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Copernicus
Tycho Brahe
Johannes Kepler
Galileo

On the Revolutions

translation and commentary by Edward Rosen

NICHOLAS COPERNICUS COMPLETE WORKS

HISTORY AND PHILOSOPHY OF SCIENCE/ EARTH AND SPACE SCIENCES

A JOHNS HOPKINS SOFTCOVER

One of the great classics of scientific literature, *On the Revolutions* ranks with Galileo's *Dialogues* and Newton's *Principia* in its impact on Western scientific thought. In this monumental work, astronomer Nicholas Copernicus presented his observational and mathematical arguments to show that the Earth and the other planets travel around the sun in circular paths. This heliocentric theory supplanted the Ptolemaic system of cosmology, which held that the Earth was the center of the solar system with the sun and planets circumnavigating it in complex epicycles.

In 1973, to commemorate the 500th anniversary of Copernicus's birth, the Polish Academy of Sciences initiated a project to publish all of the astronomer's extant works, both in their original Latin and in modern translations. Now available for the first time in softcover, *Nicholas Copernicus: Complete Works* presents Edward Rosen's authoritative English translations and commentaries from the Polish series in two parts, *On the Revolutions* and *Minor Works.* These unabridged republications include Rosen's corrections to the 1978 hardcover editions and a new introduction by his collaborator, Erna Hilfstein.

"Diligent reader, in this work, which has just been created and published, you have the motions of the fixed stars and planets, as these motions have been reconstituted on the basis of ancient as well as recent observations, and have moreover been embellished by new and marvelous hypotheses. You also have most convenient tables, from which you will be able to compute those motions with the utmost ease for any time whatever. Therefore buy, read, and enjoy."

—Nicholas Copernicus, from *On the Revolutions*

Edward Rosen, one of the world's leading authorities on Copernicus and the origins of modern astronomy, was Distinguished Professor Emeritus of the History of Science at the Graduate Center of the City University of New York. Dr. Rosen's awards include the Nicholas Copernicus Medal from the Copernicus Society of America, the Pfizer Medal from the History of Science Society, and the Gold Order of Merit from the Polish People's Republic. His other books in Renaissance science include works on Kepler, Galileo, and the invention of the telescope. His translation of Copernicus's *Minor Works* is also available in softcover from Johns Hopkins.

Foundations of Natural History
Series Editors: Paula M. Mabee and Kirk Fitzhugh

THE JOHNS HOPKINS UNIVERSITY PRESS
Baltimore and London

ISBN 0-8018-4515-7
90000
9 780801 845154

Cover design by Julie Burris
Cover illustration: Nicholas Copernicus
Courtesy of the Polish Academy of Sciences

Printed in the United States of America on acid-free paper

The original edition was published in 1978 as Volume II of *Nicholas Copernicus: Complete Works* by Polish Scientific Publishers, Warsaw and Cracow. It was edited by Jerzy Dobrzycki and sponsored by the Committee for the History of Science and by the Institute for the History of Science, Education, and Technology of the Polish Academy of Sciences. Volumes I and IV, copyright by PWN Polish Scientific Publishers.

Johns Hopkins Paperbacks edition, 1992

The Johns Hopkins University Press
701 West 40th Street
Baltimore, Maryland 21211-2190
The Johns Hopkins Press Ltd., London

Library of Congress Cataloging-in-Publication Data

Copernicus, Nicolaus, 1473–1543.
[De revolutionibus orbium caelestium. English]
On the revolutions / Nicholas Copernicus ; translation and commentary by Edward Rosen.
p. cm.—(Foundations of natural history)
Translation of: De revolutionibus orbium caelestium.
Includes bibliographical references and indexes.
ISBN 0-8018-4515-7
1. Astronomy—Early works to 1800. 2. Copernicus, Nicolaus, 1473–1543. De revolutionibus orbium caelestium. English.
I. Rosen, Edward, 1906– II. Title. III. Series.
QB41.C7613 1992
520—dc20 92-16304

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INTRODUCTION TO THE SOFTCOVER EDITION

Nicholas Copernicus (1473–1543) was indisputably the first great astronomer of modern times; the first to assign the Earth its proper planetary status and the first to provide a scientific justification for placing the sun near the center of the known universe. He initiated a revolution, not only in astronomy but also in physics, by ascribing to the Earth a circular motion, shattering the Aristotelian dichotomy that had assigned perfect and constant circular motion to the heavenly bodies and an up-and-down motion of generation and corruption to the sublunar regions. Copernicus may have used the geometrical devices of his Greek or Arab predecessors, (for example, from the "Maragha School"), yet his system, and the perception of the cosmos it established, was entirely novel.

Shortly before the five hundredth anniversary of the birth of its great countryman, the Polish Academy of Sciences undertook the monumental task of publishing all Copernicus' extant works both in Latin and in several modern languages. Each version was to comprise three volumes: Volume I, presenting the Latin facsimile of the autograph manuscript of Copernicus' major work *De revolutionibus orbium caelestium* (cited hereinafter as *Revolutions*); Volume II, containing the translation of the *Revolutions*, accompanied by extensive modern commentary; and Volume III, titled *Minor Works*, presenting translations of the remaining intellectual writings of Copernicus, with substantial commentary. As the project developed, however, the Academy decided that because the manuscripts used for the translations in the third volume were not easily accessible to all readers, a yet-unpublished fourth volume would be added containing the Latin facsimiles of the documents used in Volume III. The four volumes constitute the Academy's publication of Nicholas Copernicus' *Complete Works*.

The English translation and commentary of the *Complete Works* was entrusted to the eminent Copernican scholar Edward Rosen, Distinguished Professor of the History of Science at the Graduate School of the City University of New York. Professor Rosen chose me as his collaborator; our arduous and ultimately fruitful undertaking resulted in the publication of the first three volumes in 1972, 1978, and 1985, respectively. Sadly, Rosen passed away several months before the publication of the third volume and did not see the entirety of his work in print. It stands as testimony to his impeccable scholarship.

With the publication of this two-volume softcover edition, the Rosen translation of Copernicus' *Complete Works*—Volumes II and III of the Polish series—is now available to a broader audience. The text has not been reset, but we have included as an appendix to the translation of the *Revolutions* the list of additions and corrections that Rosen and I prepared after the publication of the hardcover edition in 1978.

At the very outset of our work in the early 1970s, we faced a number of problems. Our first concern was with the text to be used for the translation of the *Revolutions*: Should it be the first, 1543 edition of that work, or the extant autograph? The decision was far from easy, for many scholars consider the 1543 edition, although riddled with serious errors, to be the definitive version of the great work. On the other hand, the autograph, which bears no printer's marks, is regarded as an earlier version superseded by another manuscript copy; Rheticus, Copernicus' disciple, took this text with him when he departed Frombork and used it for the printed edition. In the end, we decided to use a collation of the printed version and the autograph, thus providing an edition that is closer to Copernicus' ultimate version than is either of the other texts singly. In addition, we included certain passages of historical importance that Copernicus crossed out in his manuscript.

We made these decisions after a close examination of the autograph and the 1543 edition had revealed that several important entries in the autograph were absent from the printed version. For example, in the right margin of folio 59 recto of the autograph, Copernicus added "Venus apogee at 48°20′." This entry does not appear in the 1543 edition. The place of a planetary apogee is of such importance that it is unlikely that Rheticus omitted it when preparing a copy for the printer; thus, the apogee entry must have been made by Copernicus himself after Rheticus had left Frombork. The same is true of the entries concerning the other planets on the margins of folio 60 recto, 61 recto-verso, and the longitude change in the margin of folio 59 verso.

The next problem involved the puzzling differences between the Catalog of Stars in the *Revolutions* and the catalogs known to have been available to Copernicus. We hesitated to accept a solution proposed by other scholars, namely, that Copernicus used a catalog that has not survived to modern times. Instead, our plausible reconstruction of Copernicus' line of reasoning explains all of his catalog deviations from either Ptolemy's or Giorgio Valla's catalogs.

Earlier translations of Copernicus' minor astronomical writings, the *Commentariolus* and *Letter against Werner,* were invariably done on the basis of one text, whether a manuscript or its printed version. The translations in the *Complete Works* are based on a collation of all the extant copies, some of which were discovered only recently.

Copernicus' Latin translation of the Greek *Letters* by Theophylactus Simocatta presented us with another challenge, since Copernicus' text departed considerably from that published by Aldus Manutius in 1499—the only printed version known to have been available to him at the time. Once again, earlier scholars, puzzled by the deviations, postulated that Copernicus had used another text, now unknown. After examining the microfilm of the Greek-Latin and Latin-Greek dictionary used by Copernicus, and containing his annotations, as well as the copy of Manutius' *Epistolographers,* we rejected the "different text" hypothesis in favor of a data-based explanation that could account for the discrepancies. This time, too, our endeavors were successful, and our commentary explains every error, omission, and deviation.

In 1517 and 1519, Copernicus wrote two economic treatises that differ only slightly from each other; several years later, he wrote a third, the *Monete cudende ratio* (Essay on the Coinage of Money), which varies in some small respects from the earlier two. Copernicus did not date his third treatise, and several scholars have argued for a variety of dates, ranging from 1526 to 1528. On the basis of textual and other historical evidence (cf. p. 171), we assigned a date of April 1525 to 17 July 1526. To facilitate comparisons of all three texts, *Minor Works* presents the 1517 treatise (*Meditata* [Private Reflections]) in the middle of the page, the changes contained in the 1519 treatise (*Denkschrift*) on the left, and those in the third (*Monete cudende ratio*) on the right.

In 1972, Bishop Jan Obłąk of Varmia compared the handwriting of Copernicus in Volume I of the *Complete Works* with that of the 1520 inventory of the Varmia Chapter documents. He realized that the inventory had been incorrectly attributed to Copernicus' friend Bishop Tiedemann Giese, as it bore all the characteristics of Copernicus' hand. Bishop Obłąk published the inventory's facsimile, together with the transcription of its text, its Polish translation, and a substantial commentary. Upon a careful scrutiny at the Olsztyn diocesan archives of all the extant documents (many perished during the Second World War), I corrected many of Obłąk's misidentifications and misdatings of the documents listed in the 1520 inventory (some of the dates were written using the Roman or ecclesiastical calendar).

Finally, among the commentary, corrections, and recalculations included in the appendix of this softcover edition of the *Revolutions,* is Rosen's crucial clarification of the handwritten annotations on two original copies of the book: a copy of the first edition, Ottoboniano Latino #1902, and a copy of the second edition, the "Cimelia" copy. Certain scholars had previously assigned authorship to Tycho Brahe —an attribution that, if true, would create serious inconsistencies with all other historical evidence pertaining to how Brahe made use of Copernicus' work as he developed his own, Tychonic system in the 1570s and 1580s. In a definitive reanalysis of the evidence ("In defense of Tycho Brahe," *Archive for History of Exact Sciences* 24[1980]:257–65), Rosen established that the author of the annotations on the two copies was Paul Wittich, a Silesian astronomer.

In closing, let me reiterate Professor Rosen's thanks to our friends Wanda and Tadeusz Pochopień, for their assistance in supplying us with hard-to-obtain books, as well as microfilms and photocopies of documents from various Polish libraries. I can do no better than to allow Copernicus himself the last word here, with his advice to the reader printed on the title page of the 1543 edition of the *Revolutions*: "Eme, lege, fruere" (buy, read, and enjoy [this work]).

Erna Hilfstein

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JOHANNES KEPLER and Planetary Motion

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IMMORTALS OF SCIENCE

JOHANNES KEPLER and Planetary Motion

by DAVID C. KNIGHT

PUBLISHED BY
CHATTO AND WINDUS LTD
42 WILLIAM IV STREET
LONDON WC2

I am indebted to
Dr. James S. Pickering of Hayden Planetarium,
New York City, for his helpful suggestions
concerning the manuscript of this book.
D.C.K.

PRINTED IN GREAT BRITAIN BY
LOWE AND BRYDONE (PRINTERS) LTD, LONDON

Contents

Once I measured the heavens,
Now I measure the shadows of the earth.
Although my soul came from heaven,
The shadow of my body lies here.

But it did not lie there for long. As in life he had been granted little peace, so he was granted even less in death. For the boots of the soldiers who would destroy the little churchyard and scatter its contents were already on the march.

* * * * * * * *

Chronology of Principal Events in Kepler's Life

1571 Born December 27 in Weil der Stadt, Germany.
1577–1589 Successively attends Swabian schools at Leonberg, Adelberg and Maulbronn.
1589 Enters University of Tübingen.
1594 Leaves Tübingen and accepts professorship at Graz in Styria.
1594–1600 Serves as mathematics professor and district mathematician in Graz.
1597 Marries Barbara Müller. Publishes *Mysterium Cosmographicum.*
1598 Forced out of Graz by Counter Reformation but is allowed to return.
1600 First meets Tycho Brahe at Benatky Castle near Prague. Forced out of Graz for good by Counter Reformation.
1601 Works with Tycho Brahe. Tycho Brahe dies. Kepler appointed imperial mathematician.
1601–1612 Serves as imperial mathematician at the court of Rudolf II in Prague, Bohemia.
1602 Discovers Second Planet Law, as applied to a circular orbit.
1604 Tries out oval theories of a planetary motion.
1605 Discovers First Planet Law of elliptical orbits.
1609 Publishes *Astronomia Nova,* containing first two Planet Laws.

1611 Applies for position in Linz and is accepted. Frau Barbara Kepler dies.

1612 Emperor Rudolf II dies. Matthias becomes Holy Roman Emperor. Kepler arrives in Linz.

1612–1626 Serves as district mathematician and teacher in Linz.

1613 Marries second wife, Susanna Reuttinger.

1616 First learns of witchcraft accusations against his mother.

1618 Discovers Third Planet Law. Thirty Years' War breaks out; last until 1648.

1619 Publishes *Harmonice Mundi* ("World Harmony") containing Third Planet Law. Ferdinand II becomes Holy Roman Emperor.

1620 Attends mother's witch trial and defends her.

1626 Siege of Linz. Journeys to Ulm for printing of *Rudolphine Tables.*

1627 Publishes *Rudolphine Tables.* Goes to Prague.

1628 Accepts offer of patronage by Wallenstein.

1628–1630 Lives and works in Sagan.

