Pierre-Simon Laplace (1749 – 1827)

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Pierre-Simon, marquis de Laplace was a French mathematician and astronomer whose work was pivotal to the development of mathematical astronomy and statistics. He summarized and extended the work of his predecessors in his five volume Mécanique Céleste (Celestial Mechanics) (1799 -1825). This work translated the geometric study of classical mechanics to one based on calculus, opening up a broader range of problems. In statistics, the so-called Bayesian interpretation of probability was mainly developed by Laplace.

He formulated Laplace's equation, and pioneered the Laplace transform which appears in many branches of mathematical physics, a field that he took a leading role in forming. The Laplacian differential operator, widely used in mathematics, is also named after him.

He restated and developed the nebular hypothesis of the origin of the solar system and was one of the first scientists to postulate the existence of black holes and the notion of gravitational collapse.

He is remembered as one of the greatest scientists of all time, sometimes referred to as a French Newton or Newton of France, with a phenomenal natural mathematical faculty superior to any of his contemporaries.

He became a count of the First French Empire in 1806 and was named a marquis in 1817, after the Bourbon Restoration.

Many details of the life of Laplace were lost when the family château burned in 1925. Laplace was born in Beaumont-en-Auge, Normandy in 1749. According to W. W. Rouse Ball (A Short Account of the History of Mathematics, 4th edition, 1908), he was the son of a small cottager or perhaps a farm-labourer, and owed his education to the interest excited in some wealthy neighbours by his abilities and engaging presence. Very little is known of his early years. It would seem from a pupil he became an usher in the school at Beaumont; but, having procured a letter of introduction to d'Alembert, he went to Paris to push his fortune. However, Karl Pearson is scathing about the accuracies in Rouse Ball's account and states,

"Indeed Caen was probably in Laplace's day the most intellectually active of all the towns of Normandy. It was here that Laplace was educated and was provisionally a professor. It was here he wrote his first paper published in the Mélanges of the Royal Society of Turin, Tome iv. 1766 -1769, at least two years before he went at 22 or 23 to Paris in 1771. Thus before he was 20 he was in touch with Lagrange in Turin. He did not go to Paris a raw self-taught country lad with only a peasant background! In 1765 at the age of sixteen Laplace left the "School of the Duke of Orleans" in Beaumont and went to the University of Caen, where he appears to have studied for five years. The 'École Militaire' of Beaumont did not replace the old school until 1776."

His parents were from comfortable families. His father was Pierre Laplace, and his mother was Marie-Anne Sochon. The Laplace family was involved in agriculture until at least 1750, but Pierre Laplace senior was also a cider merchant and syndic of the town of Beaumont.

Pierre Simon Laplace attended a school in the village run at a Benedictine priory, his father intending that he would be ordained in the Roman Catholic Church, and at sixteen he was sent to further his father's intention at the University of Caen, reading theology.

At the university, he was mentored by two enthusiastic teachers of mathematics, Christophe Gadbled and Pierre Le Canu, who awoke his zeal for the subject. Laplace did not graduate in theology but left for Paris with a letter of introduction from Le Canu to Jean le Rond d'Alembert.

According to his great-great-grandson, d'Alembert received him rather poorly, and to get rid of him gave him a thick mathematics book, saying to come back when he had read it. When Laplace came back a few days later, d'Alembert was even less friendly and did not hide his opinion that it was impossible that Laplace could have read and understood the book. But upon questioning him, he realized that it was true, and from that time he took Laplace under his care.

Another version is that Laplace solved overnight a problem that d'Alembert set him for submission the following week, then solved a harder problem the following night. D'Alembert was impressed and recommended him for a teaching place in the École Militaire.

With a secure income and undemanding teaching, Laplace now threw himself into original research and, in the next seventeen years, 1771 -1787, he produced much of his original work in astronomy.

Laplace further impressed the Marquis de Condorcet, and even in 1771 Laplace felt that he was entitled to membership in the French Academy of Sciences. However, in that year, admission went to Alexandre-Théophile Vandermonde and in 1772 to Jacques Antoine Joseph Cousin. Laplace was disgruntled, and at the beginning of 1773, d'Alembert wrote to Lagrange in Berlin to ask if a position could be found for Laplace there. However, Condorcet became permanent secretary of the Académie in February and Laplace was elected associate member on 31 March, at age 24.

He married Marie-Charlotte de Courty de Romanges in his late thirties and the couple had a daughter, Sophie, and a son, Charles-Émile (b. 1789).

