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Contributions From the Museum of History and Technology

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Publications of the United States National Museum

The scholarly and scientific publications of the United States National Museum include two series, *Proceedings of the United States National Museum* and *United States National Museum Bulletin*.

In these series, the Museum publishes original articles and monographs dealing with the collections and work of its constituent museums—The Museum of Natural History and the Museum of History and Technology—setting forth newly acquired facts in the fields of anthropology, biology, history, geology, and technology. Copies of each publication are distributed to libraries, to cultural and scientific organizations, and to specialists and others interested in the different subjects.

The *Proceedings*, begun in 1878, are intended for the publication, in separate form, of shorter papers from the Museum of Natural History. These are gathered in volumes, octavo in size, with the publication date of each paper recorded in the table of contents of the volume.

In the *Bulletin* series, the first of which was issued in 1875, appear longer, separate publications consisting of monographs (occasionally in several parts) and volumes in which are collected works on related subjects. *Bulletins* are either octavo or quarto in size, depending on the needs of the presentation. Since 1902 papers relating to the botanical collections of the Museum of Natural History have been published in the *Bulletin* series under the heading *Contributions from the United States National Herbarium*, and since 1959, in *Bulletins* titled “Contributions from the Museum of History and Technology,” have been gathered shorter papers relating to the collections and research of that Museum.

The present collection of Contributions, Papers 34-44, comprises Bulletin 240. Each of these papers has been previously published in separate form. The year of publication is shown on the last page of each paper.

Frank A. Taylor
Director, United States National Museum

Contributions from The Museum of History and Technology: Paper 35

The Borghesi Astronomical Clock In the Museum of History and Technology

Silvio A. Bedini

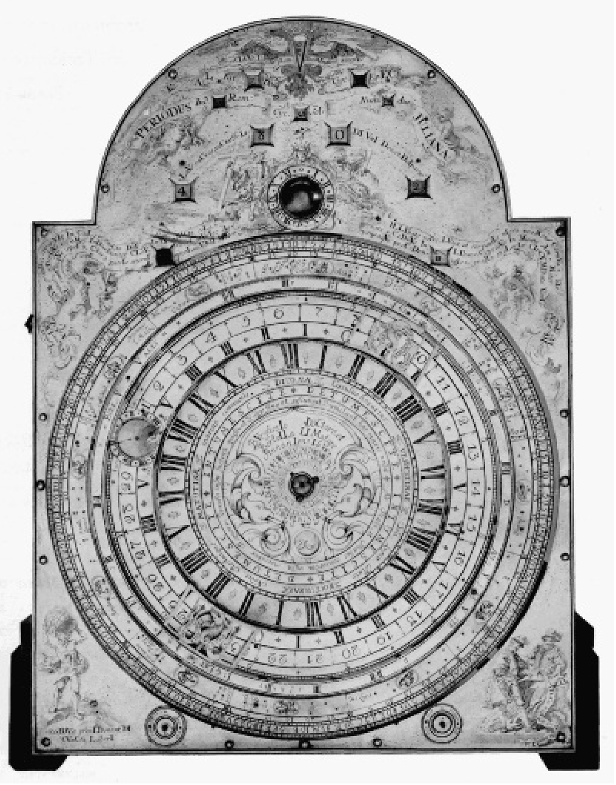

Figure 1.—The dial plate of the Borghesi clock, showing the horary and astronomical indications which are automatically presented.

Silvio A. Bedini

The Borghesi Astronomical Clock
In the Museum of History and Technology

The history of the 18th-century Borghesi astronomical clock is described here from contemporary source material. The evolution of its design by Father Francesco Borghesi and the building of the complex mechanism devised by the clockmaker, Bartolomeo Antonio Bertolla, is a story of the vision of one man turned into reality by another. The result of their collaboration is the unique, astronomical timepiece now in the Museum of History and Technology.

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"... All this work I had performed eagerly, so that, while in my room, I might contemplate leisurely, both during the day and in the night, the true face of the heavens and of the seas unobscured by clouds, even though I had no astronomical equipment."[1]

With these words, Father Francesco Borghesi (1723-1802) of Mechel described the reasons which inspired him to invent a unique astronomical clock which is now in the horological collection of the Museum of History and Technology.

This complicated mechanism, which performs a multitude of functions, was designed by Father Francesco Borghesi, a secular priest in Venezia Tridentina. It was constructed in 1764 under his direction by a provincial clockmaker named Bartolomeo Antonio Bertolla (1702-1789) of Mocenigo di Rumo. It was the second of two complicated astronomical clocks which Father Borghesi designed and which Bertolla constructed. According to contemporary sources, this clock was presented to the Empress Maria Theresa of Austria soon after its completion.

Its history is rather hazy, except for the fact that in 1780 this second Borghesi timepiece was still in the Imperial Palace in Vienna. The clock was again noted in 1927 when it was sold at a public auction in New York.[2] Subsequently, it was acquired for the Smithsonian Institution.

ACKNOWLEDGMENTS

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The translation from Francesco Borghesi's Latin texts, which made this study possible, were made by: Rev. Neil Herlihy, S.J., Rev. Francis J. Heyden, S.J., and Rev. Stephen X. Winters, S.J., Georgetown University, Washington, D.C.; and Rev. Daniel Hunter, O.P., and Rev. Robert Stenger, O.P., Dominican House of Studies, Washington, D.C.

Development of Astronomical Clocks

The history of the great theoretical and mechanical achievement which the Borghesi clock represents has been most adequately covered elsewhere.[3] Consideration of the development of equation and astronomical clocks is required here only for the purpose of relating the Borghesi timepiece with the other significant developments in this branch of horology.

The invention of the anchor escapement in about 1670, and the consequent greater accuracy in time-telling, led to increased preoccupation with precision. Daily differences in time as recorded by sundials and clocks became more noticeable. Finally, in the second half of the 17th century, some attempt was made to construct mechanical clocks combined with sundials as well as astronomical clocks.

With the improvement of precision time-telling, it became necessary to reconcile the actual difference between true and mean time. Although a great variety of time-equation tables were produced, there was a considerable margin for error in their use. This led to the construction of mechanical clocks in which the equation of time was automatically accomplished. A few were produced late in the 17th and early 18th century at considerable cost and, consequently, with little popularity. Equation sundials were also developed which were elaborately ingenious, but they were not completely practical. Inevitably, they were supplanted by the mechanical equation clock.

Probably the first documented mention of an equation clock is in the diary of John Evelyn who recorded that in 1666 he visited the Royal Society where he witnessed a curious clock, which showed the equation of time, being presented by a certain Mercator. More data on the subject appeared in the first two decades of the 18th century, when Henry Sully, Joseph Williamson, Daniel Quare, and Thomas Tompion—who were among the foremost English clockmakers of all time—produced elaborate examples of these timepieces. Another significant maker was Dowe Williamson, who became Court Clockmaker to Emperor Charles VI of Austria. In London, Joseph Williamson produced some of the finest astronomical timepieces of this type that have been known. The interest in the subject next shifted to France where many fine examples were produced during the first half of the 18th century.

Just after the middle of the 18th century, the subject of astronomical clocks suddenly became a major horological preoccupation in another region, namely, Austria, where the work in this field was apparently done exclusively by members of the clergy. The earliest was Father Philipp Matthäus Hahn (1739-1790) of Württemberg.[4] Father Hahn considered the equation of time as only one part of a plan to represent astronomical occurrences by means of clockwork. In addition to planetaria and similar mechanisms, Father Hahn produced two extraordinary astronomical, tall-case clocks, both of which survive in public museums.

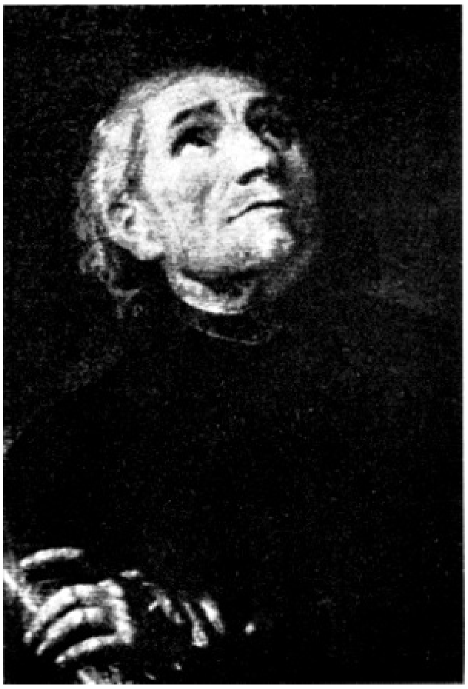

Figure 2.—Portrait of Father Francesco Borghesi, inventor and designer of the astronomical clock in the Museum of History and Technology.

Another of the clerical clockmakers was Father Aurelianus à San Daniele (1728-1782), an Augustine monk in the monastery of the Imperial Court at Vienna.[5] His four complicated astronomical clocks, which exist in museums at present, are comparable to those produced by Father Hahn. The third cleric was Brother David à San Cajetano (1736-1796) in the same Augustine order to which Father Aurelianus belonged. He achieved note as the author of various publications, including *Neue Rädergebäude*[6] [New Construction of Wheels] relating to planet-wheels, or gear-trains containing epicyclic elements. He constructed a clock based on an elaborate astronomical design which was substantially different from the others. The fourth of the ecclesiasts who designed astronomical clocks in this period was Father Klein of Prague, who produced a complicated astronomical timepiece in about 1738. [Pg 33]

The fact that such important and outstanding examples of astronomical clocks were produced exclusively by ecclesiasts in Austria during the second half of the 18th century is especially significant. It is particularly so when a fifth cleric is added to the group, also an Austrian subject although Italian by heritage, in the person of Father Francesco Borghesi.

Although only Father Borghesi's second astronomical clock is now known, it is apparent that this example in the Museum of History and Technology represents an experiment in astronomical time-telling comparable to any of the timepieces produced by Father Hahn, Father Aurelianus, Brother David à San Cajetano or Father Klein.

This combination of five clerical clockmakers who lived in the same region during the same period of time is sufficiently unusual. However, the fact that each of them apparently worked without association with any of the others leads to the conjecture that a common factor must have led them to their individual preoccupation with astronomical horology. What the link may have been is not apparent from the surviving records of the lives and works of these clerics. Certainly it was not an interest in astronomy or clockmaking per se, because other than the astronomical clocks, none of these horological inventors—with the possible exception of Father Hahn—worked in any other aspect of the fields of astronomy or horology. However, after a comprehensive study of Father Borghesi's writings, there is little doubt of the religious basis of his own inspiration.

Designer Borghesi

Father Borghesi's story takes place in the picturesque mountainous region of what was then known as Venezia Tridentina (since 1947, Trentino-Alto Adige) in northern Italy, along the Tyrolean border of Austria. Because of its strategic position as the passage between Innsbruck and Verona, the possession of the Tridentina was contested again and again in the European wars, but during Father Borghesi's lifetime, the Tridentina was under Austrian domination. [Pg 34]

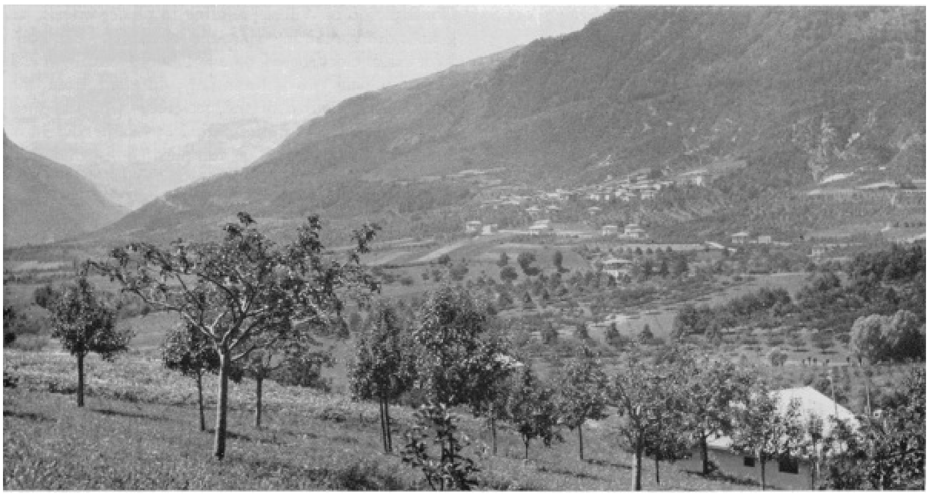

Figure 3.—Panorama of the village of Mechel in the valley of the Non, birthplace of Father Borghesi.

Deep within this mountainous district is the romantic valley of the Non, or Anáuni, with its great forests and ancient castles. Most maps do not mark it, and the tourist guides ignore it.[7] One of the chief communities is Cles, with its historic Renaissance buildings. The major city of the region is Trent on the Adige River, with its surviving Roman relics and Romanesque and Renaissance architecture.

The little villages scattered throughout the valley of the Non played no part in history, but such names as Mechel and Mocenigo di Rumo reflect the interchange of sovereignty. It was in the little village of Mechel that Francesco Borghesi was born in 1723.[8] Local records are meager and inadequate, and many of the details of Borghesi's life must be assumed. Inasmuch as the village was in a rural, agricultural district, Borghesi may have come from a family of farmers, vintners, or village tradesmen. Borghesi sought an education by entering the priesthood and was ordained a secular priest in Salzburg. He was first assigned as curate to the village parish of Rumo in the valley of the Non, a short distance from his birthplace.[9] Later, he was transferred to his native Mechel. He was inherently a man of simple tastes and of great piety. He tended to the needs of his mountain villagers and attended the births, weddings and deaths of his parishioners. It was during his assignment in this tiny community that Father Borghesi met and became friendly with the clockmaker, Bartolomeo Antonio Bertolla of nearby Mocenigo di Rumo.

Clockmaker Bertolla

Bartolomeo Antonio Bertolla was born in Mocenigo di Rumo, a short distance from Mechel, in 1702.[10] Nothing is known of his boyhood, other than the fact that he was mechanically inclined. At the age of 17 he was apprenticed to become a clockmaker with the master, Johann Georg Butzjäger of Neulengbach, a small village on the edge of the great Vienna woods.[11] This region was then part of the domain of the Archduke of Austria, of which Sankt Pölten was the capital.

Figure 4.—Portrait of Bartolomeo Antonio Bertolla, clockmaker, of Mocenigo di Rumo. The canvas in oils is owned by descendants. In the upper left-hand corner is an inscription, now hardly legible, indicating that the portrait may have been painted after Bertolla's death on January 15, 1789. Translated, it states: "Bartolomeo Antonio Bertola [sic] Celebrated Mechanician and Inventor of various Instruments. Repairer of the clocks of Venice, Verona, Trent, and other localities. Maker of the Work which combines the Copernican and Ptolemaic Systems devised by Father Francesco Borghesi of Mechel, Laureate Mathematician, and humbly offered to Her Imperial Majesty Maria Theresa. Died in piety in his home at Rumo on 15 January 1789 at the age of 86." (*Courtesy of Sig. Luigi Pippa of Milan.*)

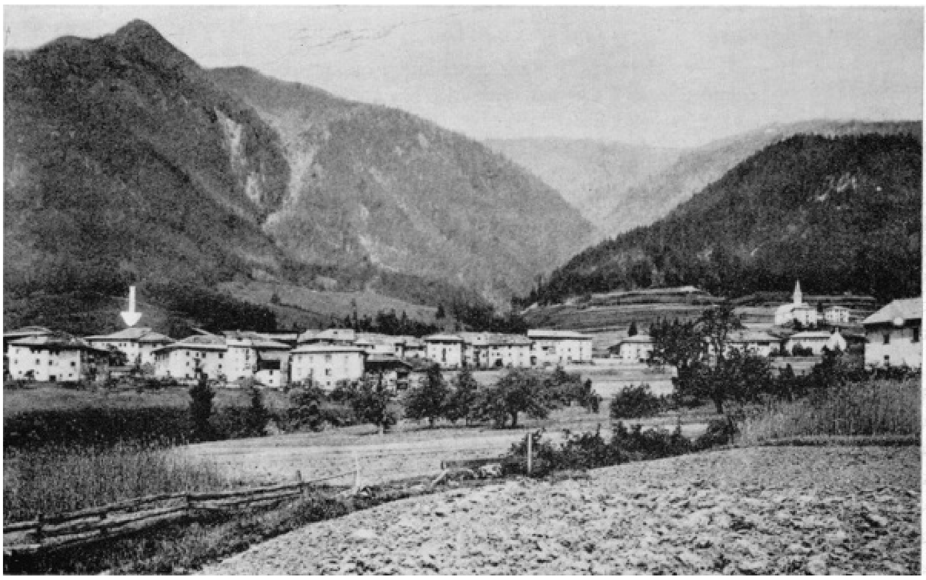

Figure 5.—The village of Mocenigo di Rumo in the valley of the Non. Arrow points to Bertolla's home and workshop at far left.

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Figure 6.—Certificate of apprenticeship awarded to Bartolomeo Antonio Bertolla upon completion of his 3-year apprenticeship at Neulengbach, dated December 27, 1722.

Bertolla began his apprenticeship with Butzjäger under the auspices of the Corporation of Blacksmiths of Sankt Pölten in 1719. His training was supervised by two master locksmiths, Johann Christian Winz and Peter Wisshofer, who were members of the Corporation, and were assigned to serve as patrons for the apprentice. It was their obligation to make certain that he received good care and adequate instruction from his master. While he worked in Butzjäger's shop, Bertolla lived with the master's family in their home.

Bertolla's 3 years at Neulengbach passed quickly as he sought to absorb all that his master could teach him. Butzjäger was considered to be a good craftsman in the region, yet today there is not even a mention of his name in the lists of clockmakers. He specialized in the production and repair of "great clocks" which included tall-case, domestic timepieces, and tower clocks. Butzjäger treated his apprentice well, and in return Bertolla rewarded him by being diligent and honest. His subsequent work is sufficient indication that he developed into an extremely skilled craftsman, and he became the equal of any clockmaker of his time.