1630 Dies in Regensburg on November 15.

* * * * * * *

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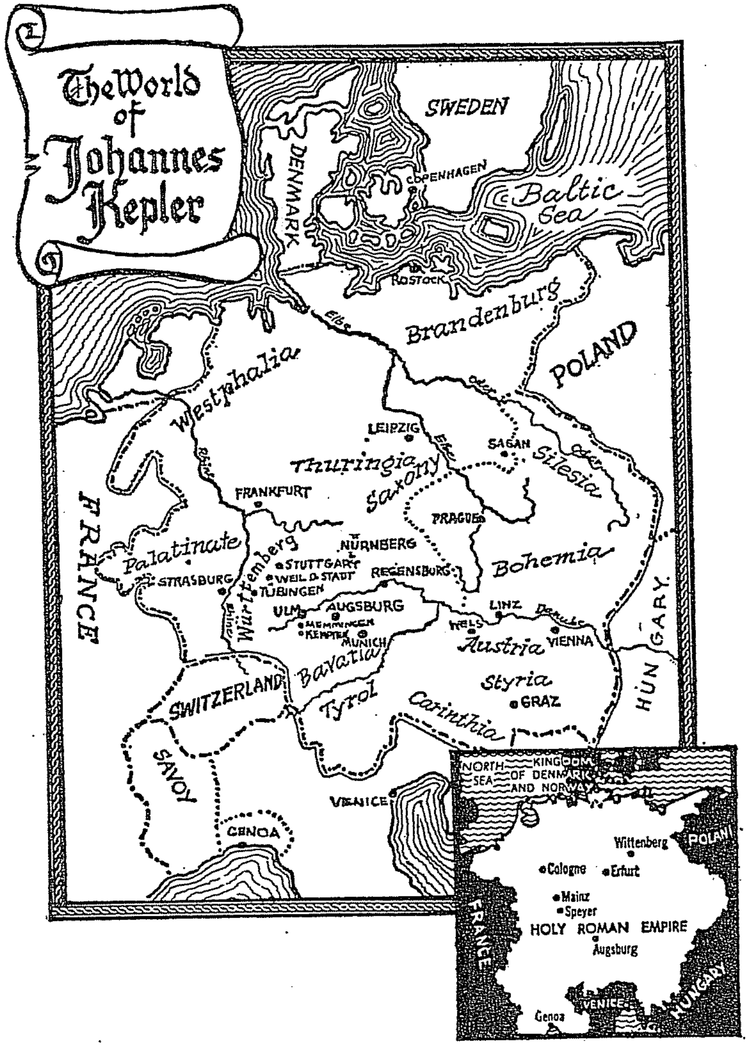

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Boyhood in Swabia and Early Schooling

DESPITE the hard life that lay ahead of him, Johannes Kepler was born at a time when Europe was awakening to new thoughts and ideas. In almost every country, great men were emerging whose contributions to culture would enrich the whole world. There was Galileo in Italy, Shakespeare and Harvey in England, Descartes in France, Cervantes in Spain, Rembrandt in Holland and many more.

Germany's contribution to this memorable list was the name of Johannes Kepler.

Born on December 27, 1571, in Weil der Stadt, a free city under the Holy Roman Empire in the southern section of Germany known as Swabia, Johannes came from a long line of Keplers who had seen better days.

In former times, the name Kepler—sometimes it was spelled "Keppler," "Kepner," or "Köpler"—had been borne by courageous medieval knights, titled noblemen and prominent businessmen. But this proud family, which had once boasted an elaborate coat of arms, had been forced by financial need to enter the craftsman's class in the early sixteenth century. This was indeed unfortunate, for had the family been able to hold on to their wealth and position, Johannes might have had a better chance to accomplish his great work in peace and security.

Yet even though the Keplers had become craftsmen, several of them still displayed the fire and ambition that had

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David C. Knight

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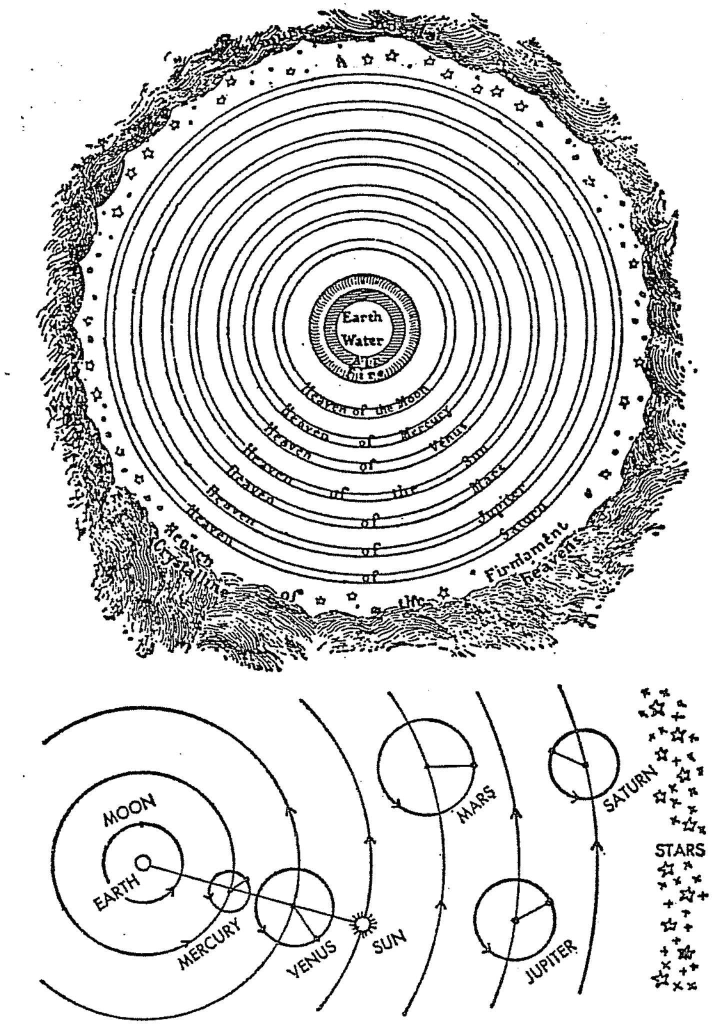
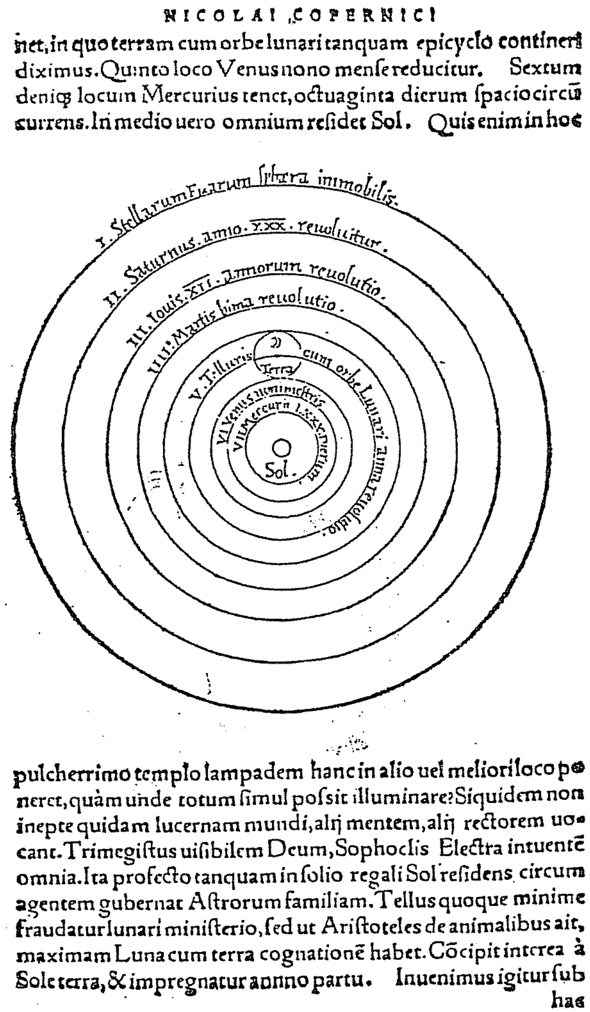
Johannes Kepler (1571 - 1630)



The Ptolemaic Universe

Above, an overall view of how Ptolemy conceived of the universe. The earth—a sphere—was set in the centre of the heavens, with the sun and planets revolving around it. Below, a close-up view showing the secondary motion of the planets. Each planet was supposed to move in its epicycle, *a small circle whose centre in turn travelled along a larger circle, the* deferent.



NICOLAI COPERNICI

net, in quo terram cum orbe lunari tanquam epicyclo contineri diximus. Quinto loco Venus nono mense reducitur. Sextum denique locum Mercurius tenet, octuaginta dierum spacio circũ currens. In medio uero omnium residet Sol. Quis enim in hoc

pulcherrimo templo lampadem hanc in alio uel meliori loco poneret, quàm unde totum simul possit illuminare? Siquidem non inepte quidam lucernam mundi, alij mentem, alij rectorem uocant. Trimegistus uisibilem Deum, Sophoclis Electra intuentẽ omnia. Ita profecto tanquam in solio regali Sol residens circum agentem gubernat Astrorum familiam. Tellus quoque minime fraudatur lunari ministerio, sed ut Aristoteles de animalibus ait, maximam Luna cum terra cognationẽ habet. Cõcipit interea à Sole terra, & impregnatur annuo partu. Inuenimus igitur sub has

The Copernican Universe

This is Copernicus' heliocentric system as reproduced from a page of his famous De Revolutionibus Orbium Celestium *("On the Revolutions of the Heavenly Bodies"). Upsetting the belief of centuries that the earth was the fixed centre of the universe, Copernicus placed the sun at the centre. This disturbed men greatly, for the earth was no longer the centre of all things. It was simply another planet orbiting the sun.*

planets were based on the circle. This belief went back to the old Greek philosophical tradition that considered a circle and a sphere (many circles) to be "perfect figures." Now, according to Euclid's geometry, there are only five solid figures that are "perfect," or *regular*. By a "regular" solid is meant one with all its faces, edges, and angles absolutely alike.

The five regular solids are these: the octahedron (an 8-sided figure); the icosahedron (a 20-sided figure); the dodecahedron (a 12-sided figure); the tetrahedron (a 4-sided figure); and the cube (a 6-sided figure). The sphere itself is not considered a regular solid since it has only one "side" or "face."

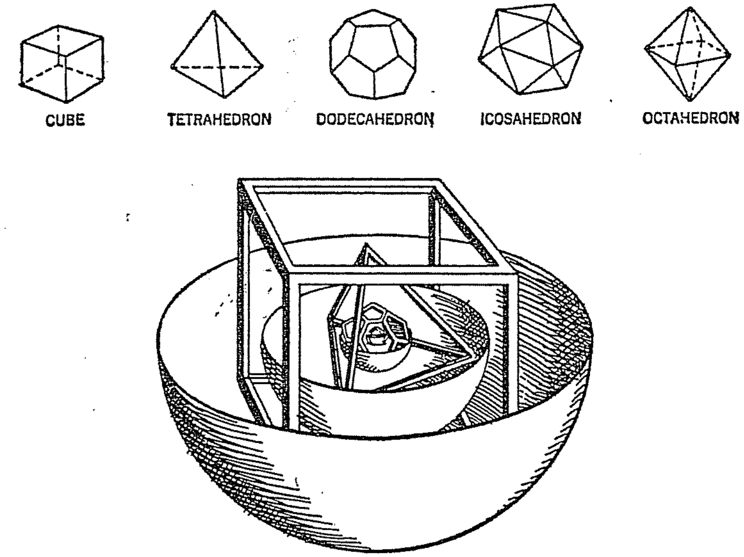
Kepler was now beside himself with excitement. Eagerly, he began to apply these five regular solids to the Copernican planetary system.

Kepler began with his own planet—the earth. He represented the earth's orbit by a sphere "as the norm and measure of all." Around this sphere, Kepler circumscribed a dodecahedron and put another sphere around it—which was approximately the orbit of Mars! Around this sphere in turn, Kepler circumscribed a tetrahedron, the corners of which roughly marked the sphere of the orbit of Jupiter. Again, around this new sphere, he circumscribed a cube, whose corners touched the sphere of the orbit of Saturn.

Now, working inward toward the sun, he inscribed in the sphere of the earth's orbit an icosahedron, the corners of which touched the orbit of the planet Venus. Lastly, inside Venus' orbit, Kepler inscribed an octahedron, whose corners roughly marked out the spherical orbit of Mercury.

Here, Kepler believed, was the reason for there being just six planets—no more and no fewer. Euclid had shown centuries ago that there could be only five regular solids. And this number corresponded exactly to the *gaps* that existed between the orbits of the six planets.

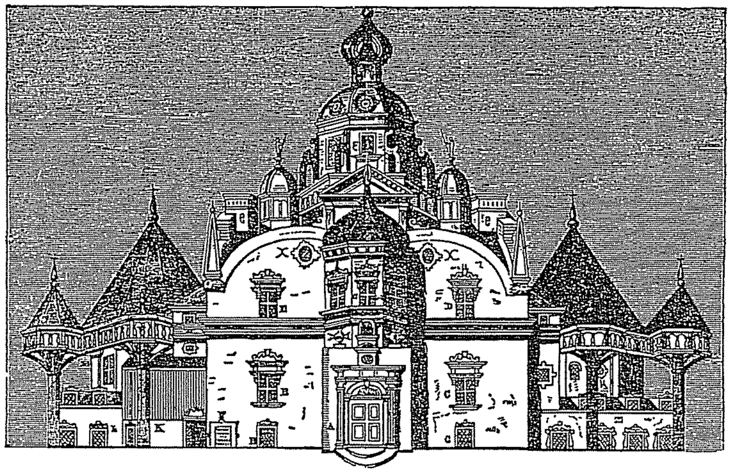
Today we realize that Kepler's ingenious theory was an accidental and untrue one. For one thing, there are nine known planets—not six. For another, their real orbital dis-



Framework model showing the five regular Euclidean solids as Kepler thought them to be among the planetary orbits. To Kepler, the arrangement provided a clue to the divine structure of the universe. Above, the five regular solids. Below, the solids as applied to the planetary orbits. The solids were supposed to fit between the spheres in the following order: Saturn, cube, *Jupiter,* tetrahedron, *Mars,* dodecahedron, *Earth,* icosahedron, *Venus,* octahedron, *Mercury.*

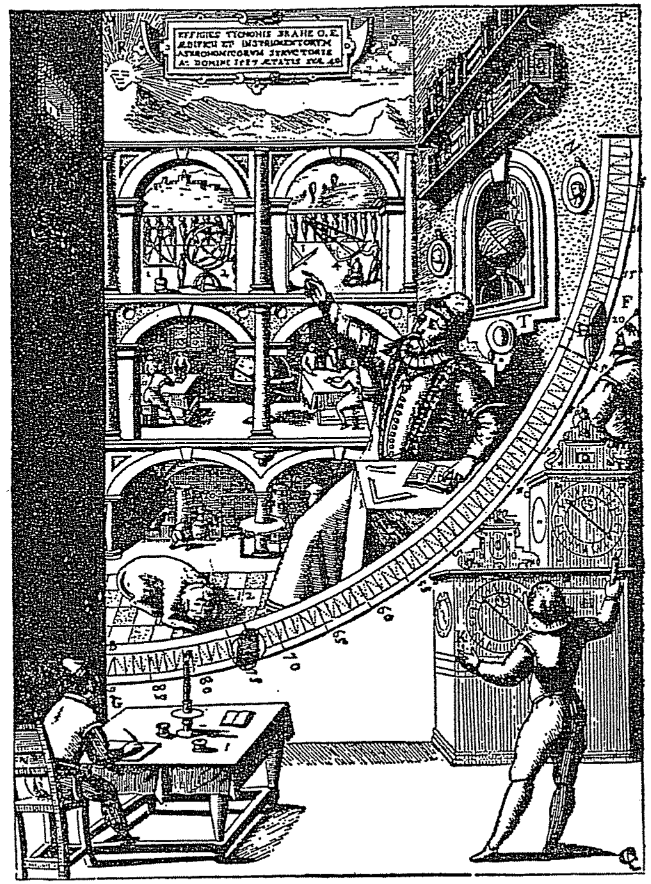
tances agree only very approximately with Kepler's theory. Moreover, the orbits of the planets were later proved by Kepler himself to be not spherical at all, but elliptical.

