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(*b*. Venice, Italy,14 August 1530; *d* Turin, Italy, 20 January 1590)

mathematics, physics.

Benedetti is of special significance in the history of science as the most important immediate forerunner of Galileo. He was of patrician status, but has not been definitely connected with any of the older known families of that name resident at Venice. His father was described by Luca Guarico as a Spaniard, philosopher, and *physicus*, probably in the sense of “student of nature” but possibly meaning “doctor of medicine.” It was to his father that Benedetti owed most of his education, which Guarico says made him a philosopher, musician, and mathematician by the age of eighteen. One of the few autobiographical records left by Benedetti asserts that he had no formal education beyond the age of seven, except that he studied the first four books of Euclid’s *Elements* under Niccolò Tartaglia, probably about 1546-1548. Their relations appear to have been poor, for Tartaglia nowhere mentions Benedetti as a pupil; Benedetti named Tartaglia in 1553 only “to give him his due” and severely criticized his writings in later years.

Benedetti’s originality of thought and mathematical skill are evident in his first book, the *Resolutio*, published at Venice when he was only twenty-two. The *Resolutio* concerns the general solution of all the problems in Euclid’s *Elements* (and of some others) using only a compass of fixed opening. Benedetti’s treatment was more comprehensive and elegant than that of Tartaglia or Ludovico Ferrara in the published polemics of 1546-1547, and was more systematic than Tartaglia’s later attack on the same problem in his final work, the *Trattato generale di numeri e misure* of 1560, in which he ignored the work of his former pupil.

Benedetti had one daughter, who was born at Venice in 1554 and died at Turin in 1580, but there is no record of his marriage. In 1558 he went to Parma as court mathematician to Duke Ottavio Farnese, in whose service he remained about eight years. In the winter of 1559/60 he lectured at Rome on the science of Aristotle; Girolamo Mei, who heard him there, praised his acumen, independence of mind, fluency, and memory. At Parma, Benedetti gave instruction at the court, served as astrologer, and advised on the engineering of public works. He also carried out some astronomical observations and constructed sundials mentioned in a later book on that subject. It appears that his private means were considerable, so that he was not inconvenienced by long delays in the payment of his salary.

In 1567 he was invited to Turin by the duke of Savoy and remained there until his death. The duke, Emanuele Filiberto, had great plans for the rehabilitation of Piedmont through public works, military engineering, and the general elevation of culture Benedetti’s duties included the teaching of mathematics and science at court. Tradition places him successively at the universities of Mondovi and Turin, although supporting official records are lacking and Benedetti never styled himself a professor. He appears, however, to have served as the duke’s adviser on university affairs; for instance, he secured the appointment of Antonio Berga to the chair of philosophy at the University of Turin in 1569. Benedetti later engaged in a polemic with Berga, and on the title page of his *Consideratione* (1579) he referred to Berga as professor at Turin, but to himself only as philosopher to the duke of Savoy.

While at Turin, Benedetti designed and constructed various public and private works, such as sundials and fountains. His learning and mathematical talents were frequently praised by the duke and were mentioned by the Venetian ambassador in 1570, when Benedetti was granted a patent of nobility. In 1585 he appears to have been married a second time or rejoined by the mother of his daughter. In the same year he published his chief work. the *Speculationum*, a collection of treatises and of letters written to various correspondents on mathematical and scientific topics.

Benedetti died early in 1590. He had forecast his death for 1592 in the final lines of his last published book. On his deathbed he recomputed his horoscope and declared that an error of four minutes must have been made in the original data (published in 1552 by Luca Guarico), thus evincing his lifelong faith in the doctrines of judiciary astrology.

Beneditti’s first important contribution to the birth of modern physics was set forth in the letter of dedication to his *Resolutio*. The letter was addressed to Gabriel de Guzman, a Spanish Dominican priest with whom he had conversed at Venice in 1552. It appears that Guzman had shown interest in Benedetti’s theory of the free fall of bodies, and had asked him to publish a demonstration in which the speeds of fall would be treated mathematically. In order to forestall the possible theft of his ideas, Benedetti published his demonstration in this letter despite its irrelevance to the purely geometrical content of the book. Benedetti held that bodies of the same material, regardless of weight, would fall through a given medium at the same speed, and not at speeds proportional to their weights, as maintained by Aristotle. His demonstration was based on the principle of

Archimedes, which probably came to his attention through Tartaglia' publication at Venice in 1551 of a vernacular translation of the first book of the Archimedean treatise on the behavior of bodies in water. Beneditti's "buoyancy theory of fall" is in many respects identical with that which Galileo set forth in his first treatise *De motu*. composed at Pisa about 1590 but not published during his lifetime.