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The 3 years of apprenticeship were completed and on December 27, 1722, Bertolla received a certificate from the Corporation of Blacksmiths which assured whomever it might concern of Bertolla's skill, diligence and honesty, and permitted him to open his own shop as a clockmaker under the auspices of the Corporation. This document, which has been preserved by Bertolla's descendants, is an interesting record of the organization of the trade guilds in the 18th century, and, for that reason, has been translated from the original German:

> We, the Superiors and other masters of the honorable corporation of municipal blacksmiths, armorers, and of smiths, in the Imperial City of St. Pölten in Austria by the river Enns, Declare by these Presents put in force by this document to anyone who waits to hear.... That the honorable and able Bartolomeo Antonio Bertolla of Rumo in Lentzberg, the Tyrol, on the 27th day of the month of December of the year 1719 was consigned as apprentice for three years, in the presence of two sponsoring masters for the purpose, the honorable Johann Christian Winz and Peter Wisshofer, both of them

master locksmiths representing the entire honorable Corporation and others of open shop—to the honorable Johann Georg Butzjäger, incorporated with us, citizen and master clockmaker for large clocks in the merchant-village of Neulengbach in Wienerwald, as his master of the art, would have therefore perfectly and rightfully worked and learned, and

that afterwards, on the day and year noted at the bottom, he will be newly declared free and independent before us, representative of an entire and honorable Corporation and with open shop, of his above-mentioned master and of the two sponsoring masters mentioned,

and since he eagerly requested a truthful certificate of apprenticeship for his honest service as an apprentice and for his good behavior, and we having great pleasure as well as the duty of favoring the truth and well knowing that the aforesaid Bartolomeo Antonio Bertolla has learned honestly the art of clockmaking for great clocks from his aforesaid master, and that he has always behaved with honesty, obedience, faithfulness and diligence both towards his master and towards us to our complete satisfaction and, therefore, we cannot in any manner refuse his request, rather we wish to grant it with a clear conscience.

We Therefore Address to Everyone and to anyone in whatever state and rank, but particularly to those interested in our branch of this art, our respectful and courteous entreaty and request to consider Bartolomeo Antonio Bertolla well recommended for his honest apprenticeship and his good behavior, and to desire to favor him in every way, in such a manner that will assure our gratitude whenever an occasion presents itself.

For this purpose, we issue, as we have declared we wish to issue to you, Bartolomeo Antonio Bertolla, this certificate of apprenticeship, attaching to it the seal of our Corporation.

Executed in the city of St. Pölten on 27 December 1722.[12]

His apprenticeship over, Bertolla returned to his native region where he soon established a reputation for himself as one of the most skillful clockmakers in the Tridentina and produced timepieces of fine quality in some quantity. No records have survived concerning his personal life, but it is believed that he married probably soon after his return. He had no children of his own. To expand his business, he eventually took into his shop two nephews, the sons of a brother and a sister, as apprentices.

Bertolla's work brought him a sufficient number of clients, and he produced elaborate clocks for his more wealthy patrons.

In 1752, it is recorded that he repaired the great clock in the campanile of the Church of the Assumption of the Virgin Mary in Cles, the regional capital of the valley of the Non. The clock dated probably from the 16th century, and it seems likely that Bertolla replaced the original two-wheel train with a three-wheel movement, and that he added the present anchor escapement.[13]

It is not possible to determine when Father Borghesi first made Bertolla's acquaintance, but it may be assumed that they had become friends in the late 1750's.

After he had come to know Bertolla, Father Borghesi apparently spent many hours in the clockmaker's shop. He was fascinated by mechanics in any form, and the complications of clockwork particularly intrigued him. Bertolla was patient with the young priest, explaining the tools he had and their uses, the clocks he produced or repaired, and the principles which were involved. Father Borghesi listened willingly and as his understanding of timepieces grew, his curiosity increased.

In spite of himself, the priest could not be satisfied with the ordinary aspects of his friend's work and wanted to learn more. From a casual pastime, the study of time became an obsession with him. There was but one recourse: he went back to studying once again. This time it was not theology, however, but the sciences. Every moment he could spare went into the perusal of books on mathematics, astronomy, and associated subjects. He progressed rapidly, driven by his overpowering interest and aided by his quick intellect.

Little by little, Borghesi managed to acquire the basic texts that explained this new world to him, probably borrowing them from old seminary friends. As each new book came into his hands, he devoured it in his desire to master its contents. He discussed each new principle or precept that he learned with Bertolla. Together, they attempted to apply his new learning to the calculations necessary for a timepiece which would demonstrate the astronomical theories in visual form. Borghesi taught himself slowly, step by step, and the result was a profound understanding of astronomical science. He conceived the project of constructing a great astronomical clock which he felt could be accomplished by combining Bertolla's mechanical skills with his own recent mastery of astronomy and mathematics.

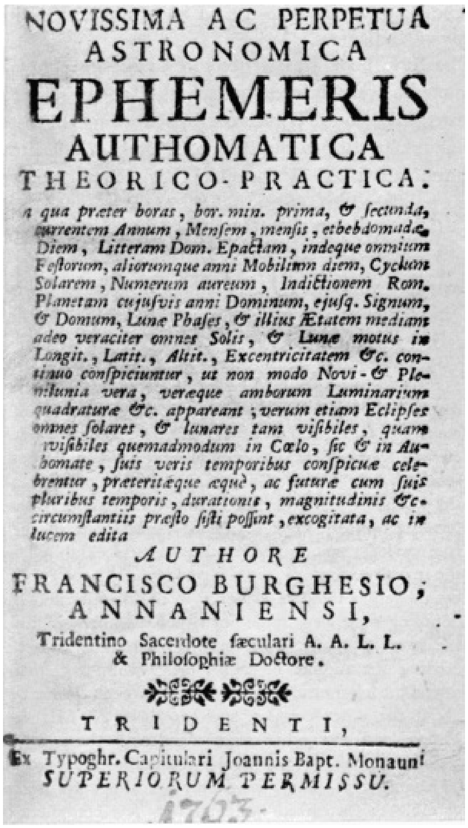
First Borghesi Clock

It is not difficult to visualize the two men, the priest and the clockmaker, as they sat together night after night working out their plans. Father Borghesi would painstakingly outline the astronomical principles he wished to have the clock exhibit and the mathematical principles which would be involved to operate them. Bertolla concentrated on them and tried to transcribe the principles into functional mechanical terms, visualizing each operation in terms of wheels and gears. Little by little the two men coordinated the numerous elements and welded them into an operating entity. They adjourned either to the stark simplicity of the rectory or, probably more often, to Bertolla's little home workshop, the priest standing over his friend while the latter worked at his bench in the dark paneled interior illuminated only by the several lamps on the work benches.

This first clock which the two men combined to create is a monument to the great scientific knowledge of the self-taught priest and the technical ability of the clockmaker—a unity combining astronomical science, mechanics, and artistry. The story of the project is told in a little book, *Novissima Ac Perpetua Astronomica...*, which Borghesi later published. Explaining the incentive which inspired him, and the premises from which he began his work, he wrote:

> From the foundation of astronomical science long ago, innumerable [and] repeated observations of both ancient and modern astronomers, emerged at last from their hiding places. Made light of by the jests of so many outstanding intellects, they have so successfully brought to light the paths of the stars and their motions, which are more complicated to us than the Gordian knots. Now it is possible for even an amateur in astronomy, sufficiently instructed, to predict for any given time not only the mean position of the planets, but also their true longitude and latitude, and even the true time of their conjunctions, and their ecliptic oppositions, with all the attendant circumstances. Yet, until now, no hypothesis has been devised which would force an automaton to show to us, before our very eyes, the eclipses of the planets in their true and certain times.
>
> For though there have been men seeking with all their might to bind by laws their artificial heavens, by I know not how many and how great calculations, and to systematize the complexities of the rotations of celestial bodies; nevertheless, all of them, as if by common agreement, considered themselves to have made great contributions to mechanico-theoretical astronomy. However, they have only attained, even though closely, the mean locations of the secondary mobiles, and those by a certain rather crude calculation. Some attained by more, some by less, but all by some degree of wandering from the truth, either worn out by the intricacies of the motions, or deceived and deceiving by the errors of their calculations. This fact those well know, who, setting about to collect information of this kind, even those publicized not long ago, with true astronomical calculation, have been bored to death while digging out by the most elementary and superficial arithmetical torture, the worst of fallacies spontaneously erupting from thence.
>
> It would seem that true calculations alone can be desired in mechanico-astronomics. Long study had not only convinced me that an automaton was within the realm of possibility, but that there were many mechanical systems by which it could be achieved. I girded myself for a new project and developed it theoretically from the ground up, but under such unhappy auspices that not only did all hope fail that anyone would ever appear who might have seemed willing to set his hand to the work, but that the new discovery itself was scoffed at by many as altogether a nightmarish delirium of an unbridled imagination.

The first months of the project must have seemed like an inspired dream to the two men, and then must have followed a period of hopeless depression. Bertolla undoubtedly felt many times that the clock was an aspiration far beyond their combined abilities and means, but the priest would not be thwarted in his ambition and refused to abandon the project. He felt that it was a work that they were destined to produce. Many times, he wrote, he chided and begged and shamed his erstwhile partner into resuming the project where it had been last abandoned. Little by little, the first clock began to take form. As each new difficulty was encountered, the two men would go back over the notes and sketches to trace the problem to its source. Often a new part of the mechanism would nullify another which had thus far operated successfully, and a complete rearrangement would be required.


NOVISSIMA AC PERPETUA
ASTRONOMICA
EPHEMERIS
AUTHOMATICA
THEORICO-PRACTICA:
a qua præter horas, hor. min. prima, & secunda, currentem Annum, Mensem, mensis, etbebdomadæ Diem, Litteram Dom. Epactam, indeque omnium Festorum, aliorumque anni Mobilium diem, Cyclum Solarem, Numerum aureum, Indictionem Rom. Planetam cujusvis anni Dominum, ejusq. Signum, & Domum, Lunæ Phases, & illius Ætatem mediam adeo veraciter omnes Solis, & Lunæ motus in Longit., Latit., Altit., Excentricitatem &c. continuo conspiciuntur, ut non modo Novi- & Plenilunia vera, veræque amborum Luminarium quadraturæ &c. appareant; verum etiam Eclipses omnes solares, & lunares tam visibiles, quam invisibiles quemadmodum in Cœlo, sic & in Authomate, suis veris temporibus conspicuæ celebrentur, præteritæque æquè, ac futuræ cum suis pluribus temporis, durationis, magnitudinis &c. circumstantiis præsto sisti possint, excogitata, ac in lucem edita
AUTHORE
FRANCISCO BURGHESIO,
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Tridentino Sacerdote sæculari A. A. L. L.
& Philosophiæ Doctore.
TRIDENTI,
Ex Typoghr. Capitulari Joannis Bapt. Monauni
SUPERIORUM PERMISSU.
1703.

Figure 7.—Title Page of Father Borghesi's first book. The translation in its entirety is: "The Most Recent, Perpetual, Astronomical Calendar Clock: Theoretical—Practical: by means of which besides the hours, the minutes and seconds; the current year, the month; the day of the month and the day of the week; the dominical letter, epact, and thence, the day of all the feastdays, both fixed and movable; the solar cycle; the golden number; the Roman indiction; the dominant planet of any year and its sign; the phases of the moon and its mean age: and all the motions of the sun and the moon as to longitude, latitude, eccentricity, etc., are immediately seen, so accurately that [not only] the true new full moons and the true quadrature, etc., of the sun and moon appear, but also, all solar and lunar eclipses —both visible and invisible; as in heaven, so on the clock, they are conspicuously celebrated in their true times, and those of the past and those of the future, with their circumstances of time and duration, magnitude, etc., can be quickly determined. All this was devised and brought to light by the author, Francesco Borghesi of Anáuni, a secular priest of Trent, A.A.L.L. & Doctor of Philosophy. (Trent: From the printshop of Giovanni Battista Monauni, With Permission of Superiors.)" (*Title page reproduced by permission of the Biblioteca della Citta di Trento.*)

Again and again, Bertolla threw up his hands in despair and begged Father Borghesi to abandon the enterprise. He protested that he was not capable of producing such a complicated mechanism; he had neither the tools nor the skill. The priest wished to produce a clock such as the world had never seen before, such as the greatest scientists and clockmakers of all time had never been able to make. But Bertolla felt that he was only a provincial craftsman who could not hope to surpass them all with only his simple tools and training.

In his book on the first clock, *Novissima Ac Perpetua Astronomica...*, Father Borghesi wrote that when he had finally come within a few weeks of the embryo stage in the development of his clock, he was faced with the problem of bolstering the sagging enthusiasm of Bertolla. The clockmaker's original enthusiasm had shown promise of great results, but as the days passed and the problems of the multiplex and generally unfamiliar apparatus to be forged for the workings of the automaton became more complex, his ardor decreased. Finally, Bertolla became so discouraged by the scoffers and frustrated by the fact that the work was insufficiently organized that Father Borghesi wrote that "it almost became a harder task for me to bolster up by daily opportunity and importunity the failing patience of the artisan, frightened away from the work already begun, than it was for me to extract from the inner recesses of mathematics and astronomy, without light and without a guide, the whole fabric of the machine itself!"

In spite of Bertolla's protests, Father Borghesi prevailed, reviving his friend's interest once more until the two were deep in the project again. Months passed as they worked together on the mechanism and it seemed as if they lived for no other purpose. Inevitably, Bertolla's health began to suffer, undermined as it was by the constant nervous tension, and he eventually became ill from mental strain. He was forced to spend some time in bed, and for many weeks the subject of the clock was not discussed. Bertolla's other work, by which he made his living, suffered and it was several months before he was able to return to his little shop.

One year passed into another and the work progressed slowly. The first clock, which easily should have been finished in less than a year, was not completed until after three full years had passed. However, when the priest and the clockmaker put the finishing touches to their great clock, the result surpassed the greatest possible expectations, for it was truly a masterpiece. Not only did it illustrate the ecliptic phenomena of the moon, the sun and earth occurring in their proper time, as well as many other things, but it showed these operations as they succeeded in proper order, taking place through the centuries.

With mutual feelings of great pride, the two friends surveyed the result of their three years of endeavor. Bertolla realized that he had reached a point of maximum achievement in his work. He probably felt that now he could relax again, that his sleep would no longer be troubled by confused nightmares of wheels and gears that did not mesh together. Time was to prove otherwise.

PUBLISHED DESCRIPTION OF THE FIRST CLOCK

Father Borghesi soon came to the conclusion that it would be desirable to have a written description to explain the mechanism of the clock and its many indicators. He thereupon wrote out the story of how the clock was made, the reasons for embarking on the enterprise, the difficulties he had encountered, and the success which had crowned his and Bertolla's mutual labors. Finally, he described the operation of the clock's mechanism and the functions of its array of indicators.

The little book was written in Latin and only a few copies were printed, presumably at the priest's own expense, on a handpress by Giovanni Battista Monauni, printer to the Bishop in Trent. The little volume was stated by contemporary writers to have been published in 1763, although no date appears on the title page. The title translated is, in part, *The Most Recent, Perpetual Astronomical Calendar Clock, Theoretical—Practical....* The work begins with an introduction for the reader in which Father Borghesi stated that:

> ... the little work, which, as far as I was concerned could easily have been finished in a year, was only completed after about three years. Fortunately, however, it was so far beyond the expectations of most, that not only am I able to foretell with certainty all the lunar ecliptic phenomena and the solar, or rather terrestrial, phenomena, carefully worked out in their true periods, among many other matters exhibited by the machine; but also, within a few hours, I can exhibit by altogether tangible evidence to the skeptics and the doubting those very same phenomena, occurring within the space of many years, or even centuries, and succeeding one another in proper order, with their many attendant circumstances. I was not much concerned about the other eclipses, such as those of Mercury, Venus, and the other stars wandering through the zodiac, or about the other solar eclipses from the transit of Mercury or Venus, since they are altogether undiscernible to the naked eye, and very few compilers of ephemerides wish them to be noted, probably for the same reason.
>
> Do not, however, expect, star-loving reader, that here anything at all that you may wish can be drawn forth as from its source, for to demand this would be almost the same as to seek to drain as from a cup all the vast knowledge of the many arithmetical sciences from the narrow confines of one book. You will understand how impossible that is when, through prolonged labor, you have grown somewhat more mature in this kind of learning.
>
> Wherefore, rather fully, and out of consideration for you, I have decided, setting aside these prolixities, with completely synoptic brevity and with all possible clarity to expound for you simply the proportion of the movements, the description of the machine, and its usage. As a result, when you have progressed a little in theoretical mechanics, you will not only be able to reduce all these things to their astronomical principles, but you may find the way more smoothly laid out for you even for perfecting the machine itself. And, thus, you may be more effectively encouraged to a successful conclusion. Let it be so now for you through the following 10 chapters!

After these rather hopeful assurances, Father Borghesi proceeded to provide a detailed description of the clock dial and functions in the 10 short chapters which he had promised, under a separate section entitled "Synopsis Totius Operis Mechanici," which is translated in its entirety in the appendix.

As Father Borghesi prepared his little volume about his first clock, and described its unusual features and outlined its functions, which were primarily to place in evidence the celestial constellations, it occurred to him that it would now be easier after the experience he had acquired with his first timepiece, to construct another clock, which would present the motions of the two astronomical systems, the Ptolemaic and the Copernican. In this first book, he promised the reader that he would undertake the second project. It is fortunate that Father Borghesi undertook this project for the second clock is the only example of his work that is known to exist today. Extensive research has not shown what happened to the first clock, although several sources state that both timepieces were presented to Empress Maria Theresa sometime between 1764 and 1780.

Second Borghesi Clock

Father Borghesi lost no time in initiating the project of the second clock. The first and most important step was to inform Bertolla and enlist his assistance. Bertolla was adamant: he had had enough of complicated astronomical movements. He was delighted by the prospect of returning to his former simple life, producing simple, domestic, elementary movements for his country clients. Father Borghesi begged and cajoled. The second clock would be a much simpler one to construct, he persisted. After all, they had gained invaluable experience from the production of the first clock. Furthermore, he had already completed its design.