Young Kepler, however, in the year 1595, believed that God had allowed to be revealed to him one of the fundamen-

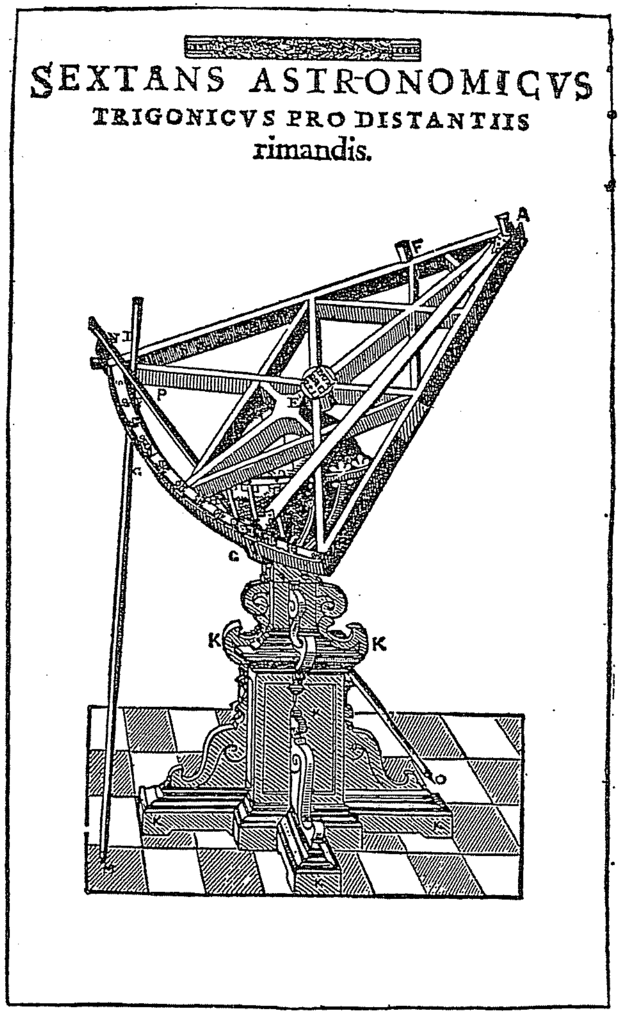


Tycho Brahe's famous "Uraniborg" on the island of Hven, twenty miles north of Copenhagen. Tycho laboured here for twenty years making his astonishingly accurate observations of the heavens. Uraniborg was a completely self-sufficient city within itself. Shown here is the façade of the castle proper; outside lay sumptuous grounds and gardens, the four observatories, and other buildings.

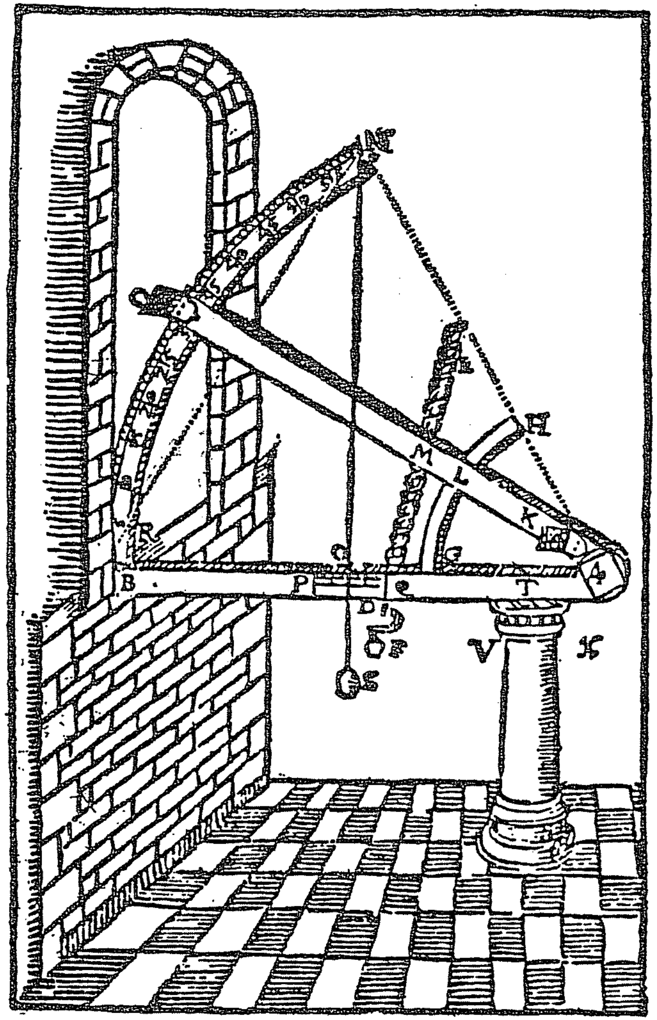
QVADRANS MVRALIS
SIVE TICHONICUS.



Hven, 1587. An old engraving showing the 40-year-old Tycho sitting in his observatory. Brahe is pointing to a slit in the wall as one of his assistants (at F) takes a sighting through it with the large quadrant. Other assistants in the background are taking observations on different levels of the observatory. Assistant at lower left is writing down the observed data.



The large sextant used by Tycho for measuring angular distances between two celestial bodies by direct sighting.



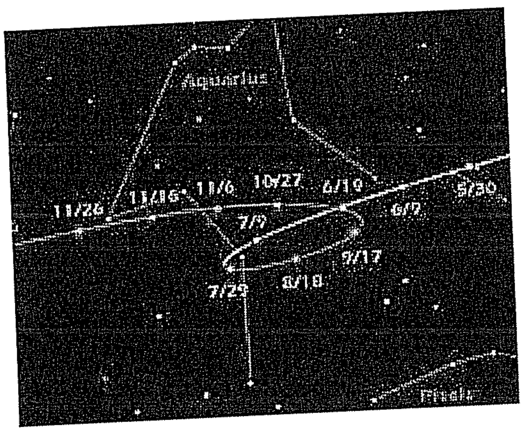
An instrument devised by Tycho Brahe for measuring the celestial altitudes of heavenly bodies. While the lower arm was fastened at the horizontal, the upper arm could be raised by means of a screw, directing the sights toward the celestial object. Then the altitude in degrees could be read off the calibrated scale.

Mars Retrograde

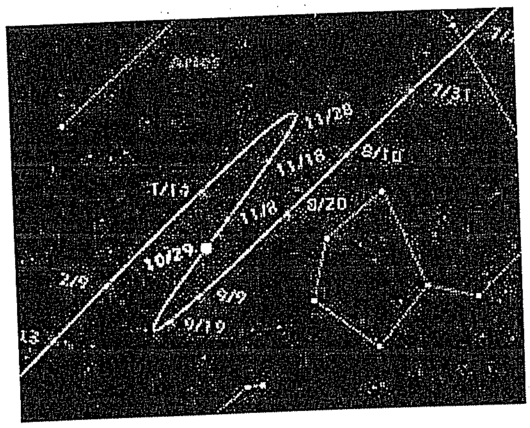
Want to watch Mars in retrograde from your backyard?
Find out where and when Mars will appear in the night sky.

If you were to look up in the eastern sky at the same time each night and note where Mars appears to be compared to the constellations of stars, you would find the planet a little farther east with each viewing. That is, Mars appears to move from west to east from one night to the next.

2003 Retrograde



2005 Retrograde



These apparent patterns caused by retrograde motion do not occur each evening. The patterns would appear if you charted Mars' position in our night sky over several months' time (during retrograde). Image Credit: NASA/JPL-Caltech

See the 2003 Mars Retrograde Animation

But every two years or so, there are a couple of months when Mars' position from night to night seems to change direction and move east to west. This strange behavior was very puzzling to early skywatchers. Did the planet really stop, back up, change its mind, and then continue to move forward? Did it have some weird, mystical meaning?

Today we know what's going on. It's an illusion, caused by the ways that Earth and Mars orbit the sun.

The two planets are like race cars on an oval track. Earth has the inside lane and moves faster than Mars -- so much faster, in fact, that it makes two laps around the course in about as much time as it takes Mars to go around once. That's why, this fall, we will be celebrating the first full martian year that NASA's Mars Exploration Rovers Spirit and Oppportunity have spent on the red planet, even though they landed nearly two Earth years ago.

About every 26 months, Earth comes up from behind and overtakes Mars. While we're passing by the red planet this year, it will look to us as though Mars is moving up and down. Then, as we move farther along our curved orbit and see the planet from a different angle, the illusion will disappear and we will once again see Mars move in a straight line.

This apparent erratic movement is called "retrograde motion." The illusion also happens with Jupiter and the other planets that orbit farther from the sun.

Just to make things a little more odd, the orbits that Earth and Mars follow don't quite lie in the same plane. It's as if the two planets were on separate tracks that are a little tilted with respect to each other. This causes another strange illusion.

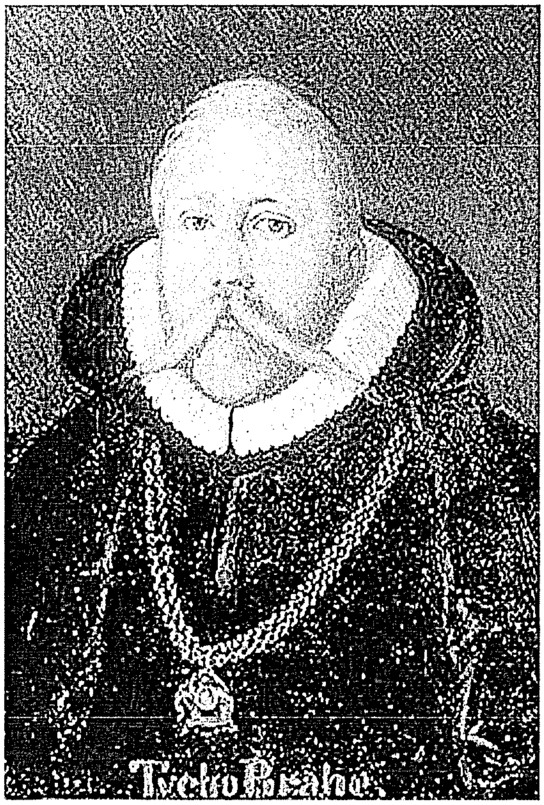
Suppose you were to draw a dot on a sky map each night to show where Mars appears as it moves forward, goes through retrograde, and then resumes its forward motion. Connect the dots, and you'll draw either a loop or an open zigzag. The pattern depends on where Earth and Mars happen to be in their tilted racetrack orbits.

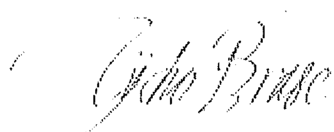
This year's martian retrograde runs from October 1 to December 9, and forms an open zigzag. Even though 2003 saw the closest approach in 60,000 years, this fall Mars will appear higher in our sky and brighter than two years ago. This is due to the tilt of the planets and the corresponding seasons. In 2003, the closest approach occurred in August - Earth's summer. The red planet was lower in Earth's sky (closer to the horizon) and, therefore, our view of it was dulled a bit by our own thick atmosphere. This year, closest approach will occur at the end of October - Earth's fall. With Mars higher in our night sky (without any atmospheric interference), it will appear clearer and crisper to sky watchers.

Tycho Brahe

From Wikipedia, the free encyclopedia

Tycho Ottesen Brahe

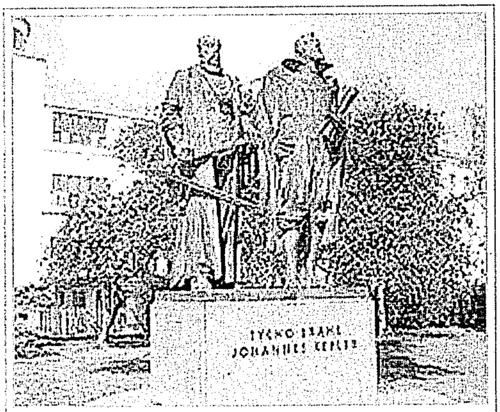


Born	14 December 1546 Knutstorp Castle, Scania, Denmark, Denmark–Norway
Died	24 October 1601 (aged 54) Prague, Holy Roman Empire
Nationality	Danish
Education	Private
Occupation	Nobleman, Astronomer
Religion	Lutheran
Spouse	Kirsten Barbara Jørgensdatter
Children	8
Parents	Otte Brahe and Beate Bille
Signature	

Tycho Brahe (14 December 1546 – 24 October 1601), born **Tyge Ottesen Brahe,**[1][2][3][4] was a Danish nobleman known for his accurate and comprehensive astronomical and planetary observations. Coming from Scania, then part of Denmark, now part of modern-day Sweden, Tycho was well known in his lifetime as an astronomer and alchemist.

In his *De nova stella* (On the new star) of 1573, he refuted the Aristotelian belief in an unchanging celestial realm. His precise measurements indicated that "new stars" (novae or also now known as supernovae), in particular that of 1572, lacked the parallax expected in sub-lunar phenomena, and were therefore not "atmospheric" tail-less comets as previously believed, but occurred above the atmosphere and moon. Using similar measurements he showed that comets were also not atmospheric phenomena, as previously thought, and must pass through the supposed "immutable" celestial spheres.[5]

Tycho Brahe was granted an estate on the island of Hven and the funding to build the Uraniborg, an early research institute, where he built large astronomical instruments and took many careful measurements, and later Stjerneborg, underground, when he discovered that his instruments in the former were not sufficiently steady. Something of an autocrat on the island he nevertheless founded manufactories such as paper-making to provide material for printing his results. After disagreements with the new Danish king in 1597, he was invited by the Bohemian king and Holy Roman emperor Rudolph II to Prague, where he became the official imperial astronomer. He built the new observatory at Benátky nad Jizerou. Here, from 1600 until his death in 1601, he was assisted by Johannes Kepler. Kepler later used Tycho's astronomical results to develop his own theories of astronomy.



Monument of Tycho Brahe and Johannes Kepler in Prague

As an astronomer, Tycho worked to combine what he saw as the geometrical benefits of the Copernican system with the philosophical benefits of the Ptolemaic system into his own model of the universe, the Tychonic system. Furthermore, he was the last of the major naked eye astronomers, working without telescopes for his observations.

Tycho is credited with the most accurate astronomical observations of his time, and the data was used by his assistant, Johannes Kepler, to derive the laws of planetary motion.

Contents

Life

Early years

Tycho was born at his family's ancestral seat of Knutstorp Castle (Danish: *Knudstrup borg*; Swedish: *Knutstorps borg*),[6] about eight kilometres north of Svalöv in then Danish Scania, now Swedish, to Otte Brahe (of the Brahe family) and Beate Bille (of the Bille family)). His twin brother died before being baptized. Tycho wrote a Latin ode to his dead twin,[7] which was printed in 1572 as his first published work. He also had two sisters, one older (Kirstine Brahe) and one younger (Sophia Brahe).

Otte Brahe, Tycho's father, was a nobleman and an important figure at the court of the Danish king. His mother, Beate Bille, came from an important family that had produced leading churchmen and politicians. Both parents are buried under the floor of Kågeröd Church, four kilometres east of Knutstorp. An epitaph, originally from Knutstorp, but now on a plaque near the church door, shows the whole family, including Tycho as a boy.

Tycho later wrote that when he was around age two, his uncle, Danish nobleman Jørgen Thygesen Brahe, "without the knowledge of my parents took me away with him while I was in my earliest youth to become a scholar". Apparently, this did not lead to dispute, nor did his parents attempt to get him back. According to one source,[8] Tycho's parents had promised to hand over a boy child to Jørgen and his wife, who were childless, but had not honoured this promise. Jørgen seems to have taken matters into his own hands and took the child away to his own residence, Tosterup Castle.