Although no mention of Benedeitt's theory has been found in books or correspondence of the period, lively discussions appear to have taken place concerning it, some persons denying the conclusion and others asserting that it did not contradict Aristotle. In answer to those contentions, Benedetti Promptly published a second book, the *Demonstratio* (1554), restating the argument and citing the particular texts of Aristotle that it contradicted. In the new preface, also addressed to Guzman, Benedetti mentioned opponents as far away as Rome who had declared that since Aristotle could not err, his own theory must be false. Such discussions may explain the otherwise remarkable conicidence that another book published in 1553 also contains a statement related to free fall. This was *II vero modo di scrivere in cifra,* by Giovanni Battista Bellaso of Brescia, in which it was asked why a ball of iron and one of wood will fall to the ground at the same time.

Two editions of Benedetti's *Demonstratio*, which was by no means a mere republication of the *Resolutio*, appeared in rapid succession. The first edition maintained, as did the *Resolutio*, that unequal bodies of the same material would fall at equal speed through a given medium. The second edition stated that resistance of the medium is proportional to the surface rather than the volume of the falling body, implying that precise equality of speed for homogeneous bodies of the same material and different weight would be found only in a vacuum. This correction of the original statement was repeated in Benedetti's later treatment of the question in *Speculationum* (1585).

Benedetti's original publication of his thesis in 1553 was designed to prevent its theft; perhaps he had in mind the fate of Tartaglia's solution of the cubic equation a few years earlier. But even repeated publication failed to protect it, and indeed became the occasion of its theft. Jean Taisnier, who pirated the work of Petrus Peregrinus de Maricourt in his *Opusculum … de natura magnetis* (1562), included with it—as his own—Benedetti's *Demonstratio*. Taisnier's impudent plagiarism enjoyed wider circulation than Benedetti's original, and was translated into English by Richard Eden about 1578. Simon Stevin cited the proposition as Taisnier's when he published his own experimental verification of it in 1586. But since Taisnier had stolen the *Demonstratio* in its earlier form, he was criticized by Stevin for the very fault which Benedetti had long since corrected in the second *Demonstratio* of 1554. Taisnier's appropriation of his book ultimately became known to Benedetti, who complained of it in the preface to his *De gnomonum* (1573). The relatively small circulation of Benedetti's works is evidenced by the fact that it was not until 1741 that general attention was first called to the theft, by Pierre Bayle.

Benedetti's ultimate expansion of his discussion of falling bodies in the *Speculationum* is of particular interest because it includes an explanation of their acceleration in terms of increments of impetus successively impressed *ad infinitum*. That conception is found later in the writings of Beeckman and Gassendi. but it appears never to have occurred to Galileo. Despite this insight, however, Benedetti failed to arrive at (or to attempt) a mathematical formulation of the rate of acceleration. the difference between Galileo's treatment and Benedetti's is perhaps related to the fact that Benedetti neglected the medieval writers who had attempted a mathematical analysis of motion and did not adopt their terminology, which is conspicuous in Galileo's early writings. Benedetti was deeply imbued with the notion of impetus as a self-exhausting force, a concept that may have prevented his further progress toward the inertial idea implicit in the accretion of impetus.

Benedetti's next contribution to physics was made about 1563, the most probable date of two letters on music written to Cipriano da Rore and preserved in the *Speculationum*. Those letters, in the opinion of Claude Palisca, entitle Benedetti to be considered the true pioneer in the investigation of the mechanics of the production of musical consonances. Da Rore was choirmaster at the court of Parma in 1561–1562, when he returned to Venice, Benedetti's letters probably supplemented his discussions with da Rore at Parma. Departing from the prevailing numerical theories of harmony, Benedetti inquired into the relation of pitch, consonance, and rates of vibration. He attributed the generation of musical consonances to the concurrence or cotermination of waves of air. Such waves, resulting from the striking of air by vibrating strings, should either agree with or break in upon one another. Proceeding thus, and asserting that the frequencies of vibration of two strings under equal tension vary inversely with the string lengths, Benedetti's empirical approach to musical theory, as applied to the tuning of instruments, anticipated the later method of equal temperament and contrasted sharply with the rational numerical rules offered by Gioseffo Zarlino. It is of interest that Zarlino was the teacher of Galileo's father, who in 1578 attacked Zarlino's musical theories on somewhat similar empirical grounds. But since Benedetti's letters were not published until 1585, they were probably not known to Vincenzio Galilei when he launched his attack.

Benedetti's first publication after his move to Turin was a book on the theory and construction of sundials, *De gnomonum* (1573), the most comprehensive treatise on the subject to that time. It dealt with the construction of dials at various inclinations and also with dials on cylindrical and conical surfaces. This book was followed by De *temporum emendatione*, on the correction of the calendar (1578). In 1579 he published *Consideratione*, a polemic work in reply to Antonio Berga, concerning a dispute over the relative volumes of the elements earth and water. As with Galileo's polemic on floating bodies, the dispute had arisen at court as a result of the duke's custom of inviting learned men to debate topics of philosophical or scientific interest before him. Of all Benedetti's books, this appears to be the only one to have received notice in a contemporary publication, Agostino Michele's *Trattato della grandezza dell'acqua et della terra* (1583).