Bertolla apparently wavered in his resolve and, unwillingly and against his better judgment, he allowed the priest's inducements to prevail. Once again, the two friends yielded their leisure hours to a study of the priest's books and drawings as Father Borghesi enthusiastically elaborated his design for the timepiece, and Bertolla attempted to transcribe astronomical indications into terms of wheel counts. The second clock was, as Borghesi had promised, much easier of execution. Within a year, it was completed and functioned with complete success.

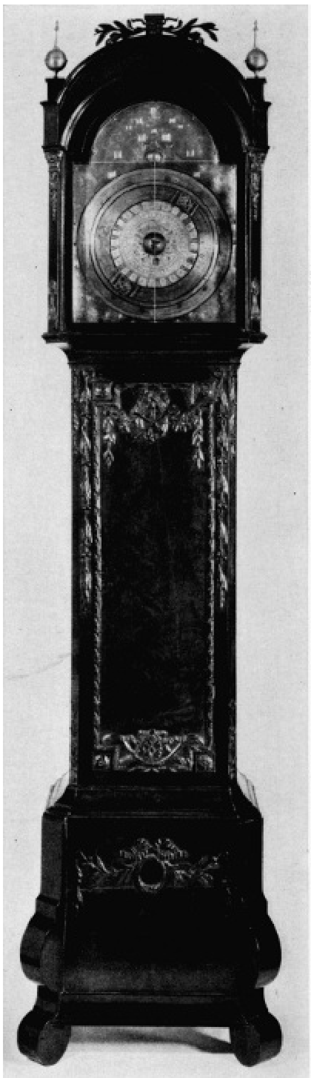


Figure 8.—The Borghesi clock in the Museum of History and Technology, constructed in 1764 by Bartolomeo Antonio Bertolla of Mocenigo di Rumo from the designs of Father Francesco Borghesi of Rumo and Mechel.

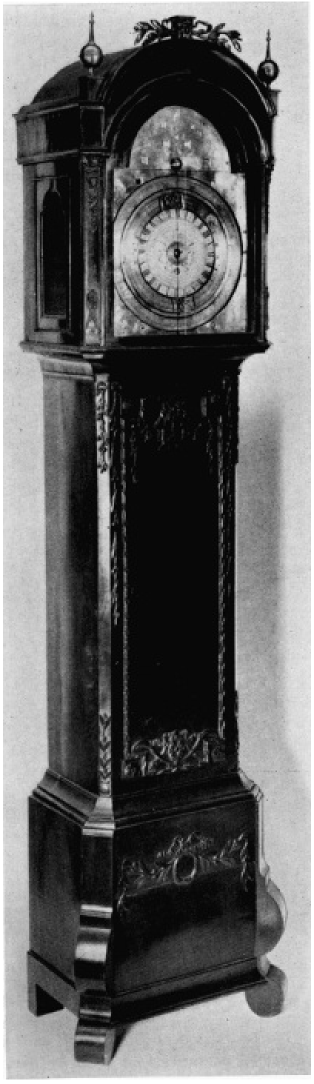


Figure 9.—Another view of the Borghesi clock.

This is the clock now in the Museum of History and Technology. It is housed in a tall case of dark-red mahogany veneered on oak, with restrained carving featuring ribands and foliate motifs. Gilt-brass decorations flank the face of the hood, which is surmounted by three gilt-brass finials in the form of orbs. A wide door in the waist may be opened to attend the weights. The case is 7 feet 8 inches high, 20-1/2 inches wide at the waist, and 14 inches in depth.

The dial is of gilt brass, measuring 21 inches high and 15 inches in width, with a number of supplementary silvered dials visible through its openings. Instead of hands, the dial utilizes three concentric rings moving around a central disc, the indications of which are read at two bisecting gilt lines inscribed in the glass face. Twelve separate functions are performed by the chapter ring assembly alone, and there are 14 openings on the dial. It is estimated that the clock performs 30 separate functions, including striking and chiming. Of the multiple chapter rings, the outermost is 1-1/8 inches wide, the center ring is 3/8 inch wide, and the innermost ring measures 1-1/4 inches in width.

THE DIAL-PLATE ENGRAVINGS

The gilt dial is incised throughout with figures and inscriptions in engraving of the very finest quality, as is evidenced in the illustrations. The frontispiece is surmounted at its center by the crowned double eagle of the House of Hapsburg, indicating the identity of the sovereign in whose reign it was made, Emperor Francis I or the Empress Maria Theresa of Austria. Below the eagle at either side are flying cherubs supporting ribands with inscriptions. Centered at the bottom of the frontispiece immediately above the chapter rings is the moving silvered orb representing the sun. Surrounding it is a tableau of the Holy Trinity, with the Virgin Mary being crowned by Christ holding a cross at the left and God with a sword in hand at the right, and a dove representing the Holy Spirit hovering over the Virgin's head. Father S. X. Winters, S.J., considers it reminiscent of the triptych "The Coronation of the Virgin" by Fra Lippo Lippi.

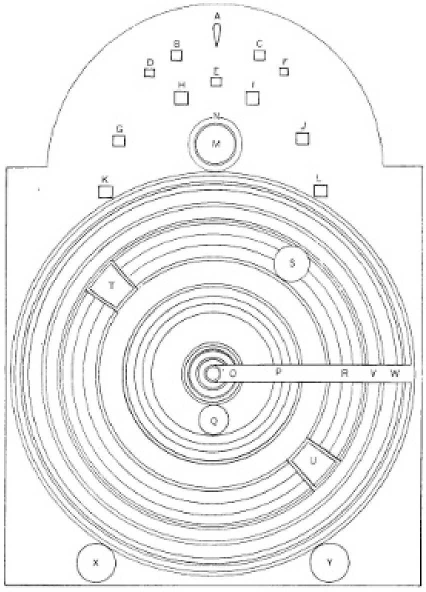


Figure 10.—Diagram of the dial plate.

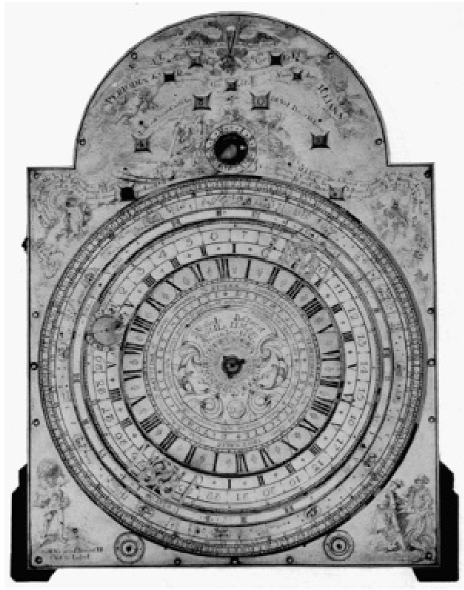


Figure 11.—Dial plate of the Borghesi clock.

KEY TO DIAGRAM OF THE DIAL PLATE

A Dominating planet, represented by its symbol and its house;

B Dominical letter (Lit. Dom.);

C Epacts (Cyc. EpEC);

D Roman indiction (Ind. Rom.), part of the reckoning of the Julian period;

E Solar cycle, (Cyc. Sol.), part of the reckoning for the Julian period;

F Golden number (Num. Aur.), part of the reckoning for the Julian period;

G, H, I, J The era, or the current year; part of the six windows of the Iris, or rainbow;

K Shuttered winding hole, for winding up the weights; part of the six windows of the Iris;

L The era, or the month of the current year; part of the Iris, or six windows of the rainbow;

M The sun in its epicycle;

N The 12 signs of the sun's anomaly;

O, P The first chapter ring representing the equatorial globe of the week, revolving from left to right;

Q The coming day indicated through the window;

R The second chapter ring; including the synodic-periodic measure of the tides, the days of the median lunar-synodic age, the signs and degrees of the signs for mean distance of the moon from the sun;

S Epicycle of the moon with signs of its anomaly;

T Head of the dragon (Cap. Draconis);

U Tail of the dragon (Cauda Draconis), for measuring eclipses of the earth and of the moon;

V Third chapter ring, with degrees of lunar latitude and some fixed stars;

W Fourth chapter ring, showing firmament of fixed stars, signs of the zodiac and degrees of the signs, the months of the year, and days of the months, revolving left to right for the course of a mean astronomical year;

X Adjustment marked *Claudit* (it closes) and *Aperit* (it opens) for disengaging dial work for the purpose of making astronomical experiments and computations;

Y Adjustment marked *Concitat* (it accelerates) and *Retardit* (it retards) for fast and slow adjustments of the movement.

In the upper spandrels of the dial are two more cherubs bearing ribands with inscriptions. In the lower left corner is a magnificent engraving of Atlas upholding the globe of the world, inscribed with the zodiac, over his head. The lower right corner features the figures of two noblemen apparently examining and discussing an orb upon a table, the significance of which is not clear.

Figure 12.—Empress Maria Theresa, to whom Father Borghesi is stated to have presented his two astronomical clocks. The coin bearing her portrait is in the Museum of History and Technology.

Figure 13.—Portrait of Francis I, Emperor of the Holy Roman Empire, to whom Father Borghesi's astronomical clock in the Museum of History and Technology appears to have been inscribed.

THE INSCRIPTIONS

Beginning with the uppermost part of the frontispiece, there are nine inscriptions in Latin on the dial plate. The topmost is *Franciscvs I sit plan. Dominator aeternvs.* The phrase has reference to Francis I, who was Emperor of the Holy Roman Empire, from 1745-1765, and husband of Empress Maria Theresa of Austria. The phrase may be translated as "May Francis I be the eternal ruler by favor of the planets" or more simply "Long Live Francis I, Emperor."[14] Although the dial plate of the Borghesi clock is inscribed with his name, the records indicate that the clock was presented to Maria Theresa. Francis I may have already died before the presentation was made.

From the left to right over the tableau of the Holy Trinity is the phrase "Lavs sacrosanctae Triadi Vni Deo, et Deiparae" (Praise [be] to the most Holy Trinity, to the one God, and to the Mother of God).

Within the upper left and right spandrels is inscribed:

> Isthaec, Signum grande apparvit in Coelo * sancta Dei genitrix amicta sole * Illibato pede Lvnae et serpentis nigra premens Cornva * bis senis pvlcherrime Coronata syderibvs * Tempe indesinenter clavsa, scatvrigo signata * Cedrvs in Libano, Cypresvs in Monte Sion * Mater pvrae Dilectionis sanctaeqve spei * Chara patris aeterni proles, Verbi Mater, sponsaqve procedentis *, gratiae et gloriae circvmdata varietate.

This inscription is a eulogy to the Virgin Mary assembled from the texts of Holy Scripture. In addition, each *lemma*, contained within asterisks, carries out the chronogram 1764, the year the clock was completed. Each *lemma* is translated and identified from the Douay-Rheims version of the Bible: [Pg 45]

> This woman: a great sign appeared in Heaven (Apocalypse 12:1) * The Holy Mother of God clothed with the sun (Apocalypse 12:1) * And with unharmed foot crushing the black horns of the moon (Apocalypse 12:1) and the serpent (Genesis 3:15) * Most beautifully crowned with twice-six (Apocalypse 12:1) * A garden [*Tempe*[15]] enclosed, sealed with a fountain [spring of water] (Song of Songs 4:12) * Like a cedar in Lebanon, and a cypress tree on Mount Zion; (Ecclesiasticus 24:17) * Mother of pure love and of holy hope: Beloved daughter of the Eternal Father, Mother of the Word, Spouse of the Holy Spirit: (Ecclesiasticus 24:24) * Surrounded with a diversity of grace and glory (Psalms 44:10).

Figure 14.—The bottom right corner of the dial plate, showing two noblemen contemplating an orb, with the inscription "Diligit Avdaces Trepidos Fortvna Repellet." (Fortune favors the daring and rejects the timid.)

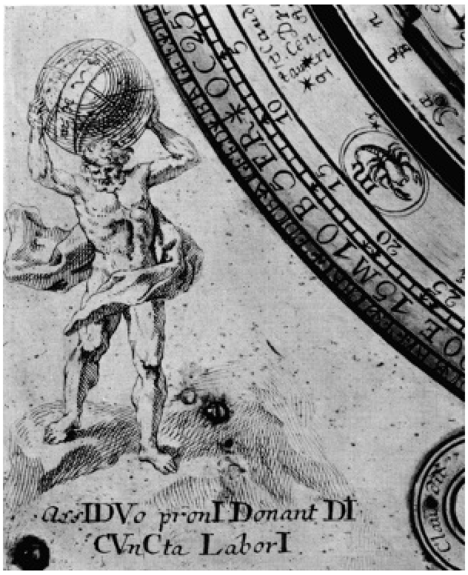


Figure 15.—The bottom left corner of the dial plate, showing the engraving of Atlas, with the inscription "Assidvo proni donant di cvncta labori." (The favorable gods willingly grant all things to the assiduous laborer.)

At the lower left corner below the figure of Atlas upholding the world is the phrase, *Assidvo proni donant di cvncta labori*. (The favorable gods willingly grant all things to the assiduous laborer.) The same phrase is quoted by Father Borghesi in the text of his second volume. The last inscription appears at the lower right corner under the figures of the two noblemen, *Diligit avdaces trepidos fortvna repellet*. (Fortune favors the daring and rejects the timid.) The last two inscriptions are in dactylic hexameter. They appear to be original compositions inasmuch as no classical prototypes have been identified.

CENTER DIAL INSCRIPTIONS

[Pg 46]

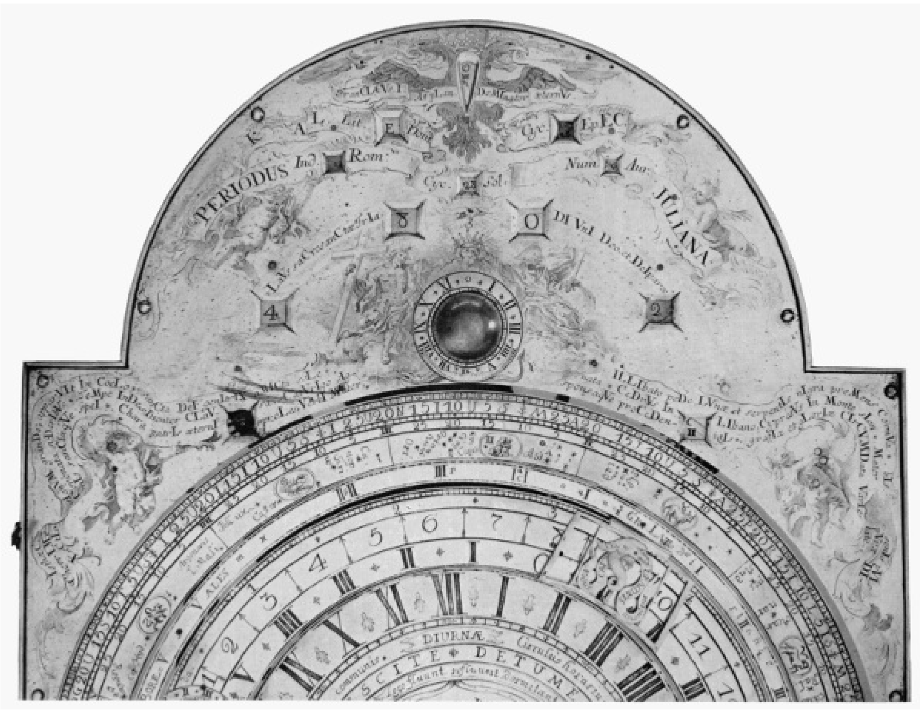


Figure 16.—Detail of frontispiece of the Borghesi clock, showing the apertures for calendar indicators and the details of the engraving.

[Pg 47]

In addition to the inscriptions previously noted on the outer dial plate, there are three major inscriptions in the central dial. The outermost states *Circulus horarius Soli, Lunae, Fixis, Nodis, Aestuique marino communis* (the hour circle, common to the sun, the moon, the fixed stars, the nodes and to the sea tide). This inscription is divided into four parts by the insertion of four divisions for the day into canonical hours: [*Horae*] *Nocturnae* (night hours); *Matutinae* (morning hours); *Diurnae* (daytime hours) and *Vespertinae* (evening hours).

The next section of the central dial is inscribed *Intumescite—Detumescite* (rise and fall of the tides) repeated at intervals of approximately every six hours. Within the next section is the following inscription, inscribed continuously around the ring:

> Lege fluunt, refluunt, dormitant hac maris undae: Ad Phoebi et Phoebes concordia iussa moventur Aequora; discordi iussu suspensa quiescunt.

Translated, this is:

> By this law the sea waves ebb and flow and lie dormant: When Phoebus and Diana agree in their commands, the waters are moved; when they disagree, the waters lie silent.[16]

Within the central boss of the dial plate, the name of the maker is inscribed:

> Bvrghesio Doctore, et Bertolla Limatore Annaniensibvs*

Translated, this is:

> [By] Doctor Borghesi and Bertolla, mechanician citizens of Anáuni.

INDICATORS IN THE FRONTISPIECE

There are 12 windows in the frontispiece, through each of which appears an indication relating to time. Beginning at the top of the frontispiece of the dial, the first opening occurs on the breast of the imperial eagle. This indicates the dominating planet, represented by its symbol, and its house.

The opening in the eagle's left claw, labeled "Lit. Dom." is the dominical letter. The first seven days in the month of January are each assigned one of the letters *a* through *g* in order of appearance. The letter which coincides with the first Sunday within this period is called the dominical letter, and it serves for the following year. In leap year, two letters are required, one to February 29th and the letter next proceeding for the remainder of the year. This letter is used in connection with establishing the date of Easter Sunday. The date of Easter regulates the dates of the other movable feasts.

The eagle's right claw is labeled "Cyc. EpEC" and represents the epact, or the age of the moon on January 1st. It serves to find the moon's age by indicating the number of days to be added to each lunar year in order to complete a solar year. Twelve lunar months are nearly 11 days short of the solar year, so that the new moons in one year fall 11 days earlier than they did the preceding year. However, 30 days are deducted as an intercalary month since the moon has made a revolution in that time, and the remainder, 3, would be the epact.