Tycho attended Latin school from ages 6 to 12, but the name of the school is not known. It is also thought he may have been taught by a private tutor between these ages. At age 12, on 19 April 1559, Tycho began studies at the University of Copenhagen. There, following his uncle's wishes, he studied law, but also studied a variety of other subjects and became interested in astronomy. The solar eclipse of 21 August 1560, especially the fact that it had been predicted,[9] so impressed him that he began to make his own studies of astronomy, helped by some of the professors. He purchased an ephemeris and books on astronomy, including Johannes de Sacrobosco's *De sphaera mundi*, Petrus Apianus's *Cosmographia seu descriptio totius orbis* and Regiomontanus's *De triangulis omnimodis*. Jørgen Thygesen Brahe, however, wanted Tycho to educate himself in order to become a civil servant, and sent him on a study tour of Europe in early 1562. Tycho was given the 19-year-old Anders Sørensen Vedel as mentor, whom he eventually talked into allowing the pursuit of astronomy during the tour.[10]

Tycho realized that progress in astronomy required systematic, rigorous observation, night after night, using the most accurate instruments obtainable. This program became his life's work. Tycho improved and enlarged existing instruments, and built entirely new ones. His sister Sophia assisted Tycho in many of his measurements. Tycho was the last major astronomer to work without the aid of telescope, soon to be turned skyward by Galileo and others.

Tycho jealously guarded his large body of celestial measurements, which Kepler took under his care following Tycho's death.[11]

Tycho's nose

While studying at University of Rostock in Germany, on 29 December 1566 Tycho lost part of his nose in a sword duel against fellow Danish nobleman (and his third cousin), Manderup Parsberg.[12][13] Tycho had earlier quarrelled with Parsbjerg over the legitimacy of a mathematic formula, at a wedding dance at professor Lucas Bachmeister's house on the 10th, and again on the 27th. Since neither had the resources to prove the other wrong, they ended up resolving the issue with a duel.[14] The duel two days later (in the dark) resulted in Tycho losing the bridge of his nose.[13] From this event Tycho became interested in medicine and alchemy.[12] For the rest of his life, he was said to have worn a replacement made of silver and gold,[12] using a paste or glue to keep it attached.[13] Some people, such as Fredric Ihren and Cecil Adams have suggested that the false nose also had copper. Ihren wrote that when Tycho's tomb was opened in 24 June 1901 green marks were found on his skull, suggesting copper.[13] Cecil Adams also mentions a green colouring and that medical experts examined the remains.[15] Some historians have speculated that he wore a number of different prosthetics for different occasions, noting that a copper nose would have been more comfortable and less heavy than a precious metal one.[2]

Death of his uncle

His uncle and foster father, Jørgen Brahe, died in 1565 of pneumonia after rescuing Frederick II of Denmark from drowning. In April 1567, Tycho returned home from his travels and his father wanted him to take up law, but Tycho was allowed to make trips to Rostock, then on to Augsburg (where he built a great quadrant), Basel, and Freiburg. At the end of 1570 he was informed about his father's ill health, so he returned to Knutstorp Castle, where his father died on 9 May 1571.[ ] Soon after, his other uncle, Steen Bille, helped him build an observatory and alchemical laboratory at Herrevad Abbey.[12]

Family life

Towards the end of 1571, Tycho fell in love with Kirsten, daughter of Jørgen Hansen, the Lutheran minister in Knudstrup.[16] She was a commoner, and Tycho never formally married her. However, under Danish law, when a nobleman and a common woman lived together openly as husband and wife, and she wore the keys to the household at her belt like any true wife, their alliance became a binding morganatic marriage after three years. The husband retained his noble status and privileges; the wife remained a commoner. Their children were legitimate in the eyes of the law, but they were commoners like their mother and could not inherit their father's name, coat of arms, or landholdings.[17] However, Kirsten and Tycho's children were later testified as legitimate by Tycho's younger sister, Sophie.

Kirsten Jørgensdatter gave birth to their first daughter, Kirstine (named after Tycho's late sister, who died at 13) on October 12, 1573. Together they had eight children, six of whom lived to adulthood. In 1574, they moved to Copenhagen where their daughter Magdalene was born. Kirsten and Tycho lived together for almost thirty years until Tycho's death.

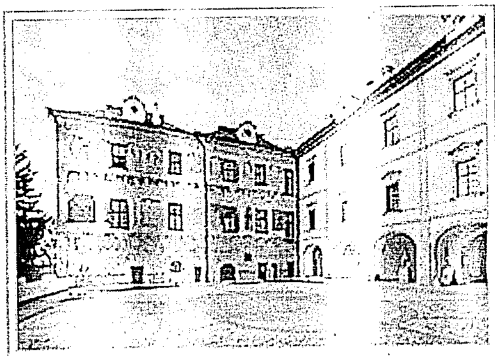
Coordinates: 50°17′22″N 14°49′52″E

Benátky nad Jizerou

From Wikipedia, the free encyclopedia

Benátky nad Jizerou (Czech pronunciation: [ˈbɛnaːtkɪ ˈnadjɪzɛrou̯]; German: *Benatek*) is a town on the Jizera river in the Central Bohemian Region of the Czech Republic, between the cities Stará Boleslav and Mladá Boleslav.

The city was the site of a castle and observatory built by astronomer Tycho Brahe.



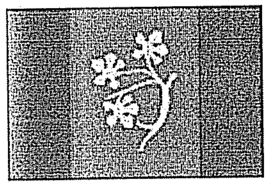
Benátky Castle

External links

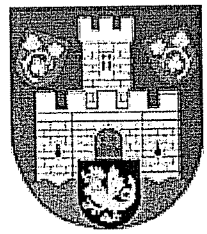
- Municipal website (in Czech) (http://www.benatky.cz/)
- Town castle (in German) (http://www.bra apamatek.cz/d-vypis.php?login benatkynj)

Retrieved from "http://en.wikipedia.org/w/index.php?

Benátky nad Jizerou
Town

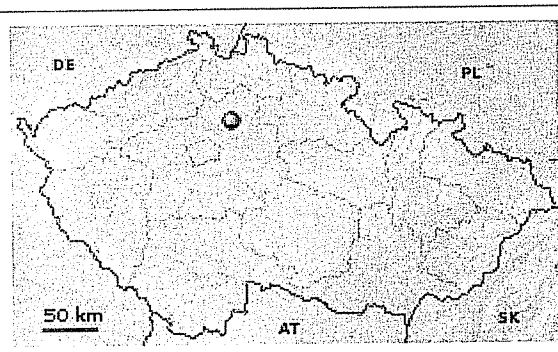


Flag



Coat of arms

Country	Czech Republic
Region	Central Bohemian
District	Mladá Boleslav
Commune	Mladá Boleslav
Municipality	**Benátky nad Jizerou**
River	Jizera
Elevation	225 m (738 ft)
Coordinates	50°17′22″N 14°49′52″E
Area	35.46 km^2 (13.69 sq mi)
Population	7,042 (*2006-10-02*)
Density	199 / km^2 (515 / sq mi)
First mentioned	1259
Mayor	Jaroslav Král
Timezone	CET (UTC+1)
- summer (DST)	CEST (UTC+2)
Postal code	293 01 - 294 71



Location in the Czech Republic

Wikimedia Commons: Benátky nad Jizerou

Statistics: statnisprava.cz

(http://www.statnisprava.cz/ebe/ciselniky.nsf/i/535451)
Website: www.benatky.cz (http://www.benatky.cz/)

title=Benátky_nad_Jizerou&oldid=497226210"
Categories: Populated places in Mladá Boleslav District
| Cities and towns in the Czech Republic | Mladá Boleslav District
| Mladá Boleslav geography stubs

Johannes Kepler

From Wikipedia, the free encyclopedia

Johannes Kepler (German pronunciation: ['kʰɛplɐ]; December 27, 1571 – November 15, 1630) was a German mathematician, astronomer and astrologer. A key figure in the 17th century scientific revolution, he is best known for his eponymous laws of planetary motion, codified by later astronomers, based on his works *Astronomia nova*, *Harmonices Mundi*, and *Epitome of Copernican Astronomy*. These works also provided one of the foundations for Isaac Newton's theory of universal gravitation.

During his career, Kepler was a mathematics teacher at a seminary school in Graz, Austria, where he became an associate of Prince Hans Ulrich von Eggenberg. Later he became an assistant to astronomer Tycho Brahe, and eventually the imperial mathematician to Emperor Rudolf II and his two successors Matthias and Ferdinand II. He was also a mathematics teacher in Linz, Austria, and an adviser to General Wallenstein. Additionally, he did fundamental work in the field of optics, invented an improved version of the refracting telescope (the Keplerian Telescope), and mentioned the telescopic discoveries of his contemporary Galileo Galilei.

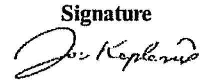
Kepler lived in an era when there was no clear distinction between astronomy and astrology, but there was a strong division between astronomy (a branch of mathematics within the liberal arts) and physics (a branch of natural philosophy). Kepler also incorporated religious arguments and reasoning into his work, motivated by the religious conviction and belief that God had created the world according to an intelligible plan that is accessible through the natural light of reason.[1] Kepler described his new astronomy as "celestial physics",[2] as "an excursion into Aristotle's *Metaphysics*",[3] and as "a supplement to Aristotle's *On the Heavens*",[4] transforming the ancient tradition of physical cosmology by treating astronomy as part of a universal mathematical physics.[5]

Johannes Kepler

A 1610 portrait of Johannes Kepler by an unknown artist

Born	December 27, 1571 Free Imperial City of Weil der Stadt near Stuttgart, HRE (now part of the Stuttgart Region of Baden-Württemberg, Germany)
Died	November 15, 1630 (aged 58) Regensburg, Electorate of Bavaria, HRE (now Germany)
Residence	Germany
Nationality	German
Fields	Astronomy, astrology, mathematics and natural philosophy
Institutions	University of Linz
Alma mater	University of Tübingen
Known for	Kepler's laws of planetary motion Kepler conjecture

Signature

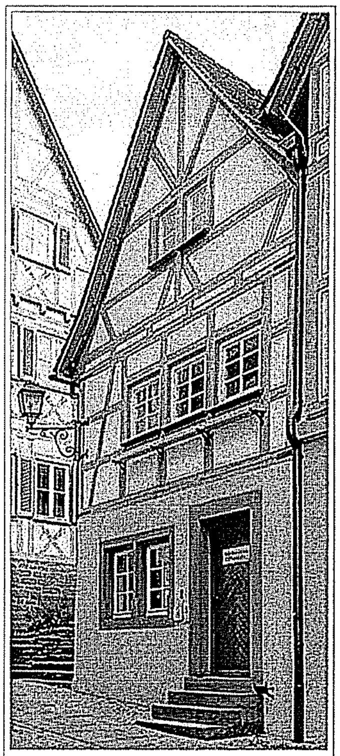


Contents

Early years

The Great Comet of 1577, which Kepler witnessed as a child, attracted the attention of astronomers across Europe.

Johannes Kepler was born on December 27, 1571, at the Free Imperial City of Weil der Stadt (now part of the Stuttgart Region in the German state of Baden-Württemberg, 30 km west of Stuttgart's center). His grandfather, Sebald Kepler, had been Lord Mayor of that town but, by the time Johannes was born, he had two brothers and one sister and the Kepler family fortune was in decline. His father, Heinrich Kepler, earned a precarious living as a mercenary, and he left the family when Johannes was five years old. He was believed to have died in the Eighty Years' War in the Netherlands. His mother Katharina Guldenmann, an inn-keeper's daughter, was a healer and herbalist who was later tried for witchcraft. Born prematurely, Johannes claimed to have been weak and sickly as a child. Nevertheless, he often impressed travelers at his grandfather's inn with his phenomenal mathematical faculty.[6]



Birthplace of Johannes Kepler in Weil der Stadt

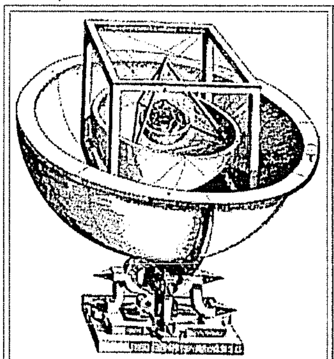
He was introduced to astronomy at an early age, and developed a love for it that would span his entire life. At age six, he observed the Great Comet of 1577, writing that he "was taken by [his] mother to a high place to look at it."[7] At age nine, he observed another astronomical event, a lunar eclipse in 1580, recording that he remembered being "called outdoors" to see it and that the moon "appeared quite red".[7] However, childhood smallpox left him with weak vision and crippled hands, limiting his ability in the observational aspects of astronomy.[8]

In 1589, after moving through grammar school, Latin school, and seminary at Maulbronn, Kepler attended Tübinger Stift at the University of Tübingen. There, he studied philosophy under Vitus Müller[9] and theology under Jacob Heerbrand (a student of Philipp Melanchthon at Wittenberg), who also taught Michael Maestlin while he was a student, until he became Chancellor at Tübingen in 1590.[10] He proved himself to be a superb mathematician and earned a reputation as a skillful astrologer, casting horoscopes for fellow students. Under the instruction of Michael Maestlin, Tübingen's professor of mathematics from 1583 to 1631,[10] he learned both the Ptolemaic system and the Copernican system of planetary motion. He became a Copernican at that time. In a student disputation, he defended heliocentrism from both a theoretical and theological perspective, maintaining that the Sun was the principal source of motive power in the universe.[11] Despite his desire to become a minister, near the end of his studies Kepler was recommended for a position as teacher of mathematics and astronomy at the Protestant school in Graz (later the University of Graz). He accepted the position in April 1594, at the age of 23.[12]

Graz (1594–1600)

Mysterium Cosmographicum

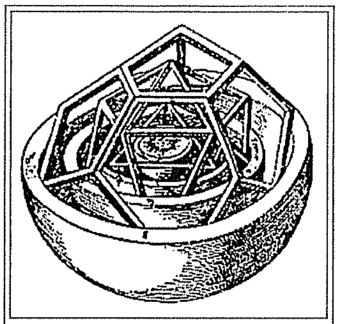
Johannes Kepler's first major astronomical work, *Mysterium Cosmographicum* (*The Cosmographic Mystery*), was the first published defense of the Copernican system. Kepler claimed to have had an epiphany on July 19, 1595, while teaching in Graz, demonstrating the periodic conjunction of Saturn and Jupiter in the zodiac; he realized that regular polygons bound one inscribed and one circumscribed circle at definite ratios, which, he reasoned, might be the geometrical basis of the universe. After failing to find a unique arrangement of polygons that fit known astronomical observations (even with extra planets added to the system), Kepler began experimenting with 3-dimensional polyhedra. He found that each of the five Platonic solids could be uniquely inscribed and circumscribed by spherical orbs; nesting these solids, each encased in a sphere, within one another would produce six layers, corresponding to the six known planets—Mercury, Venus, Earth, Mars, Jupiter, and Saturn. By ordering the solids correctly—octahedron, icosahedron, dodecahedron, tetrahedron, cube—Kepler found that the spheres could be placed at intervals corresponding (within the accuracy limits of available astronomical observations) to the relative sizes of each planet's path, assuming the planets circle the Sun. Kepler also found a formula relating the size of each planet's orb to the length of its orbital period: from inner to outer planets, the ratio of increase in orbital period is twice the difference in orb radius. However, Kepler later rejected this formula, because it was not precise enough.[13]