Laplace's early published work in 1771 started with differential equations and finite differences but he was already starting to think about the mathematical and philosophical concepts of probability and statistics. However, before his election to the Académie in 1773, he had already drafted two papers that would establish his reputation. The first, Mémoire sur la probabilité des causes par les événements was ultimately published in 1774 while the second paper, published in 1776, further elaborated his statistical thinking and also began his systematic work on celestial mechanics and the stability of the solar system. The two disciplines would always be interlinked in his mind. "Laplace took probability as an instrument for repairing defects in knowledge."

Sir Isaac Newton had published his Philosophiae Naturalis Principia Mathematica in 1687 in which he gave a derivation of Kepler's laws, which describe the motion of the planets, from his laws of motion and his law of universal gravitation. However, though Newton had privately developed the methods of calculus, all his published work used cumbersome geometric reasoning, unsuitable to account for the more subtle higher-order effects of interactions between the planets. Newton himself had doubted the possibility of a mathematical solution to the whole, even concluding that periodic divine intervention was necessary to guarantee the stability of the solar system. Dispensing with the hypothesis of divine intervention would be a major activity of Laplace's scientific life. It is now generally regarded that Laplace's methods on their own, though vital to the development of the theory, are not sufficiently precise to demonstrate the stability of the Solar System, and indeed, the Solar System is now understood to be chaotic, although it actually appears to be fairly stable.

One particular problem from observational astronomy was the apparent instability whereby Jupiter's orbit appeared to be shrinking while that of Saturn was expanding. The problem had been tackled by Leonhard Euler in 1748 and Joseph Louis Lagrange in 1763 but without success. In 1776, Laplace published a memoir in which he first explored the possible influences of a purported luminiferous ether or of a law of gravitation that did not act instantaneously. He ultimately returned to an intellectual investment in Newtonian gravity. Euler and Lagrange had made a practical approximation by ignoring small terms in the equations of motion. Laplace noted that though the terms themselves were small, when integrated over time they could become important. Laplace carried his analysis into the higher-order terms, up to and including the cubic. Using this more exact analysis, Laplace concluded that any two planets and the sun must be in mutual equilibrium and thereby launched his work on the stability of the solar system. Gerald James Whitrow described the achievement as "the most important advance in physical astronomy since Newton".

Laplace had a wide knowledge of all sciences and dominated all discussions in the Académie. Laplace seems to have regarded analysis merely as a means of attacking physical problems, though the ability with which he invented the necessary analysis is almost phenomenal. As long as his results were true he took but little trouble to explain the steps by which he arrived at them; he never studied elegance or symmetry in his processes, and it was sufficient for him if he could by any means solve the particular question he was discussing.

During the years 1784 - 1787 he published some memoirs of exceptional power. Prominent among these is one read in 1783, reprinted as Part II of Théorie du Mouvement et de la figure elliptique des planétes in 1784, and in the third volume of the Mécanique céleste. In this work, Laplace completely determined the attraction of a spheroid on a particle outside it. This is memorable for the introduction into analysis of spherical harmonics or Laplace's coefficients, and also for the development of the use of what we would now call the gravitational potential in celestial mechanics.

In 1783, in a paper sent to the Académie, Adrien-Marie Legendre had introduced what are now known as associated Legendre functions.

Laplace, with scant regard for credit to Legendre, made the non-trivial extension of the result to three dimensions to yield a more general set of functions, the spherical harmonics or Laplace coefficients. The latter term is not in common use now.This paper is also remarkable for the development of the idea of the scalar potential. The gravitational force acting on a body is, in modern language, a vector, having magnitude and direction. A potential function is a scalar function that defines how the vectors will behave. A scalar function is computationally and conceptually easier to deal with than a vector function.

Alexis Clairaut had first suggested the idea in 1743 while working on a similar problem though he was using Newtonian-type geometric reasoning. Laplace described Clairaut's work as being "in the class of the most beautiful mathematical productions". However, Rouse Ball alleges that the idea "was appropriated from Joseph Louis Lagrange, who had used it in his memoirs of 1773, 1777 and 1780". The term "potential" itself was due to Daniel Bernoulli, who introduced it in his 1738 memoire Hydrodynamica. However, according to Rouse Ball, the term "potential function" was not actually used (to refer to a function V of the coordinates of space in Laplace's sense) until George Green's 1828 An Essay on the Application of Mathematical Analysis to the Theories of Electricity and Magnetism.

The spherical harmonics turn out to be critical to practical solutions of Laplace's equation. Laplace's equation in spherical coordinates, such as are used for mapping the sky, can be simplified, using the method of separation of variables into a radial part, depending solely on distance from the centre point, and an angular or spherical part. The solution to the spherical part of the equation can be expressed as a series of Laplace's spherical harmonics, simplifying practical computation.