Below the imperial eagle two winged cherubs support a riband with three indictions of the Julian period. This period of 7980 years is the product derived from multiplying together the sums of 28, which represents the cycle of the sun; 19, representing the cycle of the moon; and 15, which represents the Roman indiction. The Julian period is reckoned to have begun from 4713 B.C. so that the period will be completed in A.D. 3267. The first of the three openings is marked "Ind. Rom." or "Roman indiction," which was an edict by the Emperor Constantine in A.D. 312, providing for the assessment of a property tax at the beginning of each 15-year cycle. It continues to be used in ecclesiastical contracts. The second opening, which occurs immediately below the eagle, is marked "Cyc. Sol." (cycle of the sun). This cycle takes a period of 28 years, after which the days of the week once again fall upon the same days of the month as they did during the first year of the former cycle. There is no relationship with the course of the sun itself, but was invented for the purpose of determining the dominical letter which designates the days of the month on which the Sundays occur during each year of the cycle. Since cycles of the sun date from 9 years before the Christian era, it is necessary to add the digit 9 to the digits of the current year and then divide the result by 28. The quotient is the number of cycles which has passed, and the remainder will be the year of the cycle answering to the current year. The third opening on the riband is labeled "Num. Aur." (golden number). Meton, an astronomer of Athens, discovered in 432 B.C. that after a period of 19 years the new and the full moons returned on the same days of the month as they had before, and this is called the cycle of the moon. The Greeks were so impressed with this calculation that they had it inscribed in letters of gold upon stone, hence the golden number. The First Council of Nicaea in A.D. 325 determined that Meton's cycle was to be used to regulate the movable feasts of the Church.

Immediately above the chapter rings is an opening through which the orb of the sun is visible.

THE CHAPTER-RING ASSEMBLY

In a separate chapter in his second volume, entitled "Descriptio Authomatis Summa totius Operis Mechanici" (Description of the Automaton—Summary of the Complete Mechanism), Father Borghesi provided a description of the functions of the various indicators, prefixing it with the short poem shown in figure 18. He then continues:

> In the middle of the frontispiece, as at the center of the universe, the terraqueous globe

of the week revolves, with a daily motion turning from right to left, bringing with it from the round window the coming day and at the circumference the circle of hours common to the sun, to the moon, to the fixed stars, to the head and tail of the dragon, and to the raging sea.

> The second circle revolves the synodic-periodic measure of the raging sea, the days of the median lunar-synodic age, the signs and individual degrees of the signs of the distance of the moon from the middle of the sun within the time of 29 terrestrial revolutions, hours 12.44.3.13. This circle revolves likewise from right to left around the center of the earth. In this second circle, another little orb revolves, bringing with it the epicycle of the moon, in which the little circle of the moon (whose illuminated middle always faces towards the sun), running from left to right through the signs of the anomaly; within 13 revolutions of the earth, hours 18.39.16. It descends from apogee to perigee and in just as many others it returns from perigee to apogee, to be carried down thus to true, back and front from the longitude and distance from the sun and from the middle of the earth.

> The third circle (on which I have tried to indicate astronomically-geometrically in their places, the degrees of lunar latitude both in the south and in the north, and some fixed stars, those, namely, which can be separated by us from the moon which goes between) from left to right turns around the center of the earth, stretching out the head and tail of the dragon, on the inside above the second circle for noting and measuring the sun (but I should rather say the earth), and the eclipses of the moon, within 346 revolutions of the earth, hours 14.52.23.

> The fourth circle, in which the heaven of the fixed stars, reduced to the correct ascent of our times, the signs of the zodiac and the individual degrees of the signs, the months of the year and the single days of the month can be seen, likewise makes its journey around the earth from left to right in 365 terrestrial revolutions, hours 5.48.56.; that is, within a median astronomical year. Above this annual orb, the sun, in its small epicycle, gliding through the 12 signs of the anomaly, within the space of 182 terrestrial revolutions, hours 15.6.58., from left to right, falls from apogee to perigee; and, within the same time, rises from perigee to apogee, and brings with it, the index, namely its central radius, inhering to the axis of the equatorial orb and cutting the four greatest circles from the center.

> When the sun has been moved around, Iris shows from six windows the era, that is, the current year. Two winged youths take their place next to Iris, carrying the Julian period: namely, the Roman indiction, the cycle of the sun and the golden number, on a leaf of paper held between them. The imperial eagle stands out on top (as if added to the frontispiece) carrying on its breast the dominating planet and in its talons the ecclesiastical calends (that is, the dominical letter and the epact).

ATTACHMENTS FOR ADJUSTMENT

Two attachments, in the form of small superimposed dials are situated at the base of the dial plate, at either side and immediately below the fourth chapter ring. In his second volume, Father Borghesi stated that they "are not moved from inside the clock, but the one at the right [inscribed *concitat* and *retardat*] serves for loosening [accelerating] and tightening [retarding] time; that is, the reins of the perpendicular."

In other words, the purpose of this attachment is for adjusting the pendulum to make the clock operate fast or slow. The second attachment, which appears at the left, and which is inscribed "Claudit" (close) and "Aperit" (open) serves the purpose of "... preparing the mechanism in a moment, as swiftly as you wish, for sustaining the astronomical experiments of which you will hear later; when these things have been done, it restores the mechanism to its natural motion at the same speed."

This adjustment relates to the final section of Father Borghesi's second book, entitled "Chronologo-Astronomicus Usus Authomatis" (Chronological-Astronomical Use of the Automaton), which is translated from the Latin in its entirety:

> With one glance at this automaton, you can quickly answer these questions: What hour the sun shows, the moon, any fixed star, the head and tail of the dragon. Is the sea swelling with periodic heat [at high tide?] or is it deflated [low tide], or quiescent? How many days is it from mean new moon or full moon? By how many signs and degrees is the moon distant from the sun, and from its nodes? What sign of the zodiac does the sun occupy, the moon, the head and tail of the dragon? Is the sun or the moon, in apogee or perigee, ascending or descending? What is the apparent speed of the sun and of the moon? What is the apparent magnitude of the solar and lunar diameter, and of the horizontal parallax of the umbra and penumbra of the earth? What is the latitude of the moon? Is it north or south? Does the moon hide [occult eclipse] any of the fixed stars from the earth dwellers, and which of these does it obscure? Is there a true new or full moon? Is the sun in eclipse anywhere on earth? What is the magnitude, and the duration of this eclipse, with respect to the whole earth? Can it be seen in the north or in the south? Is the moon in eclipse? Total or partial? Of what magnitude, etc.? What limb of the moon is obscured? How many years have passed from a given epoch? Is this

> year a leap year, or a common year—first, second, or third after leap year? What is the current month of the year, and what day of the month and of the week? Which of the planets is dominant? What days of the year do the various feasts fall on, and the movable feasts during the ecclesiastical year? And many other similar questions, which I pass over here for the sake of brevity.
>
> Besides, this device can be so arranged for any time whatsoever, past or future, and for the longitude of any region, and can be so manipulated by hand, that within the space of a very short time there can be provided in their proper order, the various orbits of the luminous bodies, their alternating eclipses, as many as have taken place through the course of many years, or even from the beginning of the world; or those that will be seen as long as the world itself shall last, with all their attendant circumstances (year, month, day, duration, magnitude, etc.). All these can be seen with great satisfaction of curiosity and of learning, and hence with great pleasure to the soul. In the meanwhile, the little bells continually play, at their proper, respective times. So that, all exaggeration aside, a thousand years pass, in the sight of this clock, as one day!
>
> I am aware of your complaints, O star-loving reader—that my description is too meager and too succinct. Lay the blame for this on those cares, hateful both to me and to you, more pressing, which forbid me and deprive you of a methodical explanation of the work.

THE CLOCK MOVEMENT

Father Borghesi specified that the entire mechanism was equal in weight to a seventh part of a *Centenarii Germanici*, a Germanic hundredweight. This is probably the Austrian centner which is equivalent to 123.4615 pounds. Therefore, the clock mechanism weighs approximately 17.6 pounds.

The clock operated for a hundred days and more at a single winding, according to Father Borghesi, and by means of a pendulum with a leaden bob weighing 60 Viennese pounds, attached at a height of 5 feet. Father Borghesi stated the weight of the pendulum to be 60 *librarum Viennensium*, but the Viennese libra does not appear among the weights of the Austrian Empire. However, using the average libra, an ancient Roman unit of weight equal to 0.7221 pound, it may be assumed that the driving weight should be approximately 45 pounds.

Father Borghesi, however, does not venture to provide any description whatsoever of the movement of his second clock in his book. He gave the following reasons:

> But beyond this, I entirely omit [a description of] the further apparatus of the very many wheels, etc., inside the clock which carry on its functions, lest I become too verbose for some persons. To explain more thoroughly the internal labyrinth of the entire mechanism, from which the movement of the circles or heavens, etc., are derived, would seem to entangle in too many complicated perplexities.... Therefore, that I might not delay longer, and perhaps to no purpose, I have thought it better to leave the whole work to the proportionate calculus of the arithmeticians and the technical skill of mechanics. If they have any desire to construct a similar mechanism, they will follow the aforesaid motions of the heavens, etc., not only by one means alone but by many, more swiftly through thoughtful study than by any amount of instruction.
>
> For whoever is well versed in the theory of calculus and sets to work at any given project, will discover any desired motion by a thousand and more ways, by one or another gearing of wheels; which an industrious mechanic will carry out in actuality and without too much difficulty. Nor is there any reason for anyone to be discouraged, so long as he is not disgusted by the amount of labor for there is nothing truer than the old saying "The favorable gods grant everything to the assiduous laborer."
>
> Nay, further, even this little work itself can be improved on and surpassed by new inventions. Otherwise that other old adage, almost as old as the world, would prove false, "What you have found already done, you can easily repeat, nor is it difficult to add to what has already been invented." Relying on this principle, I have already conceived some new things to be added to the present little work.

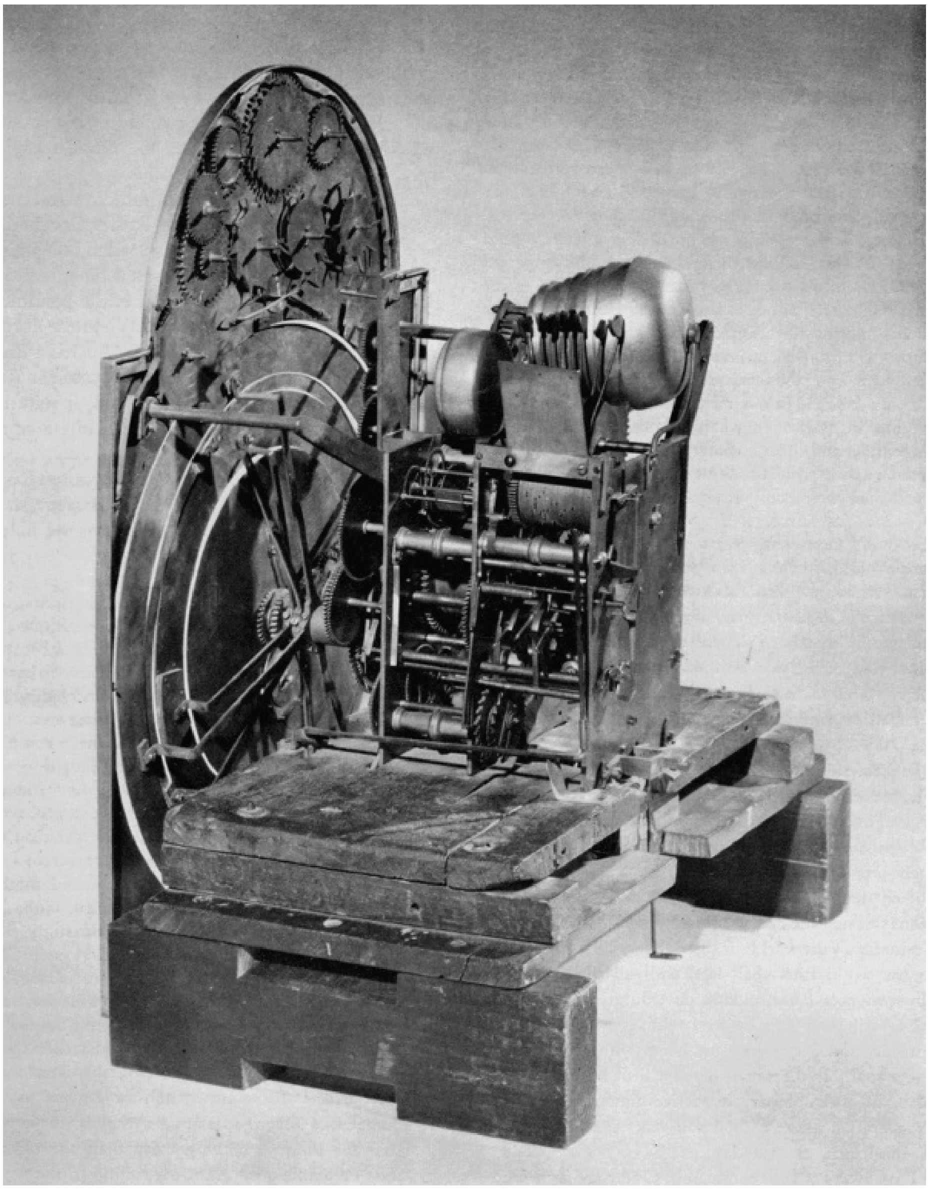


Figure 17.—Movement of Borghesi clock viewed from the right side, with details of chiming mechanism.

THE BELLS

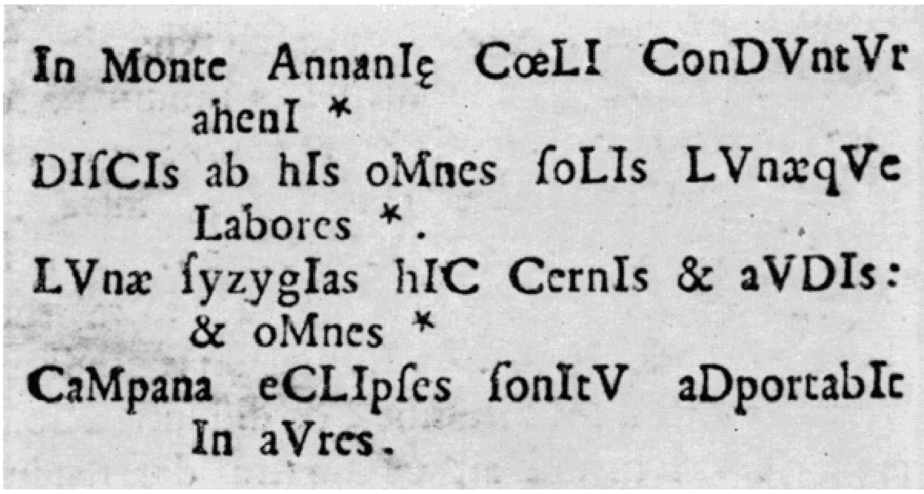
There is a discrepancy between Father Borghesi's written description in his second book of the number of bells and those which currently exist in the clock. At the present time, there are two sets of bells attached to the upper part of the movement. While Father Borghesi indicated that there were two sets of bells in the clock, he described the first set by stating that:

> ... there are three bells inside the clock: The largest, when struck by a little hammer at each mean new moon, signifies the new moon. The smallest indicates in the same way the full moon at the time of the mean full moon, by automatic sound. When on the equatorial earth, the sun appears anywhere in eclipse, two bells (the largest and the medium) sounding together automatically, announce that eclipse at the time of the mean new moon. (I think it is evident that eclipses of the sun occur at new moons and eclipses of the moon at full moon.)
>
> When the moon is eclipsed, the smallest and the medium bells, simultaneously and automatically, announce the event to the ear at the time of the mean full moon. Besides, at the proper time and automatically, the largest of these bells announces the current solar hour and the smallest bell strikes the quarter hours.

In the clock today, the first set consists of a smaller bell fixed within a larger one. It is presumably these bells that indicate the eclipses and also strike the hours and quarter hours. A pull cord attached to the striking mechanism repeats the current hour and quarter hours at will. The second set consists of nine meshed bells struck with individual hammers operated by means of a pinned cylinder as in a music box. On the hour, the chimes play one of two melodies, which may be changed at will. While not identified, these appear to be Tyrolean folk melodies. The largest of this set of bells is dissimilar to the other chimes, and may be the third bell described by Father Borghesi to signify the new moon.

CHRONOGRAMS

One of the most curious aspects of the second clock produced by Father Borghesi and Bertolla, as well as of the second published volume, is the presence of chronograms which occur repeatedly on the clock dial and throughout the *Novissimum Theorico-Practicum Astronomicum Authoma* from the title page to the end of the book. Interestingly enough, Father Borghesi did not utilize this device even once in his first little book.



In Monte AnnanIę CœLI ConDVntVr
ahenI *
DIſCIs ab hIs oMnes ſoLIs LVnæqVe
Labores *.
LVnæ ſyzygIas hIC CernIs & aVDIs:
& oMnes *
CaMpana eCLIpſes ſonItV aDportabIt
In aVres.

Figure 18.—A CHRONOGRAM in the text of Father Borghesi's second volume, indicating the year 1764. The poem is translated as: "In the Mount of 'Anáuni,' the inscrutable heavens are led, You learn from these all the labors of the sun and the moon. Here you are shown and hear the conjunction of the moon: And a bell brings to the ears by its sound, all eclipses."

Webster defines a chronogram as an inscription, sentence, or phrase in which certain letters express a date or epoch. The method used by Father Borghesi for forming chronograms was a simple one. He used combinations of uppercase and lowercase letters in two sizes in the inscriptions on the clock dial and in his writings. At first this curious combination in the inscriptions on the dial plate was a source of considerable speculation. The extremely fine quality of the engraving and artistry was such that these combinations could only be deliberate in nature and not the accidental whims or accidents of the engraver. Accordingly, they must be chronographic in intention. Such proved to be the case.