Kepler's Platonic solid model of the Solar system from *Mysterium Cosmographicum* (1600)

As he indicated in the title, Kepler thought he had revealed God's geometrical plan for the universe. Much of Kepler's enthusiasm for the Copernican system stemmed from his theological convictions about the connection between the physical and the spiritual; the universe itself was an image of God, with the Sun corresponding to the Father, the stellar sphere to the Son, and the intervening space between to the Holy Spirit. His first manuscript of *Mysterium* contained an extensive chapter reconciling heliocentrism with biblical passages that seemed to support geocentrism.[14]

With the support of his mentor Michael Maestlin, Kepler received permission from the Tübingen university senate to publish his manuscript, pending removal of the Bible exegesis and the addition of a simpler, more understandable description of the Copernican system as well as Kepler's new ideas. *Mysterium* was published late in 1596, and Kepler received his copies and began sending them to prominent astronomers and patrons early in 1597; it was not widely read, but it established Kepler's reputation as a highly skilled astronomer. The effusive dedication, to powerful patrons as well as to the men who controlled his position in Graz, also provided a crucial



Close-up of inner section of the model

doorway into the patronage system.[15]

Though the details would be modified in light of his later work, Kepler never relinquished the Platonist polyhedral-spherist cosmology of *Mysterium Cosmographicum.* His subsequent main astronomical works were in some sense only further developments of it, concerned with finding more precise inner and outer dimensions for the spheres by calculating the eccentricities of the planetary orbits within it. In 1621 Kepler published an expanded second edition of *Mysterium*, half as long again as the first, detailing in footnotes the corrections and improvements he had achieved in the 25 years since its first publication.[16]

In terms of the impact of *Mysterium*, it can be seen as an important first step in modernizing Copernicus' theory. There is no doubt that Copernicus' "De Revolutionibus" seeks to advance a sun-centered system, but in this book he had to resort to Ptolemaic devices (viz., epicycles and eccentric circles) in order to explain the change in planets' orbital speed. Furthermore, Copernicus continued to use as a point of reference the center of the earth's orbit rather than that of the sun, as he says, "as an aid to calculation and in order not to confuse the reader by diverging too much from Ptolemy." Therefore, although the thesis of the "Mysterium Cosmographicum" was in error, modern astronomy owes much to this work "since it represents the first step in cleansing the Copernican system of the remnants of the Ptolemaic theory still clinging to it." [17]

Marriage to Barbara Müller

In December 1595, Kepler was introduced to Barbara Müller, a 23-year-old widow (twice over) with a young daughter, Gemma van Dvijneveldt, and he began courting her. Müller, heiress to the estates of her late husbands, was also the daughter of a successful mill owner. Her father Jobst initially opposed a marriage despite Kepler's nobility; though he had inherited his grandfather's nobility, Kepler's poverty made him an unacceptable match. Jobst relented after Kepler completed work on *Mysterium*, but the engagement nearly fell apart while Kepler was away tending to the details of publication. However, church officials—who had helped set up the match—pressured the Müllers to honor their agreement. Barbara and Johannes were married on April 27, 1597.[18]

Portraits of Kepler and his wife in oval medallions

In the first years of their marriage, the Keplers had two children (Heinrich and Susanna), both of whom died in infancy. In 1602, they had a daughter (Susanna); in 1604, a son (Friedrich); and in 1607, another son (Ludwig).[19]

Other research

Following the publication of *Mysterium* and with the blessing of the Graz school inspectors, Kepler began an ambitious program to extend and elaborate his work. He planned four additional books: one on the stationary aspects of the universe (the Sun and the fixed stars); one on the planets and their motions; one on the physical nature of planets and the formation of geographical features (focused especially on Earth); and one on the effects of the heavens on the Earth, to include atmospheric optics, meteorology and astrology.[20]

He also sought the opinions of many of the astronomers to whom he had sent *Mysterium*, among them Reimarus Ursus (Nicolaus Reimers Bär)—the imperial mathematician to Rudolph II and a bitter rival of Tycho Brahe. Ursus did not reply directly, but republished Kepler's flattering letter to pursue his priority dispute over (what is now called) the Tychonic system with Tycho. Despite this black mark, Tycho also began corresponding with Kepler, starting with a harsh but legitimate critique of Kepler's system; among a host of objections, Tycho took issue with the use of inaccurate numerical data taken from Copernicus. Through their letters, Tycho and Kepler discussed a broad range of astronomical problems, dwelling on lunar phenomena and Copernican theory (particularly its theological viability). But without the significantly more accurate data of Tycho's observatory, Kepler had no way to address many of these issues.[21]

Instead, he turned his attention to chronology and "harmony," the numerological relationships among music, mathematics and the physical world, and their astrological consequences. By assuming the Earth to possess a soul (a property he would later invoke to explain how the sun causes the motion of planets), he established a speculative system connecting astrological aspects and astronomical distances to weather and other earthly phenomena. By 1599, however, he again felt his work limited by the inaccuracy of available data—just as growing religious tension was also threatening his continued employment in Graz. In December of that year, Tycho invited Kepler to visit him in Prague; on January 1, 1600 (before he even received the invitation), Kepler set off in the hopes that Tycho's patronage could solve his philosophical problems as well as his social and financial ones.[22] When he was an old man, he was allowed to continue his work in his home alone.

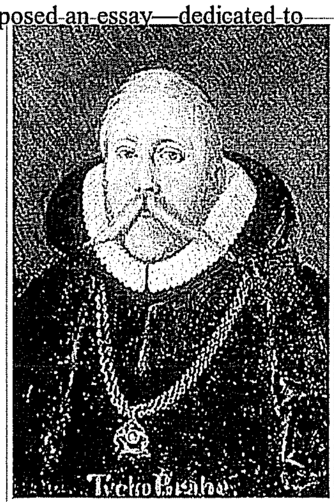
Prague (1600–1612)

Work for Tycho Brahe

On February 4, 1600, Kepler met Tycho Brahe and his assistants Franz Tengnagel and Longomontanus at Benátky nad Jizerou (35 km from Prague), the site where Tycho's new observatory was being constructed. Over the next two months he stayed as a guest, analyzing some of Tycho's observations of Mars; Tycho guarded his data closely, but was impressed by Kepler's theoretical ideas and soon allowed him more access. Kepler planned to test his theory[23] from *Mysterium Cosmographicum* based on the Mars data, but he estimated that the work would take up to two years (since he was not allowed to simply copy the data for his own use). With the help of Johannes

Jessenius, Kepler attempted to negotiate a more formal employment arrangement with Tycho, but negotiations broke down in an angry argument and Kepler left for Prague on April 6. Kepler and Tycho soon reconciled and eventually reached an agreement on salary and living arrangements, and in June, Kepler returned home to Graz to collect his family.[24]

Political and religious difficulties in Graz dashed his hopes of returning immediately to Tycho; in hopes of continuing his astronomical studies, Kepler sought an appointment as mathematician to Archduke Ferdinand. To that end, Kepler composed an essay—dedicated to Ferdinand—in which he proposed a force-based theory of lunar motion: "In Terra inest virtus, quae Lunam ciet" ("There is a force in the earth which causes the moon to move").[25] Though the essay did not earn him a place in Ferdinand's court, it did detail a new method for measuring lunar eclipses, which he applied during the July 10 eclipse in Graz. These observations formed the basis of his explorations of the laws of optics that would culminate in *Astronomiae Pars Optica*.[26]



Tycho Brahe

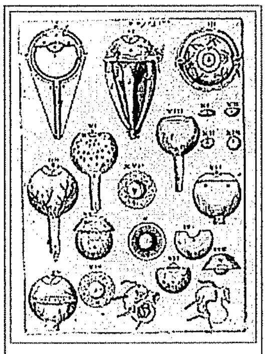
On August 2, 1600, after refusing to convert to Catholicism, Kepler and his family were banished from Graz. Several months later, Kepler returned, now with the rest of his household, to Prague. Through most of 1601, he was supported directly by Tycho, who assigned him to analyzing planetary observations and writing a tract against Tycho's (by then deceased) rival, Ursus. In September, Tycho secured him a commission as a collaborator on the new project he had proposed to the emperor: the *Rudolphine Tables* that should replace the *Prutenic Tables* of Erasmus Reinhold. Two days after Tycho's unexpected death on October 24, 1601, Kepler was appointed his successor as imperial mathematician with the responsibility to complete his unfinished work. The next 11 years as imperial mathematician would be the most productive of his life.[27]

Advisor to Emperor Rudolph II

Kepler's primary obligation as imperial mathematician was to provide astrological advice to the emperor. Though Kepler took a dim view of the attempts of contemporary astrologers to precisely predict the future or divine specific events, he had been casting well-received detailed horoscopes for friends, family and patrons since his time as a student in Tübingen. In addition to horoscopes for allies and foreign leaders, the emperor sought Kepler's advice in times of political trouble (though Kepler's recommendations were based more on common sense than the stars). Rudolph was actively interested in the work of many of his court scholars (including numerous alchemists) and kept up with Kepler's work in physical astronomy as well.[28]

Officially, the only acceptable religious doctrines in Prague were Catholic and Utraquist, but Kepler's position in the imperial court allowed him to practice his Lutheran faith unhindered. The emperor nominally provided an ample income for his family, but the difficulties of the over-extended imperial treasury meant that actually getting hold of enough money to meet financial obligations was a continual struggle. Partly because of financial troubles, his life at home with Barbara was unpleasant, marred with bickering and bouts of sickness. Court life, however, brought Kepler into contact with other prominent scholars (Johannes Matthäus Wackher von Wackhenfels, Jost Bürgi, David Fabricius, Martin Bachazek, and Johannes Brengger, among others) and astronomical work proceeded rapidly.[29]

Astronomiae Pars Optica


A plate from *Astronomiae Pars Optica*, illustrating the structure of eyes

As he slowly continued analyzing Tycho's Mars observations—now available to him in their entirety—and began the slow process of tabulating the *Rudolphine Tables*, Kepler also picked up the investigation of the laws of optics from his lunar essay of 1600. Both lunar and solar eclipses presented unexplained phenomena, such as unexpected shadow sizes, the red color of a total lunar eclipse, and the reportedly unusual light surrounding a total solar eclipse. Related issues of atmospheric refraction applied to *all* astronomical observations. Through most of 1603, Kepler paused his other work to focus on optical theory; the resulting manuscript, presented to the emperor on January 1, 1604, was published as *Astronomiae Pars Optica* (*The Optical Part of Astronomy*). In it, Kepler described the inverse-square law governing the intensity of light, reflection by flat and curved mirrors, and principles of pinhole cameras, as well as the astronomical implications of optics such as parallax and the apparent sizes of heavenly bodies. He also extended his study of optics to the human eye, and is generally considered by neuroscientists to be the first to recognize that images are projected inverted and reversed by the eye's lens onto the retina. The solution to this dilemma was not of particular importance to Kepler as he did not see it as pertaining to optics, although he did suggest that the image was later corrected "in the hollows of the brain" due to the "activity of the Soul."[30] Today, *Astronomiae Pars Optica* is generally recognized as the foundation of modern optics (though the law of refraction is conspicuously absent).[31] With respect to the beginnings of projective geometry, Kepler introduced the idea of continuous change of a mathematical entity in this work. He argued that if a focus of a conic section were allowed to move along the line joining the foci, the geometric form would morph or degenerate, one into another. In this way, an ellipse becomes a parabola when a focus moves toward infinity, and when two foci of an ellipse merge into one another, a circle is formed. As the foci of a hyperbola merge into one another, the hyperbola becomes a pair of straight lines. He also assumed that if a straight line is extended to infinity it will meet itself at a single point at infinity, thus having the properties of a large circle.[32] This idea was later utilized by Pascal, Leibniz, Monge and Poncelet, among others, and became known as geometric continuity and as the Law or Principle of Continuity.

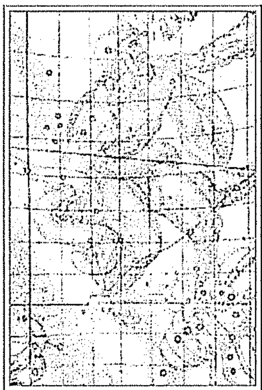
The Supernova of 1604

In October 1604, a bright new evening star (SN 1604) appeared, but Kepler did not believe the rumors until he saw it himself. Kepler began systematically observing the nebula. Astrologically, the end of 1603 marked the beginning of a fiery trigon, the start of the ca. 800-

year cycle of great conjunctions; astrologers associated the two previous such periods with the rise of Charlemagne (ca. 800 years earlier) and the birth of Christ (ca. 1600 years earlier), and thus expected events of great portent, especially regarding the emperor. It was in this context, as the imperial mathematician and astrologer to the emperor, that Kepler described the new star two years later in his *De Stella Nova*. In it, Kepler addressed the star's astronomical properties while taking a skeptical approach to the many astrological interpretations then circulating. He noted its fading luminosity, speculated about its origin, and used the lack of observed parallax to argue that it was in the sphere of fixed stars, further undermining the doctrine of the immutability of the heavens (the idea accepted since Aristotle that the celestial spheres were perfect and unchanging). The birth of a new star implied the variability of the heavens. In an appendix, Kepler also discussed the recent chronology work of the Polish historian Laurentius Suslyga; he calculated that, if Suslyga was correct that accepted timelines were four years behind, then the Star of Bethlehem—analogous to the present new star—would have coincided with the first great conjunction of the earlier 800-year cycle.[33]

Remnant of Kepler's Supernova SN 1604

Astronomia nova



The location of the *stella nova*, in the foot of Ophiuchus, is marked with an *N* (8 grid squares down, 4 over from the left).

The extended line of research that culminated in *Astronomia nova* (*A New Astronomy*)—including the first two laws of planetary motion—began with the analysis, under Tycho's direction, of Mars' orbit. Kepler calculated and recalculated various approximations of Mars' orbit using an equant (the mathematical tool that Copernicus had eliminated with his system), eventually creating a model that generally agreed with Tycho's observations to within two arcminutes (the average measurement error). But he was not satisfied with the complex and still slightly inaccurate result; at certain points the model differed from the data by up to eight arcminutes. The wide array of traditional mathematical astronomy methods having failed him, Kepler set about trying to fit an ovoid orbit to the data.[34]

Within Kepler's religious view of the cosmos, the Sun (a symbol of God the Father) was the source of motive force in the solar system. As a physical basis, Kepler drew by analogy on William Gilbert's theory of the magnetic soul of the Earth from *De Magnete* (1600) and on his own work on optics. Kepler supposed that the motive power (or motive *species*)[35] radiated by the Sun weakens with distance, causing faster or slower motion as planets move closer or farther from it.[36][37] Perhaps this assumption entailed a mathematical relationship that would restore astronomical order. Based on measurements of the aphelion and perihelion of the Earth and Mars, he created a formula in which a planet's rate of motion is inversely proportional to its distance from the Sun. Verifying this relationship throughout the orbital cycle, however, required very extensive calculation; to simplify this task, by late 1602 Kepler reformulated the proportion in terms of geometry: *planets sweep out equal areas in equal times*—Kepler's second law of planetary motion.[38]

He then set about calculating the entire orbit of Mars, using the geometrical rate law and assuming an egg-shaped ovoid orbit. After approximately 40 failed attempts, in early 1605 he at last hit upon the idea of an ellipse, which he had previously assumed to be too simple a solution for earlier astronomers to have overlooked. Finding that an elliptical orbit fit the Mars data, he immediately concluded that *all planets move in ellipses, with the sun at one focus*—Kepler's first law of planetary motion. Because he employed no calculating assistants, however, he did not extend the mathematical analysis beyond Mars. By the end of the year, he completed the manuscript for *Astronomia nova*, though it would not be published until 1609 due to legal disputes over the use of Tycho's observations, the property of his heirs.[39]

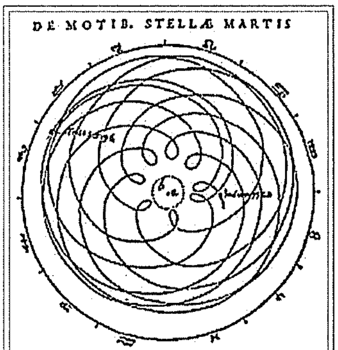


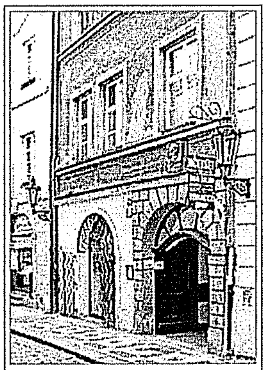
Diagram of the geocentric trajectory of Mars through several periods of apparent retrograde motion. *Astronomia nova*, Chapter 1, (1609).

