mechanics, and the theory of machines derived in part from his view that they are the principal factors of industrial progress and, therefore, of social progress.

Monge discussed the theory of machines in his course in descriptive geometry at the École Polytechnique (end of 1794). His ideas, employed by Hachette in *Traité élémentaire des machines* (1809), were derived from the principle that the function of every machine is to transform a motion of a given type into a motion of another type. Although this overly restrictive conception has been abandoned, it played an important role in the creation of the theory of machines in the nineteenth century.

Monge's *Traité élémentaire de statique* (1788) was a useful textbook, and its successive editions recorded the latest developments in the subject, for example the theory of couples introduced by Poinsot. The fifth edition (1810) included important material on the reduction of an arbitrary system of forces to two rectangular forces.

The unusual experience that Monge had acquired in metallurgy was frequently drawn upon by the revolutionary government and then by Napoleon.

Physics and Chemistry. Although the details regarding Monge's contributions to physics are poorly known, because he never published a major work in this field, his reputation among his contemporaries was solid. His main contributions concerned caloric theory, acoustics (theory of tones), electrostatics, and optics (theory of mirages).

In 1781 Monge was selected to be editor of the *Dictionnaire de physique* of the *Encyclopédie méthodique.* He did not complete this task, but he did write certain articles.

His most important research in chemistry dealt with the composition of water. As early as 1781 he effected the combination of oxygen and hydrogen in the eudiometer, and in June–July and October 1783 he achieved the synthesis of water—at the same time as Lavoisier and independently of him. Although Monge's apparatus was much simpler, the results of his measurements were more precise. On the other hand, his initial conclusions remained tied to the phlogiston theory, whereas Lavoisier's conclusions signaled the triumph of his new chemistry and the overthrow of the traditional conception of the elementary nature of water. Monge soon adhered to the new doctrine. In February 1785 he took part in the great experiment on the synthesis and analysis of water; he was subsequently an ardent propagandist for the new chemistry and actively participated in its development.

In the experimental realm, in 1784 Monge achieved, in collaboration with Clouet, the first liquefaction of a gas, sulfurous anhydride (sulfur dioxide). Finally, between 1786 and 1788 Monge investigated with Berthollet and Vandermonde the principles of metallurgy and the composition of irons, cast metals, and steels. This research enabled them to unite previous findings in these areas, to obtain precise theoretical knowledge by means of painstaking analyses, and to apply this knowledge to the improvement of various techniques.

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RENÉ TATON

MONIZ, EGAS. See **Egas Moniz, A. A. F.**

MONNET, ANTOINE-GRIMOALD (*b.* Champeix, Puy-de-Dôme, France, 1734; *d.* Paris, France, 23 May 1817), *chemistry, mineralogy.*

Little is known about Monnet's early life and education. He attended the chemistry lectures of G.-F. Rouelle at the Jardin du Roi in Paris (*ca.* 1754) and was for a time a pharmacist's assistant in Nantes. By 1767 papers on the analysis of mineral springs had attracted the attention of some scientists and of Malesherbes, who became Monnet's patron; and Monnet was able to secure a post with the Bureau du Commerce, then under the direction of Daniel Trudaine. Beginning in 1772, he also worked for Henri Bertin, minister and secretary of state in charge of mining; in 1776 he was named France's first *inspecteur général des mines et minières du royaume.* Although his title and duties varied somewhat in later years, he survived many changes in the organization of the government corps of mining engineers and was finally retired in 1802.

His employment took Monnet to Alsace and the German states to study mining and metallurgy, and after 1772 his principal duty was to inspect and to suggest improvements in the French mining industry. Many of his published works were the result of these activities, and his post as mineralogist traveling at government expense was partly responsible for his appointment, in 1777, to direct the national geological survey earlier begun by Guettard and Lavoisier.

Monnet incorporated into his writings some of the findings of contemporary German and Swedish scientists, often before their treatises were available in French. Although French scientists considered his works useful, their judgments varied when they tried to assess Monnet's talents. Early in his career, he was pronounced a chemist of genuine ability by Macquer; but despite influential patronage, he failed in his attempts to become a member of the Académie Royale des Sciences. (He belonged to learned societies in Clermont-Ferrand, Rouen, Stockholm, and Turin.) After 1790 his persistent and violent adherence to the phlogiston theory and his personal eccentricities isolated him increasingly from the scientific community.

Monnet's first wife, by whom he had a son and a daughter, died in 1779. He married the writer Mariette Moreau in 1781. Monnet's brother was a mineralogist active in the Société Littéraire de Clermont-Ferrand.

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