Borghesi used the larger size of uppercase letters to form the chronogram, and each chronogram was complete within a phrase or line. He accomplished this by using for this purpose those letters of the alphabet which form the Roman numerals. The uppercase letters found within words are copied off in the order in which they appear in the inscription or phrase. These are then converted into their numerical equivalents, and totaled. Taking the uppermost inscription on [Pg 52]
the clock dial as the first example:

FranCIsCVs I sIt pLan. DoMInator aeternVs

The letters which are intended to form the chronogram are:

```
 C  I  C  V I I  L  D   M  I V

100 1 100 5 1 1 50 500 1000 1 5
```

These figures added together total 1764.

The second inscription on the clock dial which forms a chronogram is

LaVs saCrosanCtae TrIaDI VnI Deo, et DeIparae

```
 L V  C   C  I  D  I V I  D   D  I

50 5 100 100 1 500 1 5 1 500 500 1 = 1764.
```

The third inscription required a little more planning, because of its greater length. Accordingly, Father Borghesi divided it into nine parts, each of which is separated from the other by means of asterisks. Each of the nine parts of the inscription formed a chronogram which, in every instance, totals to the date 1764, the year in which the second clock was completed. The same procedure was followed with the inscriptions in the lower left and the lower right corners of the dial as well as with the maker's inscription within the central disk. This inscription is

BVrghesIo DoCtore, et BertoLLa LIMatore AnnanIensIbVs

```
V I  D   C  L  L  L  I   M  I I V

5 1 500 100 50 50 50 1 1000 1 1 5 = 1764.
```

The inscriptions within the chapter ring are not utilized for chronograms, however. It is apparent that Father Borghesi was required to make a most careful selection of the texts for his inscriptions in order that none of the phrases included any additional letters which formed Roman numerals than would total to the date he desired to indicate, namely, 1764. Where it was necessary, he employed an asterisk to separate parts of texts so that each would produce the same total. Any letter that did not form a Roman numeral, even if capitalized or used in a larger size, did not interfere with the formation of the chronograms.

In spite of his ingenuity in designing a text which would include only such of the letters representing the Roman numerals which would provide the chronograms for 1764, Father Borghesi experienced some difficulties, particularly in place names. He accordingly changed them in order to avoid the inclusion of letters that would have disturbed his totals. Examples are MEGGL instead of MECHL, which had an extra C, and RVNNO instead of RVMO, which had an extra M.

PUBLISHED DESCRIPTION OF THE SECOND CLOCK

When the clock had been completed and proved to work successfully, Borghesi once more reduced a description of the clock and its function to published form in a second little volume published by Monauni. This second work was also in Latin, the title of which is translated as *The Most Recent Theoretical-Practical Astronomical Clock According to the Equally Most Recent System of the World*. As with his first book, Father Borghesi devoted a number of pages to a preface addressed to the reader, which is translated from the Latin:

> This mechanical instrument was far from being ready for public notice. A great deal of time and work remained to produce a machine of this new system from the very foundations; then, by a most accurate calculation to bring the motions of many wheels up-to-date with the most recent astronomical observations; and, finally, to fashion it with the craftsman's file, often enough with a weary hand. All this work I had performed eagerly, so that, while in my room, I might contemplate leisurely, both day and night, the true face of the heavens and the seas unobscured by clouds, even though I had no astronomical equipment. But, then I remembered that, in my book on the first clock, I had promised a description of a new (at least, as far as is known to me) clock. Moreover, friends with astronomical interest, who took part in the oft-repeated astronomical experiments concerning this clock, persuaded me that the intellectual world would enjoy having a greater knowledge and a description of this work. However, it was not only the promises nor the desires of many which moved me to write this work, but I also thought it was necessary to set forth, before the description of the clock, an exposition of the astronomical system according to which this clock was constructed, so that the complete work would be evident to all. I was concerned about making this timepiece more acceptable and more understandable to those people who are far distant and unable to see it, so that this present exposition would obtain credulity among all. I could find no better method than to set forth for the reader the theory of the universe which I figured out after many sleepless nights.
>
> In testing this theory day after day, it not only appeared to be complete, and true, but each day it appeared more conformable to reality; it captured my mind in such a way that I finally adhered to it. I desired, while I lived, to erect this work as a monument to the theory. To do this, I digressed a bit from the true-to-life pattern to the mechanical order so that I could transfer all the movements of the heavens, etc. (which I enjoyed thinking about more), to the plane surface of the clock's face. In this way, the ecliptical spectacles of the stars, etc., would appear at their proper times clearly before the eyes of the viewer. I could also avoid many difficulties which otherwise, perhaps, even the hands of the most skillful craftsmen could never solve.

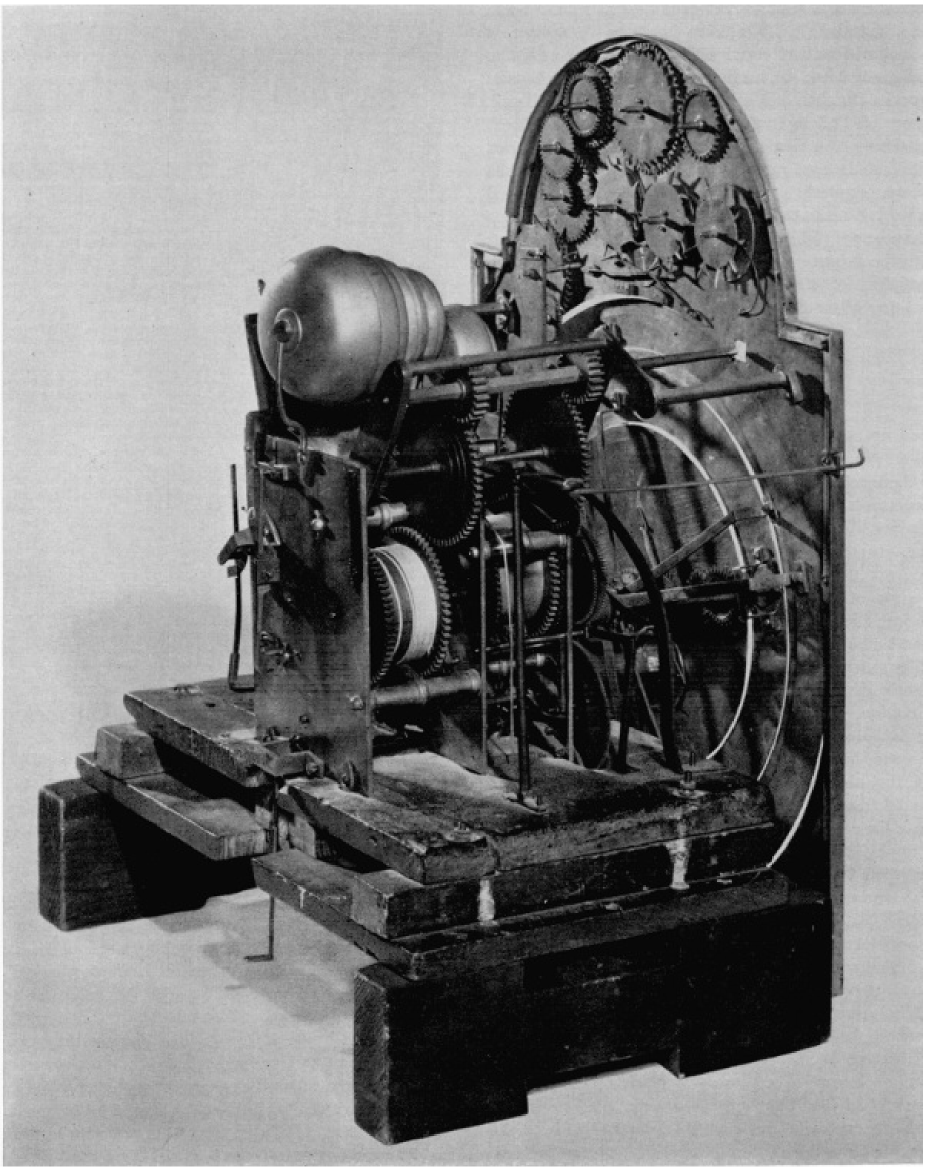
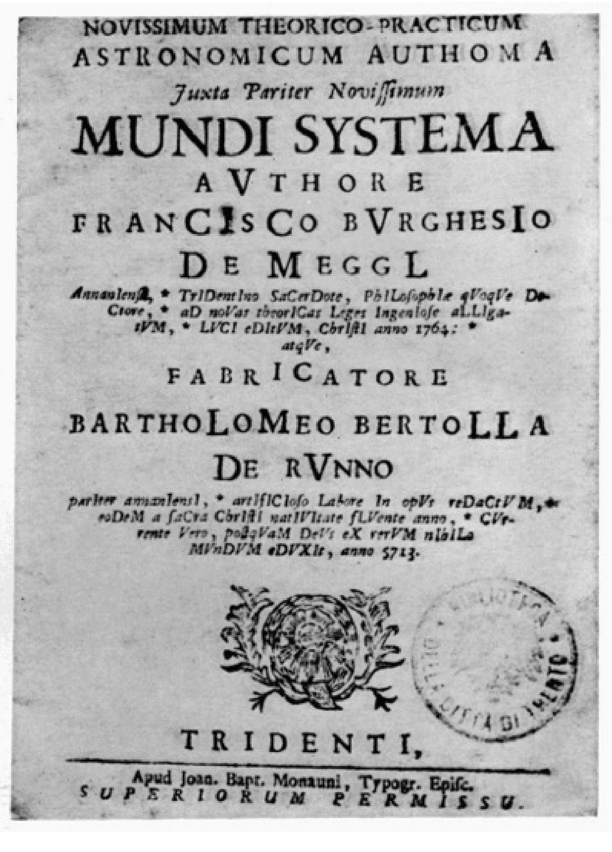


Figure 19.—Movement of the Borghesi clock, viewed from the rear, showing rear of dial plate.



NOVISSIMUM THEORICO-PRACTICUM
ASTRONOMICUM AUTHOMA
Juxta Pariter Novissimum
MUNDI SYSTEMA
AVTHORE
FRANCISCO BVRGHESIO
DE MEGGL
Annaniensi, * TrIDentIno SaCerDote, PhILosophIæ qVoqVe DoCtore, * aD noVas theorICas Leges IngenIose aLLIgatVM, * LVCI eDItVM, ChrIstI anno 1764: * atqVe,
FABRICATORE
BARTHOLOMEO BERTOLLA
DE RVNNO
pariter annaniensI, * artIfICIoso Labore In opVs reDaCtVM, * eoDeM a saCra ChrIstI natIVItate fLVente anno, * CVrrente Vero, postqVaM DeVs eX rerVM nIhILo MVnDVM eDVXIt, anno 5713.

TRIDENTI,
Apud Joan. Bapt. Monauni, Typogr. Episc.
SUPERIORUM PERMISSU.

Figure 20.—Title page of Father Borghesi's second book. The translation in its entirety is: "The Most Recent Theoretical-Practical Astronomical Clock According to the Equally Most Recent System of the World. Author: Francesco Borghesi of Mechel of Anáuni * Priest of Trent, Doctor of Philosophy * (The System of the Clock) Ingeniously connected to new theoretical laws published 1764: and the constructor, Bartholomeo Antonio Bertolla of Rumo, similarly from Anáuni * who skillfully produced this work * in this same current year of Our Lord * which is the year 5713 [sic] since God created this earth. (Trent: From the Printshop of Giovanni Battista Monauni, With Permission of the Superiors.)" ***(Title page reproduced by courtesy of the Biblioteca della Citta di***

Trento.)

> You ought to know, therefore, that as a result of my nightly meditations, I have rejected, after much consideration, all the explanations of the universe thus far published. All other theories of the make-up of the universe, however admirable, and however many there are, turn the sun and earth around in an ecliptic in an annual movement. Thus, Philolaus was the first to move the earth from the center of the universe and move it through the void; afterwards, Aristarchus of Samos and then Copernicus moved the earth with the moon. The Egyptians, as well as Pythagoras, Ptolemy, Tycho, Riciolus, Longomontanus, etc., thought that the sun moved through the degrees of the ecliptic each year. But I attributed this movement to neither earth nor sun for the movement of both is only apparent. I did not vainly surmise the annual equilibrium in all astronomical observations to be from the daily movement of the same axis moved at the poles of the heavens. Nor, in like manner, is there a better way to satisfy physical experiments. To you, then, most cultured reader: If you, perhaps, can make any use or draw pleasure from this most faithful description of my new theory and the mechanical instrument, refer it first to God on High from whom is everything that is best, and then to those avidly awaiting this little work. Lastly, if you find any statement less fitting; in your humanity, do not disdain to excuse it.

Borghesian Theory of the Universe

In Father Borghesi's second volume, there is a separate chapter entitled "An Exposition of the Latest Theory of the Universe." This follows the introduction to the reader, and in it Father Borghesi proposed:

> That you might rightly conceive my new system of the world and mechanically, as it were, construct it, imagine for yourself, beneath that most happy seat of the Blessed and above all other heavens, a kind of spherical convexity, everywhere equidistant from the center of the earth, and endowed with absolutely no motion.
>
> On the inside, at two points diametrically opposite each other, this convexity has two most sturdy poles (to speak mechanically), projecting towards the center (which you call the poles of the heavens), and the largest immobile semicircle, in some manner is drawn from the center of one pole to the center of the other. This semicircle in the middle, namely at a point equidistant from each pole, is thought to be secured by some sign, for example, by that "o," for arranging more perceptibly the seat of the sun (as will be shown later). This much must be conceived first. [Pg 55]
>
> You must understand that imposed on these poles is the first mobile [Primum Mobile], everywhere convex, and divided, into 12 equal parts [Dodecatemoria], by the 6 greatest circles, intersecting each other at the centers of the poles. Then it is divided by another equally great circle, everywhere equidistant from the poles, into two hemispheres. One hemisphere of 12 parts, proceeding in order from west [setting] to east [rising] should be assigned the respective signs of the zodiac; that is, one to Aries, the next to Taurus, and so on, etc. The circle which cuts those 12 parts transversely in the middle, you call the ecliptic. Then, these capital spaces of the Primum Mobile are subdivided by degrees, minutes, etc., both in longitude and in latitude, so that this heaven represents a kind of great spherical net, extended to capture the longitude and latitude of the stars, and Mobile on the aforementioned poles. Note, however (and this is almost the leading point of the system), in that circle of longitude which divides the sign of Gemini from Cancer and Arcitenens [Sagittarius] from Capricorn, you must conceive two points, directly opposite each other and removed about twenty-three and a half degrees from the poles: Boreal [the northern] between Gemini and Cancer; Austral [the southern] between Sagittarius and Capricorn. These two points by some power (imagine it is magnetic power), equal between them, hold the terraqueous orb suspended in the middle, by acting on the axis of the same orb (imagine it is iron) in such a way that the earth is continually drawn to those two points as to two opposite centers. It is never nearer to one, for as it is about to move towards one, the opposite power is constantly drawing it back. Thus, both those points and the axis of the earth are always held in one common line, wherever those points happen to be carried by the rotation of this heaven.
>
> Again, it is necessary for you to conceive in this heaven, first, two great circles, bisecting each other at right angles in the centers of these two magnets. One of these circles, passing through the first point of Aries and Libra in the ecliptic, is called equinoctial colure: the other circle, passing consequently between the first point of Cancer and Capricorn, is called solstitial colure. Beneath these are likewise imagined many other great circles, in the centers of the magnets dividing crosswise in the shape of an "X." But if, receding from these magnets, you describe circles (parallel to each other and ever greater and greater, up to the greatest circle which you will perceive is called the equator), equidistant from each magnet and obliquely splitting the ecliptic in the equinoctial colure, you can then behold a great, new, woven net in this heaven of

the Primum Mobile. This net most beautifully expands to extract the straight ascent and descent of the stars, etc., from the vast ocean of the heavens, catching the straight ascent in the greatest circles and, in other unequal circles, parallel to each other and obliquely cutting across, most safely catching the descent.

GLOSSARY

Anomolia or anomaly, is the angular distance of a planet from its perihelion (that point of the orbit of a planet which is nearest to the sun) as seen from the sun.

Aequinoctium or the equinox, is the time in which days and nights are equal in the space of hours. There are two equinoxes: the spring equinox—c. 8 calends of April in the sign of Aries; and the fall equinox—c. 10 calends of October in the sign of Libra.

Aeras is derived from *aera*, *aerae*, which originally meant a given number, usually used in regard to money. The word was later extended to mean a number used in any calculation, and finally it came to mean a certain time from which subsequent times were counted, e.g., *Anno Domini*, after the Birth of Christ.

Coluri or the Colures, which are two circles in the heavenly sphere, passing through the poles of the world and cutting each other at right angles: the one passes through the equinoctial points of Aries and Libra and is called *Colurus Aequinoctiorum* or equinoctial colure; the other touches the *solstitialia* of Cancer and Capricorn and is called *Colurus Solstitiorum* or solstitial colure. They are called *Colurus*, which is translated as "mutilated tails," for the part which emerges in the Antarctic is not visible and is quasitruncated.

Ecliptica or the ecliptic, is an imaginary line in the heavens in which the sun was supposed to have performed its annual course.

Epicyclus or epicycle, is a small orb which, being fixed in the deferent of a planet, is carried along with its motion and yet, with its own peculiar motion, carries the body of the planet fastened to it round about its proper center.

Iris or the rainbow. In mythology, Iris was the daughter of Thaumatis and Electra, messenger of Juno of the goddesses and Jove of the gods.

Solstitium or the solstice, is that time when the sun seems to stand still for a short time: when the sign of Cancer enters the month of June (equivalent to the summer solstice, when the sun begins to recede from us); and when the sign of Capricorn enters the month of December (equivalent to the winter solstice, when the sun begins to accede to us).

Immediately below the Primum Mobile place the heaven of the fixed stars (and, that the idea might be clearer), revolving separately on the same poles on which the Primum Mobile revolves. Through this heaven, the filaments of the little nets, etc., seem to the eyes of you on earth as if they shine. In this heaven, you should conceive in their fixed places, the fixed stars, a proportionate, inviolable distance from each other, and, indeed, if you will, the heavenly images, etc., depicted, and all carried along at the same time with their heaven by one motion.