Laplace now set himself the task to write a work which should "offer a complete solution of the great mechanical problem presented by the solar system, and bring theory to coincide so closely with observation that empirical equations should no longer find a place in astronomical tables." The result is embodied in the Exposition du système du monde and the Mécanique céleste.

The former was published in 1796, and gives a general explanation of the phenomena, but omits all details. It contains a summary of the history of astronomy. This summary procured for its author the honour of admission to the forty of the French Academy and is commonly esteemed one of the masterpieces of French literature, though it is not altogether reliable for the later periods of which it treats.

Laplace developed the nebular hypothesis of the formation of the solar system, first suggested by Emanuel Swedenborg and expanded by Immanuel Kant, a hypothesis that continues to dominate accounts of the origin of planetary systems. According to Laplace's description of the hypothesis, the solar system had evolved from a globular mass of incandescent gas rotating around an axis through its centre of mass. As it cooled, this mass contracted, and successive rings broke off from its outer edge. These rings in their turn cooled, and finally condensed into the planets, while the sun represented the central core that was still left. On this view, Laplace predicted that the more distant planets would be older than those nearer the sun.

As mentioned, the idea of the nebular hypothesis had been outlined by Immanuel Kant in 1755, and he had also suggested "meteoric aggregations" and tidal friction as causes affecting the formation of the solar system. Laplace was probably aware of this, but, like many writers of his time, he generally did not reference the work of others.

Laplace's analytical discussion of the solar system is given in his Méchanique céleste published in five volumes. The first two volumes, published in 1799, contain methods for calculating the motions of the planets, determining their figures, and resolving tidal problems. The third and fourth volumes, published in 1802 and 1805, contain applications of these methods, and several astronomical tables. The fifth volume, published in 1825, is mainly historical, but it gives as appendices the results of Laplace's latest researches. Laplace's own investigations embodied in it are so numerous and valuable that it is regrettable to have to add that many results are appropriated from other writers with scanty or no acknowledgement, and the conclusions - which have been described as the organized result of a century of patient toil - are frequently mentioned as if they were due to Laplace.

Jean-Baptiste Biot, who assisted Laplace in revising it for the press, says that Laplace himself was frequently unable to recover the details in the chain of reasoning, and, if satisfied that the conclusions were correct, he was content to insert the constantly recurring formula, "Il est aisé à voir que..." ("It is easy to see that..."). The Mécanique céleste is not only the translation of Newton's Principia into the language of the differential calculus, but it completes parts of which Newton had been unable to fill in the details. The work was carried forward in a more finely tuned form in Félix Tisserand's Traité de mécanique céleste (1889 _1896), but Laplace's treatise will always remain a standard authority.

Laplace also came close to propounding the concept of the black hole. He pointed out that there could be massive stars whose gravity is so great that not even light could escape from their surface (see escape velocity). Laplace also speculated that some of the nebulae revealed by telescopes may not be part of the Milky Way and might actually be galaxies themselves.[citation needed] Thus, he anticipated Edwin Hubble's major discovery 100 years in advance.

In 1812, Laplace issued his Théorie analytique des probabilités in which he laid down many fundamental results in statistics. In 1819, he published a popular account of his work on probability. This book bears the same relation to the Théorie des probabilités that the Système du monde does to the Méchanique céleste.

Amongst the other discoveries of Laplace in pure and applicable mathematics are:

Discussion, contemporaneously with Alexandre-Théophile Vandermonde, of the general theory of determinants, (1772);

Proof that every equation of an even degree must have at least one real quadratic factor;
Solution of the linear partial differential equation of the second order;
He was the first to consider the difficult problems involved in equations of mixed differences, and to prove that the solution of an equation in finite differences of the first degree and the second order might be always obtained in the form of a continued fraction; and
In his theory of probabilities:
Evaluation of several common definite integrals; and
General proof of the Lagrange reversion theorem.

Laplace in 1816 was the first to point out that the speed of sound in air depends on the heat capacity ratio. Newton's original theory gave too low a value, because it does not take account of the adiabatic compression of the air that results in a local rise in temperature and pressure. Laplace's investigations in practical physics were confined to those carried on by him jointly with Lavoisier in the years 1782 to 1784 on the specific heat of various bodies.

Honours:
1. Asteroid 4628 Laplace is named for him.[38]
2. He is one of only seventy-two people to have their name engraved on the Eiffel Tower.
3. The European Space Agency's working-title for the international Europa Jupiter System Mission is "Laplace".