Dioptrice, *Somnium* manuscript and other work

In the years following the completion of *Astronomia Nova*, most of Kepler's research was focused on preparations for the *Rudolphine Tables* and a comprehensive set of ephemerides (specific predictions of planet and star positions) based on the table (though neither would be completed for many years). He also attempted (unsuccessfully) to begin a collaboration with Italian astronomer Giovanni Antonio Magini. Some of his other work dealt with chronology, especially the dating of events in the life of Jesus, and with astrology, especially criticism of dramatic predictions of catastrophe such as those of Helisaeus Roeslin.[40]

Kepler and Roeslin engaged in series of published attacks and counter-attacks, while physician Philip Feselius published a work dismissing astrology altogether (and Roeslin's work in particular). In response to what Kepler saw as the excesses of astrology on the one hand and overzealous rejection of it on the other, Kepler prepared *Tertius Interveniens* (*Third-party Interventions*). Nominally this work—presented to the common patron of Roeslin and Feselius—was a neutral mediation between the feuding scholars, but it also set out Kepler's general views on the value of astrology, including some hypothesized mechanisms of interaction between planets and individual souls. While Kepler considered most traditional rules and methods of astrology to be the "evil-smelling dung" in which "an industrious hen" scrapes, there was an "occasional grain-seed, indeed, even a pearl or a gold nugget" to be found by the conscientious scientific astrologer.[41]

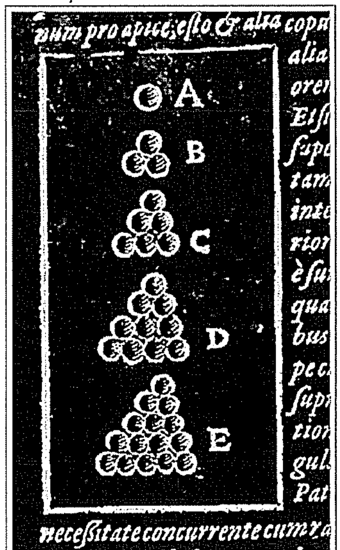
In the first months of 1610, Galileo Galilei—using his powerful new telescope—discovered four satellites orbiting Jupiter. Upon publishing his account as *Sidereus Nuncius* (*Starry Messenger*), Galileo sought the opinion of Kepler, in part to bolster the credibility of his observations. Kepler responded enthusiastically with a short published reply, *Dissertatio cum Nuncio Sidereo* (*Conversation with the Starry Messenger*). He endorsed Galileo's observations and offered a range of speculations about the meaning and implications of Galileo's discoveries and telescopic methods, for astronomy and optics as well as cosmology and astrology. Later that year, Kepler published his own telescopic observations of the moons in *Narratio de Jovis Satellitibus*, providing further support of Galileo. To Kepler's disappointment, however, Galileo never published his reactions (if any) to *Astronomia Nova*.:([42]



Karlova street in Old Town, Prague – house where Johannes Kepler lived. [1] (http://www.keplervpraze.cz Museum

After hearing of Galileo's telescopic discoveries, Kepler also started a theoretical and experimental investigation of telescopic optics using a telescope borrowed from Duke Ernest of Cologne.[43] The resulting manuscript was completed in September 1610 and published as *Dioptrice* in 1611. In it, Kepler set out the theoretical basis of double-convex converging lenses and double-concave diverging lenses—and how they are combined to produce a Galilean telescope—as well as the concepts of real vs. virtual images, upright vs. inverted images, and the effects of focal length on magnification and reduction. He also described an improved telescope—now known as the *astronomical* or *Keplerian telescope*—in which two convex lenses can produce higher magnification than Galileo's combination of convex and concave lenses.[44]

Around 1611, Kepler circulated a manuscript of what would eventually be published (posthumously) as *Somnium* (*The Dream*). Part of the purpose of *Somnium* was to describe what practicing astronomy would be like from the perspective of another planet, to show the feasibility of a non-geocentric system. The manuscript, which disappeared after changing hands several times, described a fantastic trip to the moon; it was part allegory, part autobiography, and part treatise on interplanetary travel (and is sometimes described as the first work of science fiction). Years later, a distorted version of the story may have instigated the witchcraft trial against his mother, as the mother of the narrator consults a demon to learn the means of space travel. Following her eventual acquittal, Kepler composed 223 footnotes to the story—several times longer than the actual text—which explained the allegorical aspects as well as the considerable scientific content (particularly regarding lunar geography) hidden within the text.[45]



One of the diagrams from *Strena Seu de Nive Sexangula*, illustrating the Kepler conjecture

Work in mathematics and physics

As a New Year's gift that year, he also composed for his friend and some-time patron Baron Wackher von Wackhenfels a short pamphlet entitled *Strena Seu de Nive Sexangula* (*A New Year's Gift of Hexagonal Snow*). In this treatise, he published the first description of the hexagonal symmetry of snowflakes and, extending the discussion into a hypothetical atomistic physical basis for the symmetry and posed what later became known as the Kepler conjecture, a statement about the most efficient arrangement for packing spheres.[46][47] Kepler was one of the pioneers of the mathematical applications of infinitesimals, see Law of Continuity.

Personal and political troubles

In 1611, the growing political-religious tension in Prague came to a head. Emperor Rudolph—whose health was failing—was forced to abdicate as King of Bohemia by his brother Matthias. Both sides sought Kepler's astrological advice, an opportunity he used to deliver conciliatory political advice (with little reference to the stars, except in general statements to discourage drastic action). However, it was clear that Kepler's future prospects in the court of Matthias were dim.[48]

Also in that year, Barbara Kepler contracted Hungarian spotted fever, then began having seizures. As Barbara was recovering, Kepler's three children all fell sick with smallpox; Friedrich, 6, died. Following his son's death, Kepler sent letters to potential patrons in Württemberg and Padua. At the University of Tübingen in Württemberg, concerns over Kepler's perceived Calvinist heresies in violation of the Augsburg Confession and the Formula of Concord prevented his return. The University of Padua—on the recommendation of the departing Galileo—sought Kepler to fill the mathematics professorship, but Kepler, preferring to keep his family in German territory, instead travelled to Austria to arrange a position as teacher and district mathematician in Linz. However, Barbara relapsed into illness and died shortly after Kepler's return.[49]

Kepler postponed the move to Linz and remained in Prague until Rudolph's death in early 1612, though between political upheaval, religious tension, and family tragedy (along with the legal dispute over his wife's estate), Kepler could do no research. Instead, he pieced together a chronology manuscript, *Eclogae Chronicae*, from correspondence and earlier work. Upon succession as Holy Roman Emperor, Matthias re-affirmed Kepler's position (and salary) as imperial mathematician but allowed him to move to Linz.[50]

Linz and elsewhere (1612–1630)

In Linz, Kepler's primary responsibilities (beyond completing the *Rudolphine Tables*) were teaching at the district school and providing astrological and astronomical services. In his first years there, he enjoyed financial security and religious freedom relative to his life in Prague—though he was excluded from Eucharist by his Lutheran church over his theological scruples. His first publication in Linz was *De vero Anno* (1613), an expanded treatise on the year of Christ's birth; he also participated in deliberations on whether to introduce Pope Gregory's reformed calendar to Protestant German lands; that year he also wrote the influential mathematical treatise *Nova stereometria doliorum vinariorum*, on measuring the volume of containers such as wine barrels, published in 1615.[51]

Second marriage

On October 30, 1613, Kepler married the 24-year-old Susanna Reuttinger. Following the death of his first wife Barbara, Kepler had considered 11 different matches. He eventually returned to Reuttinger (the fifth match) who, he wrote, "won me over with love, humble loyalty, economy of household, diligence, and the love she gave the stepchildren."[52] The first three children of this marriage (Margareta Regina, Katharina, and Sebald) died in childhood. Three more survived into adulthood: Cordula (b. 1621); Fridmar (b. 1623); and Hildebert (b. 1625). According to Kepler's biographers, this was a much happier marriage than his first.[53]

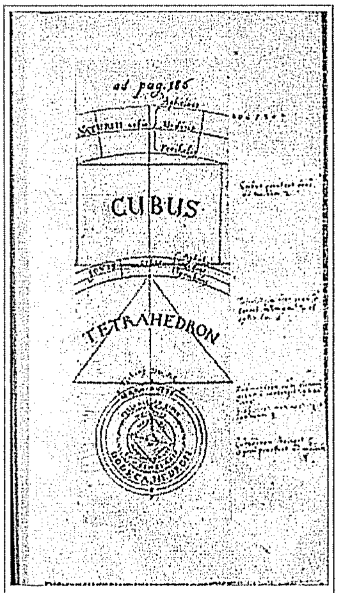

A statue of Kepler in Linz

Epitome of Copernican Astronomy, calendars and the witch trial of his mother

Since completing the *Astronomia nova*, Kepler had intended to compose an astronomy textbook.[54] In 1615, he completed the first of three volumes of *Epitome astronomiae Copernicanae* (*Epitome of Copernican Astronomy*); the first volume (books I-III) was printed in 1617, the second (book IV) in 1620, and the third (books V-VII) in 1621. Despite the title, which referred simply to heliocentrism, Kepler's textbook culminated in his own ellipse-based system. The *Epitome* became Kepler's most influential work. It contained all three laws of planetary motion and attempted to explain heavenly motions through physical causes.[55] Though it explicitly extended the first two laws of planetary motion (applied to Mars in *Astronomia nova*) to all the planets as well as the Moon and the Medicean satellites of Jupiter, it did not explain how elliptical orbits could be derived from observational data.[56]

As a spin-off from the *Rudolphine Tables* and the related *Ephemerides*, Kepler published astrological calendars, which were very popular and helped offset the costs of producing his other work—especially when support from the Imperial treasury was withheld. In his calendars—six between 1617 and 1624—Kepler forecast planetary positions and weather as well as political events; the latter were often cannily accurate, thanks to his keen grasp of contemporary political and theological tensions. By 1624, however, the escalation of those tensions and the ambiguity of the prophecies meant political trouble for Kepler himself; his final calendar was publicly burned in Graz.[57]

In 1615, Ursula Reingold, a woman in a financial dispute with Kepler's brother Christoph, claimed Kepler's mother Katharina had made her sick with an evil brew. The dispute escalated, and in 1617, Katharina was accused of witchcraft; witchcraft trials were relatively common in central Europe at this time. Beginning in August 1620 she was imprisoned for fourteen months. She was released in October 1621, thanks in part to the extensive legal defense drawn up by Kepler. The accusers had no stronger evidence than rumors, along with a distorted, second-hand version of Kepler's *Somnium*, in which a woman mixes potions and enlists the aid of a demon. Katharina was subjected to *territio verbalis*, a graphic description of the torture awaiting her as a witch, in a final attempt to make her confess. Throughout the trial, Kepler postponed his other work to focus on his "harmonic theory". The result, published in 1619, was *Harmonices Mundi* ("Harmony of the World").[58]



Geometrical harmonies in the perfect solids from *Harmonices Mundi* (1619)

Harmonices Mundi

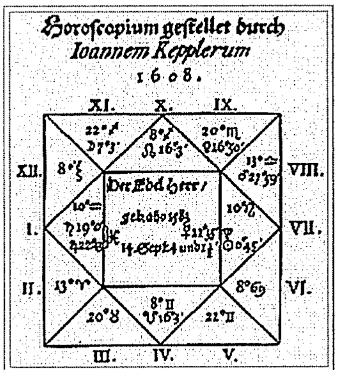
Main article: Harmonices Mundi

Kepler was convinced "that the geometrical things have provided the Creator with the model for decorating the whole world."[59] In *Harmony*, he attempted to explain the proportions of the natural world—particularly the astronomical and astrological aspects—in terms of music. The central set of "harmonies" was the *musica universalis* or "music of the spheres," which had been studied by Pythagoras, Ptolemy and many others before Kepler; in fact, soon after publishing *Harmonices Mundi*, Kepler was embroiled in a priority dispute with Robert Fludd, who had recently published his own harmonic theory.[60]

Kepler began by exploring regular polygons and regular solids, including the figures that would come to be known as Kepler's solids. From there, he extended his harmonic analysis to music, meteorology and astrology; harmony resulted from the tones made by the souls of heavenly bodies—and in the case of astrology, the interaction between those tones and human souls. In the final portion of the work (Book V), Kepler dealt with planetary motions, especially relationships between orbital velocity and orbital distance from the Sun. Similar relationships had been used by other astronomers, but Kepler—with Tycho's data and his own astronomical theories—treated them much more precisely and attached new physical significance to them.[61]

Among many other harmonies, Kepler articulated what came to be known as the third law of planetary motion. He then tried many combinations until he discovered that (approximately) "*The square of the periodic times are to each other as the cubes of the mean distances.*" Although he gives the date of this epiphany (March 8, 1618), he does not give any details about how he arrived at this conclusion.[62] However, the wider significance for planetary dynamics of this purely kinematical law was not realized until the 1660s. For when conjoined with Christian Huygens' newly discovered law of centrifugal force it enabled Isaac Newton, Edmund Halley and perhaps Christopher Wren and Robert Hooke to demonstrate independently that the presumed gravitational attraction between the Sun and its planets decreased with the square of the distance between them.[63] This refuted the traditional assumption of scholastic physics that the power of gravitational attraction remained constant with distance whenever it applied between two bodies, such as was assumed by Kepler and also by Galileo in his mistaken universal law that gravitational fall is uniformly accelerated, and also by Galileo's student Borrelli in his 1666 celestial mechanics.[64] William Gilbert, after experimenting with magnets decided that the center of the Earth was a huge magnet. His theory led Kepler to think that a magnetic force from the Sun drove planets in their own orbits. It was an interesting explanation for planetary motion, but it was wrong. Before scientists could find the right answer, they needed to know more about motion.