Conceive a straight line running from the center of the earth to that sign "o" noted in the semicircle of the supreme immobile heaven. On this line, greatly below the heaven of the fixed stars, place the center of the solar epicycle, holding an area in common with the ecliptic and subject to absolutely no motions, but at such a distance from the center of the earth that the semidiameter of the earth has little, if any, proportion with the distance of the solar epicycle from the earth. Around the sun, moving continually in this epicycle (its immobile palace) through the degrees of the anomaly, you can revolve, with motions proportionate to the system, the five planets: Mercury and Venus (the nearest barons of the sun), then Mars, Jupiter and, most remote, Saturn, with its respective satellites, etc., eccentrically surrounding the earth itself and the moon in their immense ambit and wandering by their proper motions through the zodiac.

Nevertheless, not far from the earth you should imagine fabricated, as from most refined crystal, the heaven of the moon everywhere equidistant from the center of the earth and revolving separately on the same poles (prolonged even to this place) on which the Primum Mobile and the heaven of the fixed stars revolve. In the middle of this, that is, in some point equally removed from the poles, you place the center of the lunar epicycle, movable also by the common rotation of the lunar heaven. I refrain from the other movements of the moon in latitude, etc., as also those of the five planets, etc., which the theory in no way excludes, lest by a variety of congested motions explained too abundantly, either you might be confused about the fundamental concept of the system or, while adorning the theory and trying to embellish the least things more widely, you might reject also the things which are capital.

Here you already have the whole machine, but still inert and to be animated for the first time by motions accommodated to the system. Nevertheless, before I assign motion to the individual parts of the world, so that the thing might later appear more clearly to you, I arrange all things thus: first, as if by hand, I turn the Primum Mobile until the Boreal magnetic point comes to the level or the area of the semicircle described in the supreme immobile convexity; then I turn the heaven of the fixed stars until, for example, the heel of Castor (a star of the third magnitude), almost in the ecliptic and indeed in our time not far distant from the solstitial colure, likewise falls nearly at the level of the aforesaid semicircle. Later, I turn the lunar heaven until I bring the center of the lunar epicycle to the same level. Then, I turn the earth until some predetermined city, for example, Trent, situated in the northern zone with a latitude of about forty-six degrees, is brought to the oft-mentioned level.

From things arranged in this way and from what has gone before, it is evident (with the motions of the luminaries in epicycles left out, however, lest you be distracted by the explanation) that at Trent, just as in the whole northern hemisphere, it is the summer solstice; and, conversely, in the southern hemisphere, it is the winter solstice. The reason is because the northern magnetic point together with the northern half of the earthly axis is at its highest point towards the sun, immovably residing in a line sent through the level of the highest semicircle; and, conversely, the southern magnetic point with the corresponding half of the axis is most removed from the same. It further follows, that noonday and the new moon coincide, and the heel of Castor almost reaches the summit, etc.

Now, beginning from this hypothetical situation of the whole world as from the root of the motions, I move all things in their circles so that the earth turns on its axis with a revolving motion from west to east in each 24 hours of median time. The lunar heaven completes one circle around its poles likewise from west to east in the time of 29 terrestrial revolutions, hours 12.44.3.13.1. The sphere of the fixed stars on the same poles revolves once from east to west within 365 revolutions of the earth, hours 6.9.29.1. The Primum Mobile on the poles (common to the heaven of the fixed stars and the heaven of the moon), is moved once in the same way from east to west, a little faster, however, than the heaven of the fixed stars, yet within 365 revolutions of the earth, hours 5.48.56; that is, within a median astronomical year.

Now, behold for yourself a new world supported on new poles and provided with new motions and laws. Now you, reader and lover of the stars, turn it, and revolve it as long as it pleases you, and compare it astronomically and physically with the Copernican or the Tychonian systems or with whatever one pleases you more, and judge which one seems more consonant with nature when all things are examined. But if you aren't able to reconcile this theory with some astronomical observations or physical experiments and think it should be eliminated from the group of theories, see that I might know this [Pg 57] while life is still my companion, so that I might think with you, if this is possible. Also, so that, in gratitude for the detected or perhaps hidden error, I might speak or write, and you won't have to shout in vain in bold ridicule and with no applause after the fleeing shades of the dead and the mute ashes. But, if you object that the daily motion of the revolving earth and the annual motion of its whirling axis do not sufficiently agree with certain texts of Sacred Scripture, and if those things which the Copernicans and the Longomontanists say do not convince you, then reject my whole system as an old wives' tale.

Last Years

There is a break in the story of Borghesi and Bertolla for the next five years. The second clock may have been the last project on which the priest and the clockmaker worked together, for very good reasons. The two clocks must have represented a considerable financial investment in materials and in time, and neither of the men was in sufficiently affluent circumstances to undertake the luxury of such a hobby without some form of recompense. The publication of the two little volumes must have also been done at Father Borghesi's expense. The income of the parish priest in a small mountain village could not have been equal to the relatively great costs of the projects that had been completed. It seems probable that the priest attempted to sell his clocks to a wealthy patron, perhaps the Baron of Cles, or he may have attempted to obtain some form of recompense for the continuation of his research. However, no records can be found of such patronage if it existed. If Borghesi had received financial assistance while the projects were in progress, he would certainly have made adequate mention of the patron's name and assistance in one or the other of the two volumes which he published.[17]

The next record relating to Borghesi which has been found is the description of a letter written by an anonymous mathematician late in 1768 or early in 1769. It was 28 pages in length, written in Latin, in the form of a reply to the writer's brother, on the subject of the clock invented by Borghesi. It consisted primarily of a criticism launched against Borghesi's first little volume published in 1763.

The anonymous letter is without date, place, or signature. This writer claimed that Father Borghesi had made many errors in his book, presumably in the description of the clock's functions, and in the basic theories upon which the priest had predicated his research. No complete copy of the letter's text has been found for study, although it is described at length in Tovazzi's *Biblioteca Tirolese*. Tovazzi noted that four copies of the letter existed at that time, and that he personally had filed one in the Biblioteca di Cles in Trent. However, every attempt to locate a copy at the present time has been unsuccessful.

If the anonymous letter was brought to the attention of Father Borghesi, it must have introduced a disturbing note into his life and cost the priest many unhappy moments. He was not, however, dissuaded from his preoccupation with horology. Several years later, in 1773, Father Borghesi was working on yet another astronomical clock, this time presumably without the assistance of Bertolla. This third clock was reported by Tovazzi to have been "of minimum expense but of maximum ingenuity."

No subsequent information relating to it has come to light, and there is no record that it was actually completed.

Again there is a period of silence in the life of Father Borghesi which no amount of research has yet been able to pierce. Whatever the circumstances may have been, it is reported by several of the sources noted that both the first and the second clock did, in fact, become the property of the Empress Maria Theresa in Vienna. The presentation was made sometime during the period between the completion of the second clock in 1764 and the year 1780. There is some discrepancy in the contemporary accounts as to whether Father Borghesi presented one or two clocks to the Empress, but all the sources with but one exception record that both clocks were acquired by the Empress.

It is doubtful that Father Borghesi had originally intended to give his clocks to the Empress at the time that they were made, for he would most certainly have made some mention of such an intention in the two little volumes which he published about them. If he saw the letter published by the anonymous mathematician in late 1768 or 1769, it is possible that he decided to make the presentation in expiation of his sense of guilt for the amount of his time which the creation of the timepieces had consumed. On the other hand, it is just as possible that Father Borghesi may have forwarded copies of his two little volumes to the Imperial Court at Vienna, and that the Empress
expressed a desire to acquire the clocks.

Father Tovazzi states that in 1780 "the clock invented by him [Borghesi] was preserved in Vienna, Austria, at the Imperial Court from which the inventor was receiving an annual pension of 400 florins." No records in the Palace archives relating to the clock have yet been found, nor records of payment of an annuity to Father Borghesi. However, a more exhaustive investigation of the Furniture Depository of the Imperial Court may bring forth related records. It was the implication in Father Tovazzi's account that the second clock had been presented to the Empress prior to the publication of the anonymous, critical letter in 1768 or 1769. He believed that it was envy of Father Borghesi's ingenuity, fame and financial benefit that had caused the anonymous mathematician to publish his letter, for Tovazzi asked "Who would have encountered opposition to such a marvel? Envy is not yet dead, and has always reigned."

This last-mentioned theory about the presentation may be the most likely one. Some evidence may be found in the second clock itself which bears out this assumption. The multiple chapter ring, with its many inscriptions, is engraved and silvered in a relatively crude manner, presumably by Bertolla himself. The main dial plate, however, which is of gilt brass, is engraved with the utmost skill by one of the great masters of the art. The inscription below the Imperial Hapsburg eagle relates to Francis I, Emperor of the Holy Roman Empire. It is entirely possible that although Father Borghesi originally had no intention of giving the clock to the Emperor or the Empress at the time that it was made, he later changed his mind. Accordingly, he may have commissioned a master engraver, possibly in Trent or in Vienna itself, to produce a dial plate which would be of such a quality as to be worthy of the Emperor himself. If so, this was done shortly after the clock was completed, for the Emperor died in August of the following year. Perhaps by the time that the clock was ready, the Emperor had already died, and Father Borghesi gave the clock instead to Maria Theresa without revising the inscription.

The acceptance of the clocks by the Empress, and the annuity which was his reward, would have constituted considerable honor even for one of the foremost clockmakers of the Empire, but for a humble parish priest in a little village, such notable Imperial recognition was overwhelming. Possibly as a result of it, a change was noted in Father Borghesi in the next few years. His conscience began to bother him, and he began to question whether he had done right in spending so much of his time and thought on his horological research. He became more and more confused in his own mind. Had he spent too much time in mechanical studies to the neglect of his ecclesiastical duties? If this had been the case, he had committed the most grievous sin.

Exaggerated though these thoughts may appear, they were undoubtedly of the most critical importance to the middle-aged priest. His mental turbulence and confusion increased daily, and it soon became apparent to others around him. By June 1779, he was completely in the grip of his obsession, and his parishioners began to whisper amongst themselves that their pastor was being tortured by the devil. They were unable to help him, and he became more and more preoccupied with his problem. The years passed slowly as the pastor became more vague and more tortured by his conscience.[18]

There probably was continued contact between Father Borghesi and Bertolla for at least some time after the development of his illness. Bertolla had retired from active work, but continued to pursue his interests in his clockshop as much as his health and advanced years permitted. A clock which he made at the age of 80 survives and is described and illustrated in the following section on "The Clocks of Bartolomeo Antonio Bertolla." Finally, on January 15, 1789, Bertolla passed away and Father Borghesi was left alone, deprived of the companionship he had enjoyed with the older man for the past two or three decades. One of Bertolla's nephews continued to work in the master clockmaker's workshop, but there did not appear to be any association between the younger man and Father Borghesi.

At last, in 1794, Father Borghesi lost his sanity completely, and he was forced to relinquish his pastoral duties to a curate. For the remaining eight years of his life, he continued to live in the rectory of the little parish church in Mechel where most of his life had been spent, his needs undoubtedly attended by the parishioners he could no longer serve. During this period, until his death at the age of 79 on June 12, 1802, Father Borghesi lived on, oblivious of those around him. Seemingly, he retired to another world; perhaps to that universe which he had tried to reproduce in his second clock.

The Clocks of Bartolomeo Antonio Bertolla

The ingenuity displayed in the Borghesi clock by its constructor, Bartolomeo Antonio Bertolla, requires a consideration of the other examples of his work that have survived. The most important of his clocks are probably the one in the Episcopal Palace at Trent and another made for the Baron of Cles.

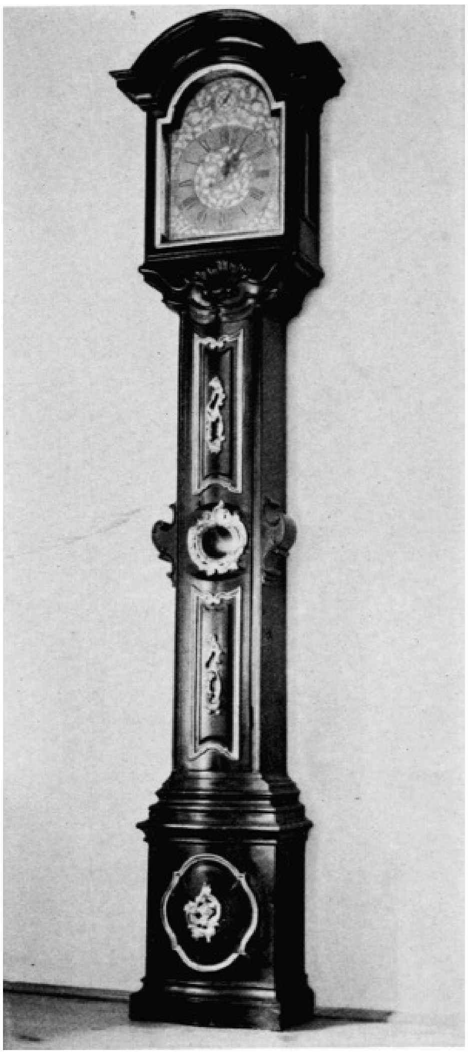


Figure 21.—Tall-case clock by Bertolla in the Episcopal Palace in Trent, made for Bishop Cristoforo Sizzo di Noris. A striking and repeating clock with lunar phases. *(Courtesy of Museo Nazionale della Scienza e della Tecnica, Milan.)*

The one which survives in the Episcopal Palace to the present time, is extremely tall and is housed in an elaborately decorated narrow case of black or ebonized wood approximately 9 to 10 feet in height. The upper part of the case is decorated with elaborately carved and gilt rococo motifs. The movement operates for one year at a winding, indicates and strikes the hours, and shows the lunar phases. It has an alarm, and will repeat the strike at will, indicating the number of the past hour and the quarters. The gilt brass dial is decorated with silver-foliated scrollwork in relief at the corners, inside the chapter ring, and within the broken arch. Featured above the chapter ring is the coat of arms, executed in silver, of the patron for whom the clock was made, Cristoforo Sizzo di Noris. Di Noris was Bishop of Trent for 13 years, from 1763 to 1776.

The clock which Bertolla made for the Baron of Cles is a tall, narrow, case clock of ebony or ebonized pearwood which is approximately 9-1/2 feet in height. The decoration of the case is considerably more conservative than the one made for Di Noris, but the black wood is decorated with silver trim and carved designs in the wood itself. The dial is decorated with silver scrollwork and spandrels within and around a raised chapter ring. The clock operates for one month at each winding, has an alarm, indicates and strikes the hours, and will repeat the quarters. This handsome timepiece is still in the possession of the descendants of the Baron of Cles.

According to Pippa,[19] certain characteristics become apparent in a study of the surviving clocks by Bertolla. The tall-case clocks are narrow and range in height from 7-3/4 feet to 10-1/2 feet. The cases had this excessive height in order to obtain the greatest fall for the month and year movements which Bertolla constructed. For the weight assembly, he substituted a drum wound with a key at the point of the driving wheel in place of the customary pulley. The addition of an intermediate wheel augmented the drop of the weight.

Figure 22.—Interior of Bertolla's workshop, showing detail of ceiling. ***(Courtesy Museo Nazionale della Scienza e della Tecnica, Milan.)***

Figure 23.—Interior of Bertolla's workshop, showing the main workbench and the collection of clockmakers' tools. ***(Courtesy of Museo Nazionale della Scienza e della Tecnica, Milan.)***

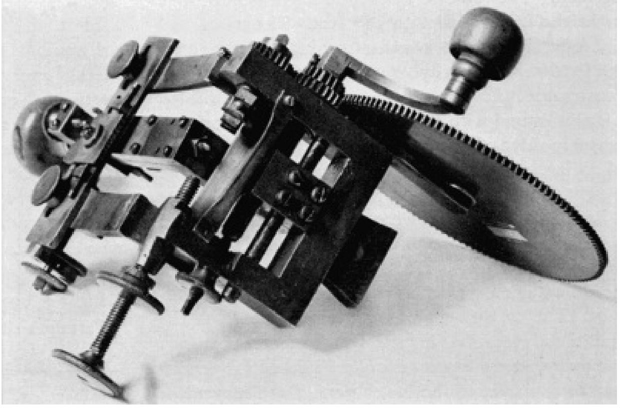


Figure 24.—Fusee cutter used by Bertolla. Now in the collection of the Museo Nazionale della Scienza e della Tecnica, Milan.

Figure 25.—Interior of Bertolla's workshop, showing details of paneling and floor case with Bertolla manuscripts. ***(Courtesy of Museo Nazionale della Scienza e della Tecnica, Milan.)***

Bertolla's movements were solidly constructed from well-hammered brass and iron. He favored the recoil anchor escapement in his clocks and the Graham dead-beat anchor escapement with a seconds' pendulum. The escapement was not always placed in the traditional location in the upper center between the plates. Bertolla occasionally displaced the pendulum to one side, to the lower part of the movement or placed it entirely between two other small plates.[20]

He utilized every type of striking work, including the music-box cylinder common in the clocks of the Black Forest and the rack and snail. Bertolla most frequently employed the hour strike and *grand sonnerie*. He often used a single hammer on two bells of different sound with the rack and snail. An example of this type is the clock he produced at the age of 80. To achieve the necessary axis of rotation for the hammer, which is perpendicular to the plate when it strikes the hours, it moves to an oblique position and displaces one of the two long pins in an elongated opening.

Bertolla's dial plates were generally well executed, with a raised or separate chapter ring applied to a brass or copper plate, such as a copper-plate *repoussé* and gilt with baroque motifs, or upon a smooth brass plate with spandrels of *repoussé* work usually of silver, in relief and attached. The engraving of the chapter rings was excellent. The hands were well executed in steel or perforated bronze, and occasionally of *repoussé* copper; gilt was applied to the hands made of forged steel.