Benedetti's final work, containing the most important Italian contribution to physical thought prior to Galileo, was the *Diversarum speculationum* (1585). Its opening section includes a number of arithmetical propositions demonstrated geometrically. Other mathematical sections include a treatise on perspective, a commentary on the fifth book of Euclid's *Elements*, and many geometrical demonstrations—including a general solution of the problem of circumscribing a quadrilateral of given sides; the development of various properties of spherical triangles, circles, and conic sections; discussion of the angle of contact between circular arcs; and theorems on isoperimetric figures, regular polygons, and regular solids.

The section on mechanics is largely a critique of certain parts of the pseudo-Aristotelian *Questions of Mechanics* and of propositions in Tartaglia's *Quesiti, et inventioni diverse*. Benedetti disputed Tartaglia's assertion that no body may be simultaneously moved by natural and violent motions, although he did not enter into a discussion of projectile motion giving effect to composition He did, however, assert clearly and for the first time that the impetus of a body freed from rapid circular motion is rectilinear and tangential in character, a conception of fundamental importance to his criticisms of Aristotle and to his attempted explanation of the slowing down of wheels and of spinning tops.

Following the section on mechanics is an attack on many of Aristotle's basic physical conceptions. This section restates the "buoyancy theory of fall" as it was set forth in the second edition of the *Demonstratio*. For equality of speed of different weights falling *in vacuo*, Benedetti proposed a thought experiment that is often said to be identical with Galileo's, although the difference is considerable. Benedetti supposes two bodies of the same weight connected by a line and falling *in vacuo* at the same speed as a single body having their combined weight; he appeals to intuition to show that whether connected or not, the two smaller bodies will continue to fall at the same speed. In Galileo's argument, two bodies of different weight—and therefore of different speeds, according to Aristotle—are tied together; by the Aristotelian assumption, the slower would impede the faster, resulting in an intermediate speed for the pair. But the pair being heavier than either of its parts, it should fall faster than either, under the Aristotelian rule. Thus Galileo's argument, unlike Benedetti's, imputes self-contradiction to Aristotle's view. Benedetti's discussion of the ratios of speeds of descent in different media is also essentially different from Galileo's in *De motu*, for it includes both buoyancy and the effect of resistance proportional to the surface; the latter effect was neglected by Galileo in his earlier writings.

Again, Benedetti correctly holds that natural rectilinear motion continually increases in speed because of the continual impression of downward impetus, whereas Galileo wrongly believed that acceleration was an accidental and temporary effect at the beginning of fall only, an error which vitiated much of the reasoning in *De motu* and was corrected only in his later works. These differences create historical perplexities described below.

Another of Benedetti's contributions to mechanics is the description of hydrostatic pressure and the idea of a hydraulic lift, prior to Stevin's discussion of the hydrostatic paradox (1586). Benedetti also attributed winds to changes in density of air, caused by alterations of heat. In opposition to the view that clouds are held in suspension by the sun, he applied the Archimedean principle and stated that clouds seek air of density equal to their own; he also observed that bodies are heated by the sun in relation to their degree of opacity.

Benedetti published no separate work on astronomy, but his letters in the *Speculationum* show that he was an admirer of Copernicus and that he was much concerned with accuracy of tables and precise observation. His astronomical interests appear to have been astrological rather than physical and systematic, as were those of Kepler, Galileo, and Stevin. Benedetti offered a correct explanation of ruddy color of the moon under total eclipse, however, based on refraction of sunlight in the earth's atmosphere.

Benedetti's scientific originality and versatility leave little doubt that his work afforded a basis for the overthrow of Aristotelian physics. The extent of its actual influence on others, however, presents very difficult questions. Stevin was certainly unaware of Benedetti when he published his basic contributions to mechanics and hydrostatics. He had seen Benedetti's *Speculationum* before 1605, when he published on perspective, but in that work he built more on Guido Ubaldo del Monte than on any other writer. Kepler mentioned Benedetti but once, and only in the most general terms. Willebrord Snell's attention was called to Benedetti by Stevin. The case of Galileo is the most perplexing. It is widely held that he was directly indebted to Benedetti for the ideas underlying *De motu*, but the resemblances of those ideas are easily accounted for by the Archimedean principle and the medieval impetus theory, easily accessible to both men independently, while the differences, particularly with respect to acceleration and the accumulation of impressed motion, are hard to explain if the young Galileo had the work of Benedetti before him. The absence of Benedetti's name in Galileo's books and notes, where other kindred spirits such as Gilbert and Guido Ubaldo are praised, is suggestive: much more so is the fact that Benedetti is not mentioned to or by Galileo in the vast surviving correspondence of his time. Jacopo Mazzoni has been proposed as a positive link—he was a colleague and friend of Galileo's at Pisa about 1590, and certainly knew Benedetti's work by 1597; but since Galileo left Pisa for Padua in 1592, the connection is uncertain. Benedetti appears to have remained unknown to Galileo's teacher at Pisa, Francesco Buonamico, who in 1591 published a treatise, De *motu*, of over a thousand pages. On the whole, it appears that Benedetti's *Speculationum* was not widely read by his contemporaries, despite its outstanding achievements in extending the horizons of mathematics, physics, and astronomy beyond the Peripatetic boundaries.

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