Rudolphine Tables and his last years



Kepler's horoscope for General Wallenstein

In 1623, Kepler at last completed the *Rudolphine Tables*, which at the time was considered his major work. However, due to the publishing requirements of the emperor and negotiations with Tycho Brahe's heir, it would not be printed until 1627. In the meantime religious tension—the root of the ongoing Thirty Years' War—once again put Kepler and his family in jeopardy. In 1625, agents of the Catholic Counter-Reformation placed most of Kepler's library under seal, and in 1626 the city of Linz was besieged. Kepler moved to Ulm, where he arranged for the printing of the *Tables* at his own expense.[65]

In 1628, following the military successes of the Emperor Ferdinand's armies under General Wallenstein, Kepler became an official advisor to Wallenstein. Though not the general's court astrologer per se, Kepler provided astronomical calculations for Wallenstein's astrologers and occasionally wrote horoscopes himself. In his final years, Kepler spent much of his time traveling, from the imperial court in Prague to Linz and Ulm to a temporary home in Sagan, and finally to Regensburg. Soon after arriving in Regensburg, Kepler fell ill. He died on November 15, 1630, and was buried there; his burial site was lost after the Swedish army destroyed the churchyard.[66] Only Kepler's self-authored poetic epitaph survived the times:

> *Mensus eram coelos, nunc terrae metior umbras*
> *Mens coelestis erat, corporis umbra iacet.*
>
> I measured the skies, now the shadows I measure
> Skybound was the mind, earthbound the body rests.[67]

Reception of his astronomy

Kepler's laws were not immediately accepted. Several major figures such as Galileo and René Descartes completely ignored Kepler's *Astronomia nova.* Many astronomers, including Kepler's teacher, Michael Maestlin, objected to Kepler's introduction of physics into his astronomy. Some adopted compromise positions. Ismael Boulliau accepted elliptical orbits but replaced Kepler's area law with uniform motion in respect to the empty focus of the ellipse while Seth Ward used an elliptical orbit with motions defined by an equant.[68][69][70]

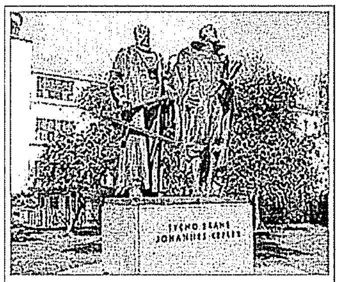
Several astronomers tested Kepler's theory, and its various modifications, against astronomical observations<the last one is/M.T.K Al - Tamimi/ Natural Science 2 (2010) 786-792>. Two transits of Venus and Mercury across the face of the sun provided sensitive tests of the theory, under circumstances when these planets could not normally be observed. In the case of the transit of Mercury in 1631, Kepler had been extremely uncertain of the parameters for Mercury, and advised observers to look for the transit the day before and after the predicted date. Pierre Gassendi observed the transit on the date predicted, a confirmation of Kepler's prediction.[71] This was the first observation of a transit of Mercury. However, his attempt to observe the transit of Venus just one month later, was unsuccessful due to inaccuracies in the Rudolphine Tables. Gassendi did not realize that it was not visible from most of Europe, including Paris.[72] Jeremiah Horrocks, who observed the 1639 Venus transit, had used his own observations to adjust the parameters of the Keplerian model, predicted the transit, and then built apparatus to observe the transit. He remained a firm advocate of the Keplerian model.[73][74][75]

Epitome of Copernican Astronomy was read by astronomers throughout Europe, and following Kepler's death it was the main vehicle for spreading Kepler's ideas. Between 1630 and 1650, it was the most widely used astronomy textbook, winning many converts to ellipse-based astronomy.[55] However, few adopted his ideas on the physical basis for celestial motions. In the late 17th century, a number of physical astronomy theories drawing from Kepler's work—notably those of Giovanni Alfonso Borelli and Robert Hooke—began to incorporate attractive forces (though not the quasi-spiritual motive species postulated by Kepler) and the Cartesian concept of inertia. This culminated in Isaac Newton's *Principia Mathematica* (1687), in which Newton derived Kepler's laws of planetary motion from a force-based theory of universal gravitation.[76]

Historical and cultural legacy

Beyond his role in the historical development of astronomy and natural philosophy, Kepler has loomed large in the philosophy and historiography of science. Kepler and his laws of motion were central to early histories of astronomy such as Jean Etienne Montucla's 1758 *Histoire des mathématiques* and Jean-Baptiste Delambre's 1821 *Histoire de l'astronomie moderne.* These and other histories written from an Enlightenment perspective treated Kepler's metaphysical and religious arguments with skepticism and disapproval, but later Romantic-era natural philosophers viewed these elements as central to his success. William Whewell, in his influential *History of the Inductive Sciences* of 1837, found Kepler to be the archetype of the inductive scientific genius; in his *Philosophy of the Inductive Sciences* of 1840, Whewell held Kepler up as the embodiment of the most advanced forms of scientific method. Similarly, Ernst Friedrich Apelt—the first to extensively study Kepler's manuscripts, after their purchase by Catherine the Great—identified Kepler as a key to the "Revolution of the sciences". Apelt, who saw Kepler's mathematics, aesthetic sensibility, physical ideas, and theology as part of a unified system of thought, produced the first extended analysis of Kepler's life and work.[77]

Modern translations of a number of Kepler's books appeared in the late-nineteenth and early-twentieth centuries, the systematic publication of his collected works began in 1937 (and is nearing completion in the early 21st century), and Max Caspar's Kepler biography was published in 1948.[78] However, Alexandre Koyré's work on Kepler was, after Apelt, the first major milestone in historical interpretations of Kepler's cosmology and its influence. In the 1930s and 1940s Koyré, and a number of others in the first generation of professional historians of science, described the "Scientific Revolution" as the central event in the history of science, and Kepler as a (perhaps the) central figure in the revolution. Koyré placed Kepler's theorization, rather than his empirical work, at the center of the intellectual transformation from ancient to modern world-views. Since the 1960s, the volume of historical Kepler scholarship has expanded greatly, including studies of his astrology and meteorology, his geometrical methods, the role of his religious views in his work, his literary and rhetorical methods, his interaction with the broader cultural and philosophical currents of his time, and even his role as an historian of science.[79]



Monument to Tycho Brahe and Johannes Kepler in Prague, Czech Republic

The debate over Kepler's place in the Scientific Revolution has also produced a wide variety of philosophical and popular treatments. One of the most influential is Arthur Koestler's 1959 *The Sleepwalkers*, in which Kepler is unambiguously the hero (morally and theologically as well as intellectually) of the revolution.[80] Influential philosophers of science—such as Charles Sanders Peirce, Norwood Russell Hanson, Stephen Toulmin, and Karl Popper—have repeatedly turned to Kepler: examples of incommensurability, analogical reasoning, falsification, and many other philosophical concepts have been found in Kepler's work. Physicist Wolfgang Pauli even used Kepler's priority dispute with Robert Fludd to explore the implications of analytical psychology on scientific investigation.[81] A well-received, if fanciful, historical novel by John Banville, *Kepler* (1981), explored many of the themes developed in Koestler's non-fiction narrative and in the philosophy of science.[82] Somewhat more fanciful is a recent work of nonfiction, *Heavenly Intrigue* (2004), suggesting that Kepler murdered Tycho Brahe to gain access to his data.[83] Kepler has acquired a popular image as an icon of scientific modernity and a man before his time; science popularizer Carl Sagan described him as "the first astrophysicist and the last scientific astrologer."[84]

10 euro Johannes Kepler silver coin

The GDR stamp featuring Johannes Kepler

The German composer Paul Hindemith wrote an opera about Kepler entitled *Die Harmonie der Welt*, and a symphony of the same name was derived from music for the opera.

In Austria, Johannes Kepler left behind such a historical legacy that he was one of the motifs of a silver collector's coin: the 10-euro Johannes Kepler silver coin, minted on September 10, 2002. The reverse side of the coin has a portrait of Kepler, who spent some time teaching in Graz and the surrounding areas. Kepler was acquainted with Prince Hans Ulrich von Eggenberg personally, and he probably influenced the construction of Eggenberg Castle (the motif of the obverse of the coin). In front of him on the coin is the model of nested spheres and polyhedra from *Mysterium Cosmographicum*.[85]

In 2009, NASA named the Kepler Mission for Kepler's contributions to the field of astronomy.[86]

In New Zealand's Fiordland National Park there is also a range of Mountains Named after Kepler, called the Kepler Mountains and a Three Day Walking Trail known as the Kepler Track through the Mountains of the same name.

Veneration

Kepler is honored together with Nicolaus Copernicus with a feast day on the liturgical calendar of the Episcopal Church (USA) on May 23.[87]

Works

- *Mysterium cosmographicum* (*The Sacred Mystery of the Cosmos*) (1596)
- *De Fundamentis Astrologiae Certioribus* On Firmer Fundaments of Astrology (http://www.johannes.cz/kepler.php) (1601)
- *Astronomiae Pars Optica* (*The Optical Part of Astronomy*) (1604)
- *De Stella nova in pede Serpentarii* (*On the New Star in Ophiuchus's Foot*) (1604)
- *Astronomia nova* (*New Astronomy*) (1609)
- *Tertius Interveniens* (*Third-party Interventions*) (1610)
- *Dissertatio cum Nuncio Sidereo* (*Conversation with the Starry Messenger*) (1610)
- *Dioptrice* (1611)

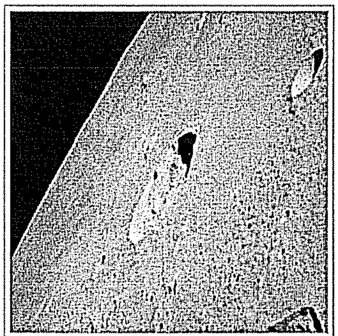
- *De nive sexangula* (*On the Six-Cornered Snowflake*) (1611)
- *De vero Anno, quo aeternus Dei Filius humanam naturam in Utero benedictae Virginis Mariae assumpsit* (1613)
- *Eclogae Chronicae* (1615, published with *Dissertatio cum Nuncio Sidereo*)
- *Nova stereometria doliorum vinariorum* (*New Stereometry of Wine Barrels*) (1615)
- *Epitome astronomiae Copernicanae* (*Epitome of Copernican Astronomy*) (published in three parts from 1618–1621)
- *Harmonice Mundi* (*Harmony of the Worlds*) (1619)
- *Mysterium cosmographicum* (*The Sacred Mystery of the Cosmos*) 2nd Edition (1621)

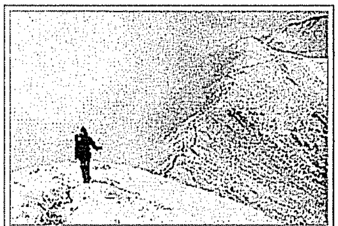
- *Tabulae Rudolphinae* (*Rudolphine Tables*) (1627)
- *Somnium* (*The Dream*) (1634)

See also

- History of astronomy
- History of physics
- Scientific revolution
- Kepler triangle
- Kepler problem
- Kepler-Bouwkamp constant

Named in his honor


The lunar crater Kepler


Kepler Track alpine ridgeline, New Zealand

- Kepler's laws of planetary motion for astronomical calculations
- The Kepler Mission, a space photometer designed to search for Earth-like planets launched by NASA on March 6, 2009
- The Johannes Kepler ATV, the second Automatic Transfer Vehicle (ATV) launched by ESA to resupply the ISS. The ATV launched in February 2011 and deorbited in June 2011.
- The Kepler Solids, a set of geometrical constructions, two of which were described by him
- The Kepler Mountains and the Kepler Track on the South Island of New Zealand
- Kepler's Star, Supernova 1604, which he observed and described
- Kepler, a crater on the moon
- Kepler, a crater on Mars
- 1134 Kepler, an asteroid
- Kepler, an opera by Philip Glass
- Die Harmonie der Welt, an opera by Paul Hindemith
- Johannes Kepler University Linz: In 1975, nine years after its founding, the College for Social and Economic Sciences Linz (Austria) was renamed Johannes Kepler University Linz in honor of Johannes Kepler, since he wrote his magnum opus *Harmonice Mundi* in Linz.
- Kepler College, Seattle, Washington
- Numerous schools, streets, observatories and others named after him, e.g.:
  - Kepler Gymnasium (high school), Tübingen
  - Keplerstraße in Hanau near Frankfurt am Main
  - Keplerstraße in Munich, Germany
  - Keplerstraße and Keplerbrücke in Graz, Austria
  - Keplerplatz, a station on the U1 line of the Vienna U-Bahn rapid transit (Metro) system
  - Johannes Kepler Grammar School,[88] at the site where Kepler lived in Prague
- Kepler Launch Site
- Kepler, a high end graphics processing unit currently being developed by Nvidia for their GeForce GPU series
- The Kepler Building, a satellite manufacturing plant for Surrey Satellite Technology Ltd, Surrey, UK.

Notes and references

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6. ^ Caspar. *Kepler*, pp. 29–36; Connor. *Kepler's Witch*, pp. 23–46.
7. ^ *a b* Koestler. *The Sleepwalkers*, p. 234 (translated from Kepler's family horoscope).
8. ^ Caspar. *Kepler*, pp. 36–38; Connor. *Kepler's Witch*, pp. 25–27.
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15. ^ Caspar. *Kepler*, pp.65–71.
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18. ^ Caspar, *Kepler*. pp.71–75.
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20. ^ Caspar. *Kepler*, pp.85–86.
21. ^ Caspar, *Kepler*, pp.86–89
22. ^ Caspar, *Kepler*, pp.89–100
23. ^ Using Tycho's data, see 'Two views of a system' (http://knol.google.com/k/the-sky-before-the-telescope#)

24. ^ Caspar, *Kepler*, pp. 100–08.
25. ^ Caspar, *Kepler*, p. 110.
26. ^ Caspar, *Kepler*, pp. 108–11.
27. ^ Caspar, *Kepler*, pp. 111–22.
28. ^ Caspar, *Kepler*, pp.149–153
29. ^ Caspar, *Kepler*, pp.146–148, 159–177
30. ^ Finger, "Origins of Neuroscience," p 74. Oxford University Press, 2001.
31. ^ Caspar, *Kepler*, pp.142–146
32. ^ Morris Kline, Mathematical Thought from Ancient to Modern Times, p 299. Oxford University Press, 1972.
33. ^ Caspar, *Kepler*, pp.153–157
34. ^ Caspar, *Kepler*, pp.123–128
35. ^ On motive species, see: Lindberg, "The Genesis of Kepler's Theory of Light," pp.38–40
36. ^ "Kepler's decision to base his causal explanation of planetary motion on a distance-velocity law, rather than on uniform circular motions of compounded spheres, marks a major shift from ancient to modern conceptions of science.... [Kepler] had begun with physical principles and had then derived a trajectory from it, rather than simply constructing new models. In other words, even before discovering the area law, Kepler had abandoned uniform circular motion as a physical principle." Peter Barker and Bernard R. Goldstein, "Distance and Velocity in Kepler's Astronomy", *Annals of Science,* 51 (1994): 59–73, at p. 60.
37. ^ Koyré, *The Astronomical Revolution*, pp.199–202
38. ^ Caspar, *Kepler*, pp.129–132
39. ^ Caspar, *Kepler*, pp.131–140; Koyré, *The Astronomical Revolution*, pp.277–279
40. ^ Caspar, *Kepler*, pp.178–181
41. ^ Caspar, *Kepler*, pp.181–185. The full title is *Tertius Interveniens, das ist Warnung an etliche Theologos, Medicos vnd Philosophos, sonderlich D. Philippum Feselium, dass sie bey billicher Verwerffung der Sternguckerischen Aberglauben nict das Kindt mit dem Badt aussschütten vnd hiermit jhrer Profession vnwissendt zuwider handlen*, translated by C. Doris Hellman as "*Tertius Interveniens*, that is warning to some theologians, medics and philosophers, especially D. Philip Feselius, that they in cheap condemnation of the star-gazer's superstition do not throw out the child with the bath and hereby unknowingly act contrary to their profession."
42. ^ Caspar, *Kepler*, pp.192–197
43. ^ Koestler, *The Sleepwalkers* p 384
44. ^ Caspar, *Kepler*, pp.198–202
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48. ^ Caspar, *Kepler*, pp.202–204
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50. ^ Caspar, *Kepler*, pp.208–211
51. ^ Caspar, *Kepler*, pp.209–220, 227–240
52. ^ Quotation from Connor, *Kepler's Witch*, p 252, translated from an October 23, 1613 letter from Kepler to an anonymous nobleman
53. ^ Caspar, *Kepler*, pp.220–223; Connor, *Kepler's Witch*, pp.251–254.
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56. ^ Wolf, *A History of Science, Technology and Philosophy*, pp.140–141; Pannekoek, *A History of Astronomy*, p 252
57. ^ Caspar, *Kepler*, pp.239, 300–301, 307–308
58. ^ Caspar, *Kepler*, pp.240–264; Connor, *Kepler's Witch*, chapters I, XI-XIII; Lear, *Kepler's Dream*, pp.21–39
59. ^ Quotation from Caspar, *Kepler*, pp.265–266, translated from *Harmonices Mundi*
60. ^ Caspar, *Kepler*, pp.264–266, 290–293
61. ^ Caspar, *Kepler*, pp.266–290
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External links

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- *Harmonices mundi* (http://posner.library.cmu.edu/Posner/books/book.cgi?call=520_K38PI) ("The Harmony of the Worlds") in fulltext facsimile; Carnegie-Mellon University
- Johannes Kepler (http://plato.stanford.edu/entries/kepler) entry by Daniel A. Di Liscia in the *Stanford Encyclopedia of Philosophy*
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- Walter W. Bryant. *Kepler* (http://www.gutenberg.org/etext/12406) at Project Gutenberg (1920 book, part of *Men of Science* series)
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- Online Galleries, History of Science Collections, University of Oklahoma Libraries (http://hos.ou.edu/galleries/16thCentury/Kepler/) High resolution images of works by and/or portraits of Johannes Kepler in .jpg and .tiff format.