Figure 26.—Dial plate of a brass lantern clock made by Bertolla, found in his workshop after his death. ***(Courtesy of Museo Nazionale della Scienza e della Tecnica, Milan.)***

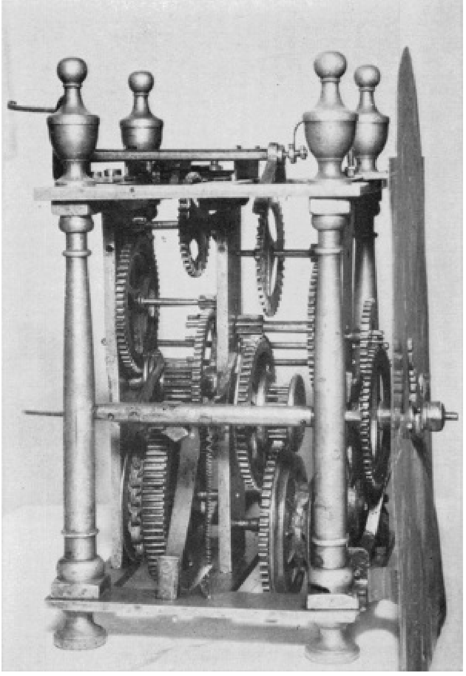


Figure 27.—Movement of a brass lantern clock made by Bertolla. ***(Courtesy of Museo Nazionale della Scienza e della Tecnica, Milan.)***

In the course of time, Bertolla's home workshop passed from one generation to another within the family. Inevitably, it underwent many modifications until the only original part of the building that remained intact from Bertolla's time was his clockshop.

Within the last few years, the workshop room was acquired complete with contents from Bertolla's descendants, and installed in the Museo Nazionale della Scienza e della Tecnica in Milan as an exhibit of a typical 18th-century clockmaker's shop. The original workshop was dismantled in Mocenigo di Rumo and completely rebuilt in the museum, including the walls, ceiling and floor. The paneling and woodwork of the walls and ceiling, which have been preserved intact, are hand-cut fir, with columns, trim and moldings carved by hand. A small painting is featured in the center of the coffered ceiling. The original shop benches and chests of drawers are set around the reconstructed shop and Bertolla's tools and equipment laid out as they had been originally. Other clockmaker's tools and equipment in the museum's collection are also displayed. Approximately 40 percent of the tools are the original items from Bertolla's shop. [Pg 64] Parts of clocks and works in progress are on view on the benches as they were in Bertolla's time.[21] Also preserved in the museum are sketches found in Bertolla's manuscripts, some of which are reproduced on the following pages.

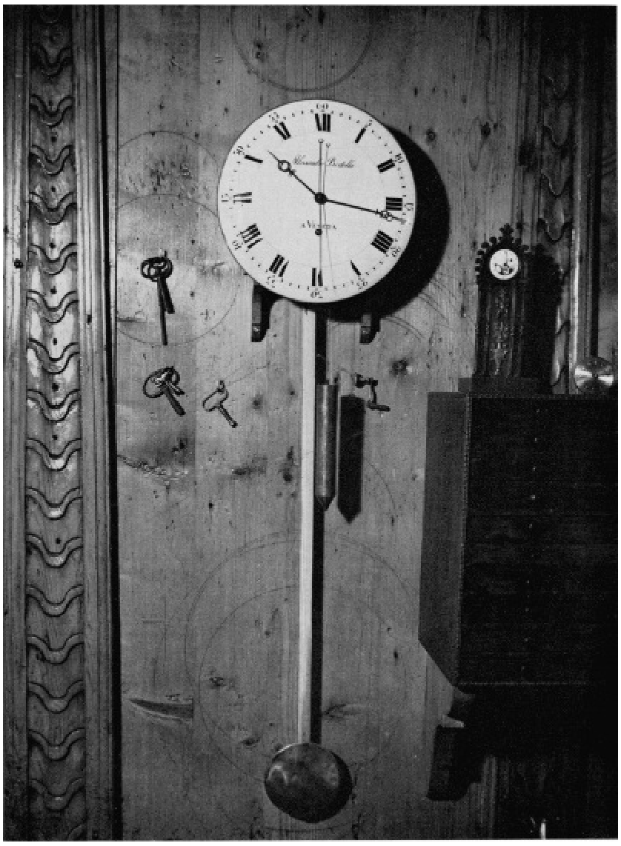


Figure 28.—Detail of wall of Bertolla's workshop, with regulatory clock made by his nephew, Alessandro Bertolla of Venice. Note wheel layouts, etc., scribed in the paneling. ***(Courtesy of Museo Nazionale della Scienza e della Tecnica, Milan.)***

Figure 29.—Table clock by Bertolla in the collection of Doctor Vittorio dal Lago of Bergamo. The dial indicates the days of the week and of the month, the names of the months and lunar phases. The clock strikes the hours and quarters and repeats. ***(Courtesy of Sig. Luigi Pippa of Milan.)***

The shop contains two completed clocks made by Bertolla. One is a weight-driven lantern clock typical of the 18th century, Italian style with brass dial, plates and posts, anchor escapement, and striking work. The dial is engraved in the usual style of Bertolla's baroque design, and the hands are of pierced bronze. Another clock associated with Bertolla and found in the shop, was made by his nephew, Alessandro Bertolla, who worked in Venice after his apprenticeship with his uncle had been completed. This clock is a regulator with a seconds' pendulum and sweep hand on an enameled dial. The original case has not survived.

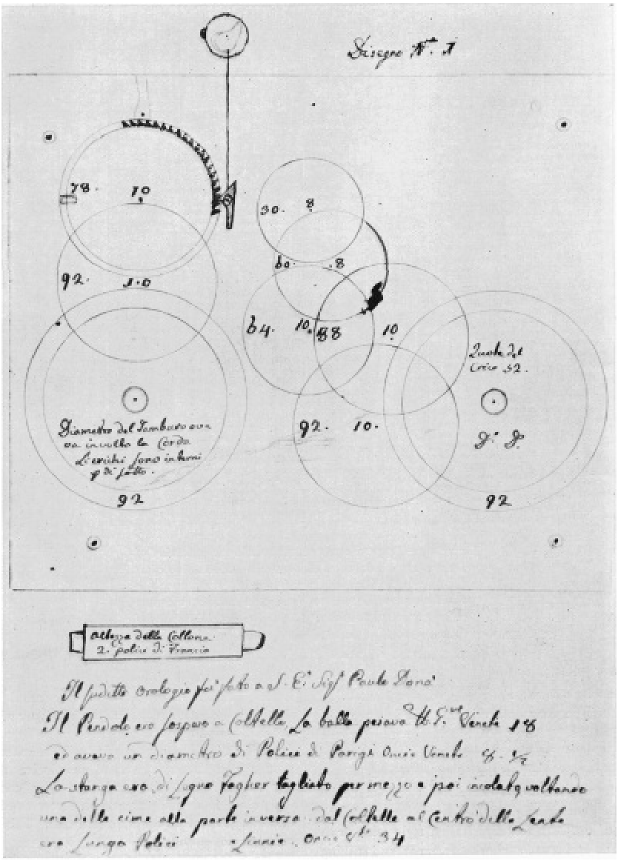


Figure 30.—Layout of the wheelwork of a clock made by Bertolla for His Excellency Paulo Dona, inscribed "Design No. 1." *(Courtesy of Museo Nazionale della Scienza e della Tecnica, Milan.)*

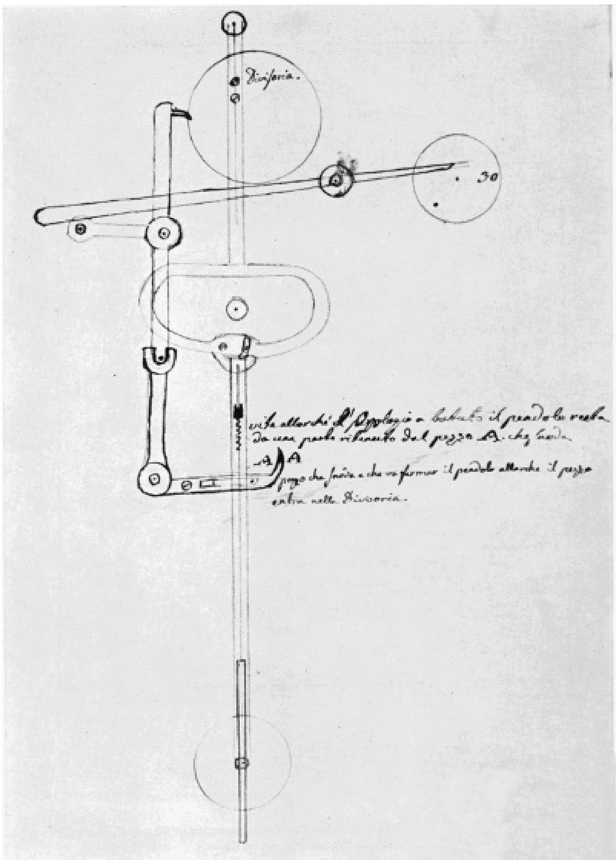


Figure 31.—Pendulum arrangement sketch for an unidentified clock found in Bertolla's workshop. *(Courtesy of Museo Nazionale della Scienza e della Tecnica, Milan.)*

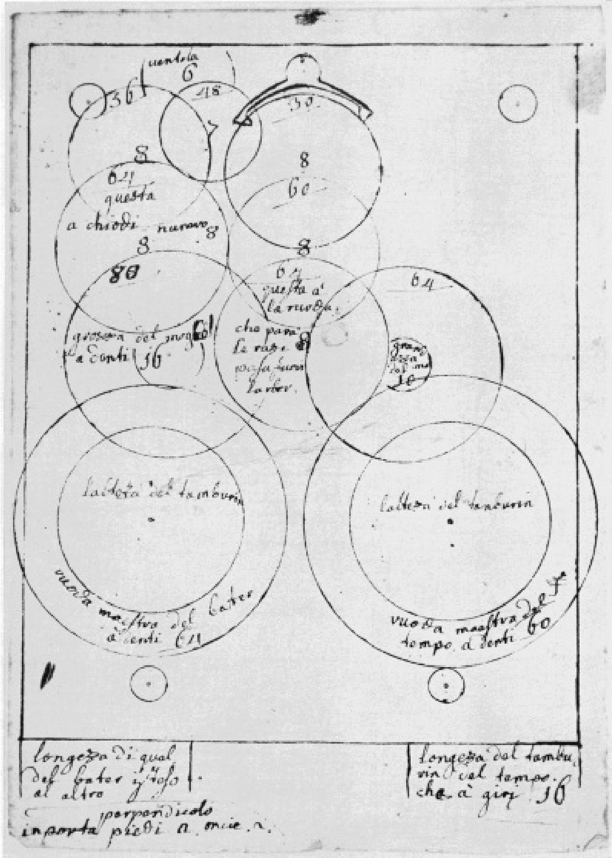


Figure 32.—Striking clock sketch found in Bertolla's manuscripts. ***(Courtesy of Museo Nazionale della Scienza e della Tecnica, Milan.)***

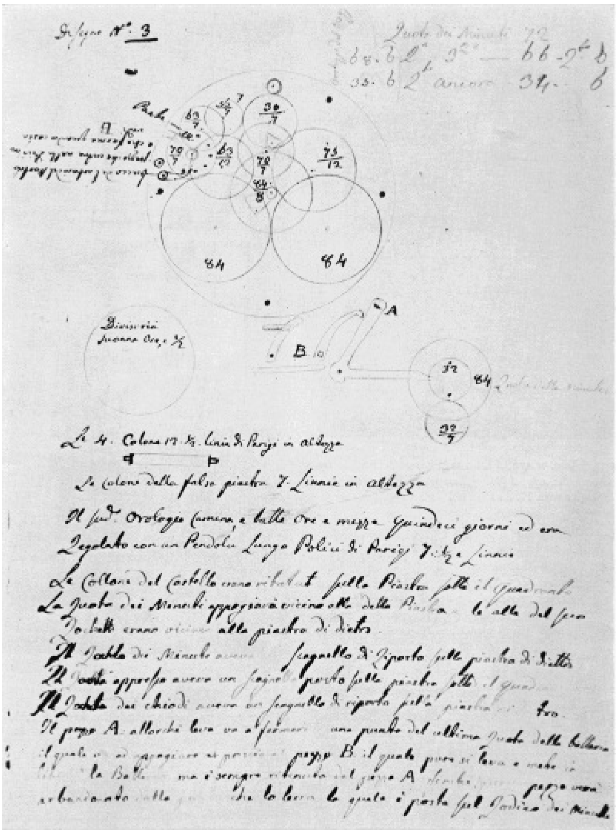


Figure 33.—Fifteen-day striking clock sketch, inscribed "Design No. 3," found in Bertolla's workshop. ***(Courtesy of Museo Nazionale della Scienza e della Tecnica, Milan.)***

Figure 34.—DIAL PLATE of a brass lantern clock made by Bertolla at the age of 80. *(Courtesy of Museo Nazionale della Scienza e della Tecnica, Milan.)*

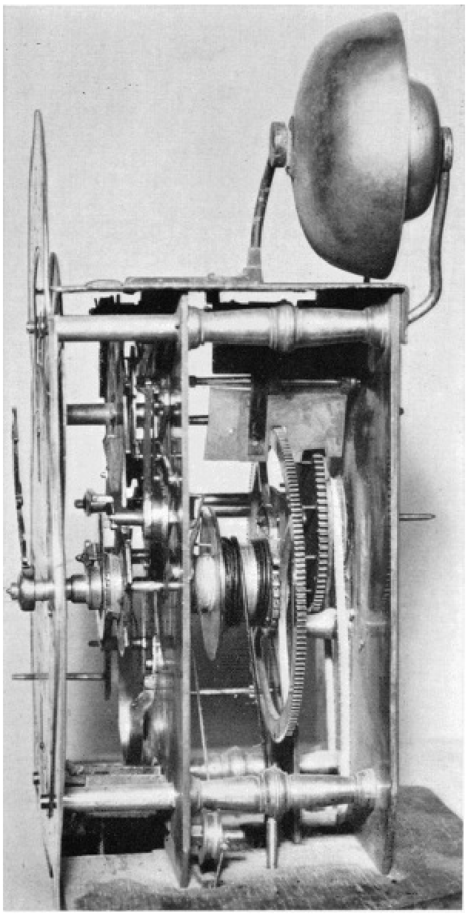


Figure 35.—MOVEMENT of brass lantern clock produced by Bertolla at the age of 80, showing details of movement and double bell. *(Courtesy of Museo Nazionale della Scienza e della Tecnica, Milan.)*

One of the most interesting of Bertolla's clocks, and probably the last one which he produced, was found in his workshop. This timepiece indicates the hours, minutes and quarters by means of a single hand or index. The weight-driven clock strikes the hours and quarters on two bells with a single hammer. The chapter ring, which is soldered to the dial plate, is marked for the minutes on the outer rim and for the four quarters inside it. Over the center of it, is a semicircular opening in the dial plate through which is visible a revolving disk attached behind the dial plate. This disk is marked with the hours and revolves from right to left, the current hour being indicated by a projection from the minute ring. The brass dial plate is engraved with simple floral designs in the corners and around the broken arch. There is no comparison between this crude and simple decoration and the extremely fine quality of the engraving on the dial plate of the Borghesi clock, for instance. In the center of the dial plate is engraved the following:

> "Questo orologio l'ideai e lo feci nella mia avanzata età d'anni 80. Bart^{o} Ant^{o} Bertolla"
>
> (I designed and made this clock at my advanced age of 80 years. Bartolomeo Antonio Bertolla.)

FOOTNOTES:

[1] BORGHESI, *Novissimum Theorico-Practicum Astronomicum Authoma Juxta Pariter Novissimum Mundi Systema...*, pp. 8-9.

[2] WENHAM, "Tall Case Clocks," p. 33.

[3] VON BERTELE, "The Development of Equation Clocks," parts 1 through 5.

[4] ENGELMANN, *Philipp Matthäus Hahn*; VISCHER, *Beschreibung mechanischer Kunstwerke....*

[5] LLOYD, *Some Outstanding Clocks Over Seven Hundred Years, 1250-1950*, pp. 116, 118, 120.

[6] SAN CAJETANO, *Praktische Anleitung für Künstler....*

[7] FRANCH, *La Valle di Non.*

[8] BONOMI, *Naturalisti, Medici e Tecnici Trentini*, p. 16

[9] AMBROSI, *Scrittori ed Artisti Trentini*, pp. 132, 525.

[10] Ibid.

[11] Pippa, "Antonio Bartolomeo Bertolla," pp. 22-23.

[12] Ibid., p. 22.

[13] Ibid., p. 23.

[14] The abbreviation in the inscription "pLan" is difficult to interpret. According to Father F. X. Winters, S.J., it may represent "sit planetis" or "sit planetarum." The use of an abbreviation was necessary to prevent the addition of another letter I or M, which would have disturbed the formation of the chronogram desired. Literally, "sit planetis" means "May he be eternal ruler *by* [or *through*] favor of the planets," while "sit planetarum" is to be translated "May he be eternal ruler *of* the planets." Father Winters considered both versions somewhat overexaggerated and proposed that the best translation might be "Long Live Francis I, Emperor."

[15] The word "Tempe" refers to the Vale of Tempe, in Thessaly, through which the Peneus River flows. It is between Mounts Olympus and Ossa, and is situated between the town of Larissa and the sea. In mythology, it is told that these mounts were originally joined and Hercules separated them to allow the river to pass between them. The word "Tempe" is also used to mean any pleasant place. Thus, the inscription "Tempe indesinenter clausa, Scaturigo signata" is literally translated "Tempe always closed, A fount of water sealed up" or, freely translated, as "A garden enclosed, a fountain sealed up."

[16] "Phoebi" or Phoebus, called Apollo, the sun god; Phoebes or Diana, the moon goddess, sister of Apollo.

[17] Pippa, op. cit. (footnote 11), pp. 23-25.

[18] Perini, *Statistica del Trentino, Biblioteca Communale del Trentino*, vol. 2, p. 57 (cons. 6, carta 9); Tovazzi, *Biblioteca Tirolese*, pp. 406-407.

[19] Pippa, op. cit. (footnote 11), pp. 24-25.

[20] Piamonte, *La Nauna Descritta al Viaggiattore*.

[21] Esposti, "La Sala 'Innocente Binda' al Museo della Scienza e della Tecnica di Milano," pp. 18-21.

Appendix

SYNOPSIS OF THE COMPLETE MECHANICAL WORKS OF THE FIRST CLOCK

[Translated from the section entitled "Synopsis Totius Operis Mechanici" in Francesco Borghesi's first book *Novissima Ac Perpetua Astronomica Ephemeris Authomatica Theorico-Practica*....]

I

Of three movable indices, the farthest from the center of the dial is fitted with an index on either side and marked with four segments of a circle. Immediately below are five numbers, divided into the days of setting the measure of the mean-synodic age of the moon, and into signs, degrees of the signs, and of the distance of the moon from the sun. These, in each revolution, revolve once around the solar disk superimposed on the mean synodic-lunar disk, and also around the lunar disk. The upper indices, meanwhile, in the two external greatest orbits, measure the time continuously, in the accustomed manner of the Germans—the middle index measuring by hours and the uppermost by the first minutes [of hours].

II

Inside these three circles, perpendicular above their center, is a small index of the seconds of minutes. At each first minute of time, being the fastest of all, it describes the smallest orbit. Next to this are two other slightly larger circles divided into 30 degrees, one [rotating?] from the right, the other from the left. These two indices are arranged in such a fashion that the one rotating from the observer's left completes its period 12 times during one, mean, solar-astronomical year. The one [rotating] from the right likewise completes its cycle 12 times during the period of one mean-synodic moon. In between these, there is placed another small sphere, divided into 40 arbitrary parts, whose dial does not move automatically, but is moved by hand for speeding up or slowing down the course of the time, or of the perpendicular.

III

Diagonally from the sides of the center of the three larger indices, six other indices revolve: three on the left from one center, and three on the right from another. The uppermost of the three which are on the right of the observer [and which are] decorated with a small disk of the sun, runs its cycle once during a mean solar-astronomical year. The second measures the distance of the sun from its apogee. The third revolves 12 times, with each lunar revolution from one node to the same [repeated] node. Under the point of the uppermost index, first lie the months of the year which are inscribed, and the days of each month, but having only 28 days assigned to February; then the signs of the zodiac, and their several degrees. The circle corresponding to the middle index, extending through the first semicircle from apogee to the lower perigee and returning through the second semicircle to the upper locations of apogee, shows the true equation or eccentricity of the sun, joined with the little equation of the moon in syzygy. [These equations are] measured by geometric-astronomic proportion for each distance of the sun from its apogee or perigee in degrees, and in sufficiently small parts of degrees, with the title added above in their proper places, whether an addition is to be made to the mean location of the sun or a subtraction from the same, so that the true longitude of the sun may be calculated. Three circles are assigned to the lowest index, of which 30 degrees of distance of the moon from its nodes comprise the larger. The middle circle is based on the hypothesis of the mean invariable diameters (that is, of the sun, the moon, and the terrestrial shadow), and is divided into hours and quarters of duration. The last circle is divided by the trigonometric laws into the inches of magnitude of lunar eclipses. Lying between these circles, there is another eccentric circle (black with a spot) exhibiting the shadow of the earth, in which the little moon sinks itself, carried by the lowest index. In any ecliptic full moons, the patent number of inches of immersion somehow affects the minds of the cultured, but also the scheme of maximum obscuration affects the eyes of the illiterate themselves.

IV

Of the three indices which revolve from the left, the uppermost completes its cycle within 12 hours, just as the hour index. The middle one with two pointers on diametrically opposite sides, carries the marks of conjunction and opposition of the luminous bodies, with a movement equal to the course of the sun from lunar apogee or perigee. The lowest index, fitted with a single pointer, indicates the motion of the moon from its apogee or perigee. Under these three indices, there is situated a common circle, divided into 12 parts, each of which are further divided into 30 parts through its outer circumference. I have said a common circle, for, with respect to the first index, the division represents 12 hours, and the double subdivision representing the double set of minutes of the hours serves for an excitator for anytime at all, at will. For as often as the little index reaches the twelfth hour, first being moved by hand wherever you prefer, a little hammer strikes the little bell many times. But if you observe the second or the third index, the first division provides the signs, and the subdivision of the signs gives the individual degrees of the distance of the sun from the lunar apogee, or of the moon from its apogee, respectively. To this is added two other interior circles from the same center: to the larger is inserted the equation of the center of the moon in its conjunctions and oppositions; and on the smaller the equation of the same moon in its quarters, astronomically-geometrically proportioned to the distance of the moon from its apogee or perigee. In the first case, the equation is to be subtracted from the mean longitude of the moon, descending from apogee to perigee; in the second case, to be added to the mean longitude of the moon ascending from perigee to apogee; and, in the third semicircle of the index, as the rubric directs, common to both equations, added around the center.

V

Perpendicularly under the center of the machine, two other indices are carried about one and the same center. The one nearer to the observer—bearing in one of two points diametrically opposite the small disk of the sun, in the other the disk of the moon—runs a course equal to the motion of the sun from the head or the tail of the dragon (*Draco*). The other, of simple construction, marked with a small moon, signifies in like manner the motion of the moon from the head or the tail of the dragon.

Immediately below, there is a larger circle, common [referring] to both these indices, which is divided into 12 parts. Each of these parts in turn, in the outer periphery, is subdivided further into 30 parts, which are the 12 signs of the zodiac and the individual degrees of the signs of distance of the sun and the moon from the head of the dragon.

In the second circle is read the latitude of the moon, measured by degrees, etc., on a trigonometric scale, by signs and degrees of distance of the moon from its nodes, that is, from the head or tail of the dragon. When the second index is descending from the head of the dragon to the tail, the latitude will be to the north of the solar path; that is, the ecliptic. On the other hand, it will be south of the ecliptic when the same index is returning upward from the tail to the head of the dragon as advised by the title inscribed on the third circle.

Finally, on the fourth and last circle are seen more prime minutes of the circle for reducing the orbit of the moon to the ecliptic. That the true longitude of the moon may be obtained more accurately, these must be subtracted from the longitude of the moon already calculated in the first and third quadrant of the circle of the second index. On the other hand, they are to be added to the same in the second and fourth quadrant, as is noted in their respective places, according to the theory of right ascensions.

Here, then, [you have] as finally completed, delineation of the great index which was partially described before in this book.

From two points of that index which perpendicularly correspond to the center of these circles, a pair of compasses, by an unvaried aperture up to the circumference of the first larger circle, has marked off four segments of a circle. The two larger segments, equal among themselves, in one aperture refer to the sun, and the two smaller in the other, likewise equal, refer to the moon. The one pointer is for determining the solar eclipses; the other, for lunar. Both segments of each division, like little wings of the index, stretch to the extent of the degree of distance of the moon from its nodes, and to which that determined latitude corresponds. On one side, that latitude precisely equals the radii of the earth, the sun, and the moon, as the termini of solar eclipses; and, on the other side, precisely equals the radii of the earth's shadow and of the moon, as the confines of lunar eclipses. The apexes of the last index, diametrically limited [opposite], indicate the age of the moon, and its mean distance from the sun; one pointer, upon which the sun sits, measuring the mean days and degrees from the full moon; the other, on which the moon sits, measuring the mean days and degrees from the new moon.

VI

Besides the larger and smaller indices already mentioned, all [of which] revolve within the periphery of the three largest circles, six dials in this clock also revolve within the same circles which are to be seen through six openings of the frontispiece. The first of these, intended to indicate the phases of the moon by an unusual method (completely black, and decorated with the characters of the principal aspects of the moon) continually revolves interiorly around the center of the machine and at the new moon, it completely removes from sight the face of the moon through the round window. It continually recedes through the first half of the circle until, at the time of the full moon, it restores the moon, looking out with a full star. Soon again, too slow to be observed, it returns through the other half of the circle, so that in the next conjunction, the whole face of the moon may have a covering of darkness, once again to be removed.

The other dials are moved by spontaneous advances at stated times. The first of these shows, through a square opening, the day of the month; the second, through another opening, shows the current day of the week with the characters of the seven planets which, according to ancient superstition, preside over each day of the week (now, by a truer form of religion divided by the Church into ferias, etc.); that is, the sun, the moon, Mars, Mercury, Jupiter, Venus and Saturn, to which I have added the numbers of the ferias. These two little dials are advanced daily, by a sudden movement at midnight. The remaining three are changed automatically only once a year on the first of January.

The first of these dials contains five little cells, opening from a common window: in the first cell, at the edge of the dial, is found the dominical letter; in the second, the cycle of the sun; in the third, the character; in the fourth, the sign; and, in the fifth, the house of the planet dominating the year. The second dial shows the epacts, with the golden number. The third, and last of all, shows the Roman cycle.

Finally, as indicated by the epact and the dominical letter in an immovable table added outside, are the feastdays and other movable events of the year; that is, Easter, the four seasons, the Rogation Days, etc.

VII

But lest the various movements of the indices and the various beginnings of the divisions tend to cause some fatigue, the precaution has been taken, that all the indices by common law are moved from the top towards the right of the observer, and from thence all the arithmetic divisions of the circles take their beginning. And lest the multitude of different figures should deceive the eye, the larger divisions of the circles have been marked by Roman numbers, that is, by capital letters of the alphabet; others, in other places, by differently colored numbers. Thus, the movements of the indices, the distribution of the circles and the multitude of numbers not only do not disturb the eyes and the mind, but rather marvelously delight them. [Pg 74]

VIII

After having completed briefly the description of the dial and the indices and their motions, I have not without reason delayed in satisfying the desires of many who wish to learn at least the method by which, from this mechanism, may be calculated the true times of new and full moons, and their ecliptics. In order to make these matters clearer, it is necessary that they be explained here at greater length.

With the indices, then, adjusted astronomically-geographically to the longitude of any given region, and to the mean time whether past, present or future, and assuming the clock to be in normal operation (as at present it has been for a whole year and more), then the moon will be in conjunction with the sun in the heavens. When the equations on the mechanism are examined, the sun and moon shall be found to be in the same degree of longitude, and in the same part of a degree. There will also be an ecliptic new moon that is in conjunction with a solar eclipse, or rather with a terrestrial eclipse. This will occur if, at that time, both apexes of the first index, located below the center of the clock, are hidden by the two segments of the circle extending from the center of the mechanism through the lowest index.

And the eclipse will be greater and greater and, consequently, visible in more regions of the earth, the more deeply the two pointers, indicating the distance of the sun from its apogee, are hidden in the center of the segments.

But whether the eclipse takes place in the head or in the tail of the dragon, or whether it is north or south, is indicated by the small disk of the sun attached to one of the two pointers hidden by the segments of the circle. If, at that time, the little disk shall be found in the head of the dragon inscribed on the plane of the dial, then the sun has been snatched from the earth and ingloriously entombed, as it were, in the huge jaw of the dragon. Then, ... the heavens themselves will lend aid to the woeful pomp of the senseless funeral in full darkness by suddenly lighting the unhappy lamps of the fixed stars. However, if the little disk occupies the tail of the dragon on the mechanism, then the sun in the heavens also, as if freed from the toils of the immense dragon's tail, will emerge without difficulty.

The center of the eclipse will traverse the hemisphere of the earth north of the solar path, always nearer to the pole of the ecliptic, in proportion to the inclination of the disk to the north. On the other hand, if the little disk inclines to the left semicircle, then the people south of the solar path will enjoy the spectacle of the total central eclipse.

But if the little disk remains neutral (inclining neither way) and remains halfway between the two sections of the circle, then the greatest solar eclipse will take place at the equator and those who live near the poles of the ecliptic will not enjoy a trace of that eclipse. This is because the half of the equatorial diameter enormously outmeasures even the greatest apparent semidiameters of the sun and of the moon, even taking as a norm the smallest horizontal parallax of the moon.

What has been said about the true new moon is to be understood also, proportionately, about the true full moon. For when, with respect to the equations of the centers, the moon shall be distant on the mechanism by a full semicircle from the sun (also in the heavens it will be truly in opposition to the sun) there will be a true full moon. Likewise, the moon in the heavens will be in eclipse if, at the time of opposition, the pointers of the little index (which we mentioned before) situated below the center of the clock are so far away from the belly of the dragon that they are forced to lie under the two smaller segments of the circle which, in all full moons, are always to be moved from the index of the synodic moon to the region of that little index. As a matter of fact, the closer the little pointers approach to the middle of the segments, the more obscured it will be.

You will know, furthermore, that the eclipse of the moon occurs in the head of the dragon if the disk of the little moon, attached to the other point of the little index, is raised to the head of the dragon; conversely, when the little disk of the moon inclines to the tail, the eclipse is taking place in the tail of the dragon.

And, accordingly, when you observe the little moon of the index inclined to one or other section of the circle, so also in the heavens, the eclipse of the moon is only partial and the northern or the southern part of the moon is illuminated.

The current time will indicate whether the lunar eclipse is visible or not. As the new moon ecliptic falls during the day, the eclipse will not be visible, since the earth denies a sight of the moon which is below the horizon. But, conversely, if there are no clouds, the eclipse will be visible anywhere, if the luminous bodies are ecliptically in opposition at night. [Pg 75]

Since lunar eclipses appear to all people as being of the same magnitude and duration, and begin and dissipate at the same absolute moment of time, I decided to reveal another facet of this spectacle on the right side of the center of the clock (see chapter III above). There, at the time of the true ecliptic full moon, as the pointer of the third little index shows, you can ascertain the hours, etc., of duration, and the inches of greatest obscuration. The little moon attached to the index is a model of the actual eclipsed moon.

IX

Thus, with the aid of this machine, solar and lunar eclipses of the past can be recalled and future ones can be foreseen. Indeed, if the index of prime minutes is speeded up by hand, whose wheel imparts motion to the other indices and shields, then, the dials and openings will foretell the year, month, day, hour, etc., of any future eclipse. I foresaw that the times would thus be evolved too slowly, and that the clock wheels would be considerably worn by repeated experiments (if, for instance, by the rotation of the index of prime minutes, to whose period only a single hour corresponds, the future new and full moon ecliptics were being investigated). Therefore, I took care that the wheel which immediately communicates motion to the index of the synodic moon should be so fitted internally to the mechanism that by the reversal of any external index, the wheel would be removed from its proper position; whenever desired, it could be quickly and most accurately restored to its proper place.

In this way, since the close meshing of the wheels is released, you can extend the experiment for many years, even for many centuries. You have only to guide with your hand the index of the synodic moon on the circles, always intently observing whether, in the passage which this index makes over the little index, both pointers of the little index are hidden by the segments of the circle. Having observed this, look at the index moved by hand, for if this has carried the solar disk halfway between the two larger segments of the circle to the region of the hidden little index, then you will know that eclipse will be a solar eclipse. On the other hand, you will know that it will be a lunar eclipse, if the index (moved by hand) has carried the moon, situated between the two smaller segments of the circle, to the same region (i.e., the hidden part of the circle). The solar disk and the lunar disk alternately will reveal to you the circumstances of both eclipses. The current year will be given by the Julian period, reducible to any desired epoch, and, contained in the solar cycle, the golden number and the Roman cycle. The month of the year and also the day of the month will be indicated by the pointer of the little index, first on the right side of the clock. And what I have said of future eclipses should be equally understood of past eclipses, so long as the index, which can be moved either way at will, is moved in reverse.

Finally, though 55 wheels were employed to carry so many dials, all are driven by one source of power not exceeding the third part of a Germanic hundred-weight which, suspended at the geometric height of five feet (about the ordinary stature of a man), keeps the whole machine in operation for a hundred days and more.

Although the machine repeats hours and quarter hours at will and, consequently, the number of wheels and the rest of the apparatus necessary for these functions is thereby increased, it has not grown to an unwieldy size, however much one might erroneously imagine it to be. It does not exceed the bulk of ordinary clocks hanging from a wall; indeed, it scarcely equals these.

The entire machine, ready for operation, does not weigh more than 156 ounces, although it is made of steel or brass throughout and further weighted with two bells and a rather large brass dial-plate.

Of course, there are many more things to be said, especially about the mechanical structure of the wheels, but fearing to tire my kind reader unduly by exceeding the bounds of a summary, I am forced to put an end, though unwillingly, to this sufficiently shortened explanation of the work. I have hope of giving satisfaction to many more when I shall have communicated to the learned world another and completely new automatic work, grander than this present one. It is already theoretically completed in all its calculations, but still to be worked out mechanically from the very beginning, if but God, thrice Best and Greatest, bless the undertaking and mercifully grant life and health—to whom be in, and from, and through all things, all honor and glory in eternity and beyond.

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Wenham, Edward. Tall case clocks. *The Antiquarian Magazine* (May 1927), vol. 8, no. 4, p. 33. [The Borghesi clock is illustrated only from a photograph of the Anderson Art Galleries in New York, and mislabeled "Astronomical Clock made in Jena, 1656, in elaborate mahogany case."]

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Transcriber's Note

Footnotes have been moved to the end of the main section of the paper, and illustrations have been moved to eliminate breaks in paragraphs. Minor punctuation errors have been corrected without note. The following typographical errors have been corrected:

p. 37 ... his curiosity increased ... [Had 'curiousity'.]
p. 41 Bertolla apparently wavered in ... [Had 'waivered'.]
p. 43 ... contained within asterisks, carries ... [Had 'carrie'.]
p. 45 ... Assidvo proni donant di cvncta labori. [Had 'ronip'.]
p. 45 ... assiduous laborer.) The same ... [Had 'saem'.]
p. 48 ... 12 signs of the anomaly, within ... [Had 'anamoly'.]
p. 51 ... the larger size of uppercase letters ... [Had 'letter'.]
p. 54 ... rightly conceive my new system of the ... [Had 'sytem'.]
p. 55 ... leading point of the system ... [Had 'they'.]
p. 55 ... Cancer; Austral [the southern] ... [Closing bracket added.]
p. 55 ... of the earth are always held in one ... [Had 'alway'.]
p. 56 ... all things in their circles so that ... [Had 'than'.]
p. 56 ... satellites, etc., eccentrically ... [Had 'excentrically'.]
Footnote 4: *Philipp Matthäus Hahn* [Had 'Matthaus'.]

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