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十磅重砲彈的落下速度應是一磅重子彈的十倍

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亞里斯多德說一百磅重的球從100倍臂長的高度落地時的一磅球才只落下 1 倍臂長的高度"

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有本人所有研究中
最重要的結果

伽里略的自我評價獲得
現代科學家的一致同意

愛因斯坦

對事實而言，純靠推理獲得的主張
空洞而無意義

伽里略完全瞭解完全了解這一点
而把這一点帶進科學
所以
他確實是現代
物理學之父
更精確的說應
該是
現代科學之父

分類：
編號：
總號：

P. 42 – P. 43 of "大學物理學 — 力學, 熱學"
↓
張三慧

馬文蔚

所产生的位移$\boldsymbol{v}_0 t$与同时间沿 Oy 轴的匀加速直线运动所产生的位移 $gt^2/2$ 之和. 于是,斜抛物体的运动方程为

$$\boldsymbol{r}=\boldsymbol{v}_0 t+\frac{1}{2}\boldsymbol{g}t^2 \tag{1}$$

按图 1-9 所选定的坐标轴及起始条件,在 $t=0$ 时,有

$$\begin{cases}x_0=0, & v_{0x}=v_0\cos\alpha\\ y_0=0, & v_{0y}=v_0\sin\alpha\end{cases}$$

和

$$a_x=0,\qquad a_y=-g$$

可得

$$\begin{cases}x=v_0 t\cos\alpha\\ y=v_0 t\sin\alpha-\dfrac{1}{2}gt^2\end{cases} \tag{2}$$

消去方程中的 t,有

$$y=x\tan\alpha-\frac{g}{2v_0^2\cos^2\alpha}x^2 \tag{3}$$

这就是斜抛物体的轨迹方程. 它表明在略去空气阻力的情况下,抛体在空间所经历的路径为一抛物线(如图 1-10).

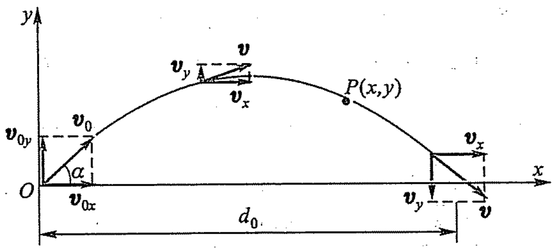


图 1-10

从图 1-10 可以看出,当抛体落回水平面上时,$y=0$. 若把抛体落地点与原点 O 间的距离 d_0 称之为射程,那么由式(3)可得

$$d_0=\frac{2v_0^2}{g}\sin\alpha\cos\alpha=\frac{v_0^2}{g}\sin 2\alpha$$

从上式可看出,在给定初速 v_0 的情况下,射程 d_0 是抛射角 α 的函数. 由最大射程的条件,有

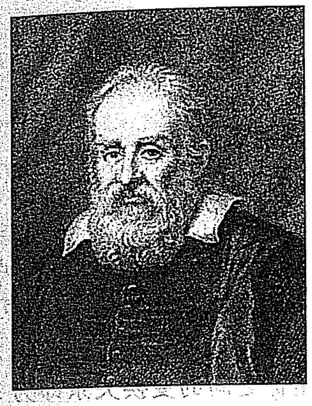
$$\frac{\mathrm{d}d_0}{\mathrm{d}\alpha}=\frac{2v_0^2}{g}\cos 2\alpha=0$$

得

$$2\alpha=\pi/2 \quad 或 \quad \alpha=\pi/4$$

这就是说,当 $\alpha=\pi/4$ 时,抛体的射程最大①,其值为 $d_{0m}=\dfrac{v_0^2}{g}$

① 伽利略最早对斜抛运动作了论述,指出:在略去空气阻力的情况下,当抛射角为45°时,抛体抛得



伽利略(Galileo Galilei,1564—1642),杰出的意大利物理学家和天文学家,实验物理学的先驱者,提出著名的相对性原理、惯性原理、抛体的运动定律、摆振动的等时性等等. 伽利略捍卫哥白尼日心学说.《关于两门新科学的对话和数学证明对话集》一书,总结了他最成熟的科学思想以及在物理学和天文学方面的研究成果.

在上述的讨论中,忽略了空气阻力. 若空气阻力较大,则物体经过的路径为一不对称的曲

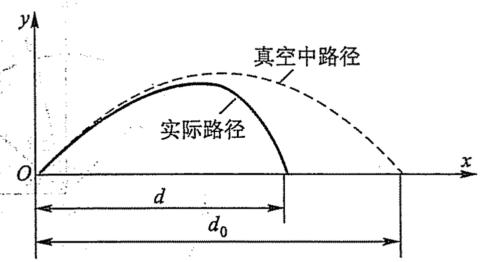


图 1-11

线①,实际射程 d 往往比真空中射程 d_0 小很多(图 1-11). 表1-1给出了弹丸在真空中和在空气中射程的情况.

表 1-1 在真空和空气中弹丸射程的比较

	初速 v_0/(m·s^{-1})	射角 α	真空射程 d_0/m	实际射程 d/m
7.6 mm 枪弹	800	15°	32 700	3 970
85 mm 炮弹	700	45°	50 000	16 000
82 mm 迫击炮弹	60	45°	367	350

利用斜抛物体的运动方程式(2),经适当修正,可粗略估算出洲际导弹的射程②.

① 关于空气阻力对抛体运动轨迹的影响将在第二章第 2-4 节的例 4 中讨论.

② 参阅马文蔚等主编《物理学原理在工程技术中的应用》(第三版)之"洲际导弹的射程"(北京,高

馬利亞可能從前輩修女以及前來治病的醫師學到這些知識和技巧。可是識字（包括拉丁文）則毫無疑問來自伽利略的傳授，因爲整個修道院中，語言文字的能力無人可和馬利亞相比。修道院院長遇到重要的正式文件時，也都要求馬利亞執筆。

根據一六三三年秋天的通訊，可以發現伽利略將發現的一些物質強度的證據，在朋友之間廣爲流傳。他把他們的意見或建議寫進《兩種新科學》第二天的對話之中，他們也都以此爲榮。

後來伽利略自認《兩種新科學》「比本人之前出版的所有著作都優越」，因爲書中「含有本人所有研究中最重要的結果。」他自估對阻抗和運動所得的結論超越一切使他名垂千古的天文發現。身爲世上第一個製造適當的望遠鏡而且把它指向天空的人，他當然引以自傲，但是他仍然認爲自身最大的才智在於觀測整個世界、了解其成員的運動、以及以數學方式描述這一切。❺

在剛開始撰寫《兩種新科學》時，伽利略還寫了劇本寄給馬利亞，讓修女們演出。顯然是爲歡迎大使夫人而作的準備，因爲她還是有意前來修道院參觀。遺憾的是這個劇本沒有流傳下來，唯一證明該劇本存在的證據，是馬利亞在信中的道謝。她讀完第一幕的時候，寫信說：「您的劇本真了不起。」

羅馬的尼可里尼大使告訴烏爾班八世，西恩那的伽利略服從教皇陛下和梵蒂岡，表現眞像模範犯人。西恩那教區教士向烏爾班檢舉皮可羅米尼總主教的行動，說他經常邀集學

者進餐、討論，對於伽利略先生的心情寧靜頗有助益。換言之，皮可羅米尼總主教不把伽利略看成是認罪的囚犯，卻給予貴賓般的縱容。

一位不知名人士向羅馬的官員檢舉：「總主教到處宣揚伽利略遭受不公的審判；伽利略是世上第一的人才；縱然他的著作遭禁，仍將名垂千古；當代所有的智者都信仰他的學說。身為總主教居然散播這樣的種籽，恐有不良後果，所以特地報告如上。」

❶編註：伽桑狄（Gassendi, Pierre.1592-1658），法國哲學家。

❷編註：梅森（Mersenne, Marin 1588-1648），法國哲學家。

❸編註：費馬（de Fermat, Pierre 1601-1665），法國數學家。

❹原註：後來伽利略為了表示謝意，將《兩種新科學》呈獻給「榮耀的貴族、諾艾爾伯爵、國王陛下的諮議官、聖靈騎士、陸軍元帥」等等。

❺原註：伽利略的自我評價，獲得後代科學家的一致同意。愛因斯坦說：「對事實而言，純靠推理獲得的主張空洞而無意義。伽利略完全了解這一點，而把這一點帶進科學界，所以他確是現代物理學之父，更精確的說應該是現代科學之父。」

我的心靈和渴望

《兩種新科學》

托斯卡尼全境從十月底就大雨不停，一直延續到十一月。潮溼的天氣使伽利略的關節炎病情加劇，加深馬利亞的倦怠。修道院的前院長安吉拉在潮溼的秋天中去世；修女們冒雨把她安葬在院裡的墓園。

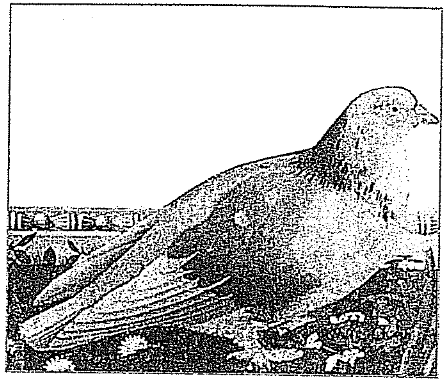
我就是復活，我就是生命；信我者死後還能復生；信我的活人將得永生。

〈撒迦利亞頌歌〉(Canticle of Zechariah)

然而醫院中生病的修女都還支撐得住。伽利略沒有辦法把松雞送去，因為獵取松雞的季節已到尾聲，毫無收穫。馬利亞也一樣搜購不到蒿雀送給父親；西恩那不產蒿雀，而伽利略卻特別喜歡。

她寫信向父親道歉：「本週之所以遲遲沒有寫信，實在是因為女兒希望買到蒿雀送去時再寫。可是聽說它們都已飛走，所以一隻也沒找到。要是早幾個星期就知道您的希望該有多好，何況當時女兒正為該送些什麼東西使您高興而大傷腦筋。女兒和您可真是同病相憐了。」

她說因為大雨的緣故，家中庭院無法種植豌豆；可是雨過必定天晴，到那時他就能返家了。「因為渴望您能親自前來拿取，女兒沒有附寄藥丸。關於如何處置您的決定該在本週抵達，女兒切盼能夠立刻獲知。」



▲圖30-1　灰松雞

可是消息杳如黃鶴，伽利略等候得焦躁不安，加上亟於依賴女兒信件的安慰，竟然指責馬利亞疏於寫信安慰老父。

十一月五日馬利亞在信上說：「女兒相信，如果您能夠以看穿天空的方式了解女兒的內心和憧憬，您就會相信女兒多麼希望每天都能收到您的來信，也希望每天都寫信向您請安。那麼您就不會像上一封信那樣的責怪女兒了。因為這正是上帝讓我們父女重新團聚之前，女兒能夠從您那兒獲得、而且也是女兒所能獻給您的最大安慰和滿足。」

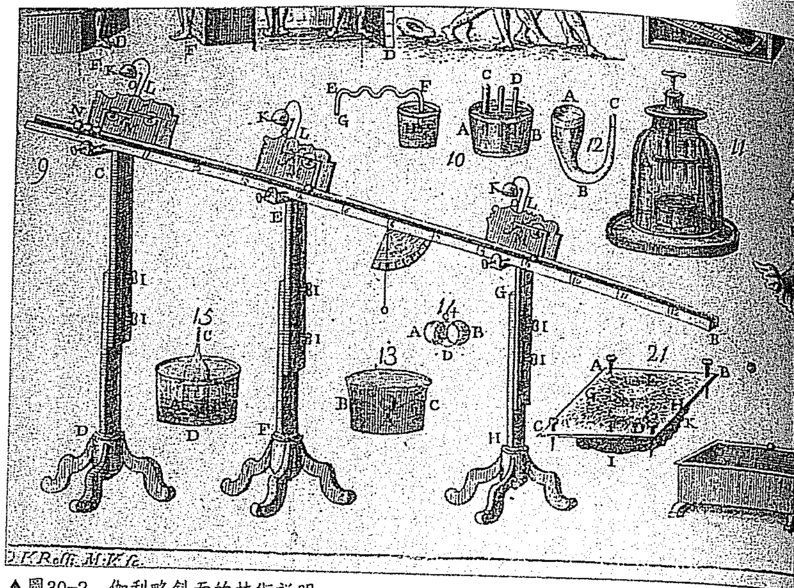
然後她告訴父親，她如何千方百計終於從一位大公的僕人手中買到他熱切盼望的萵雀。她隨時可以派傑波取得萵雀直接送請傑里先生轉交。數天之後伽利略在信中表示謝意，但隻字未提離開西恩那的事情。

她立刻在同月十二日週六回信：「您在信中隻字不提是否收到羅馬方面的任何消息，女兒感到十分驚訝。根據傑拉迪尼先生的說法，我們本來相信萬聖節（十一月一日）之前就能獲知相關的決定，所以女兒懇求您把事情進行的情況老實告知，好讓女兒安心。此外，如果您認為女兒可以了解，也請您把目前寫作的主題告訴女兒。請您放心，女兒當然不會隨意張揚。」

其實馬利亞應該知道伽利略著作的性質。當初伽利略受審期間從珍珠屋取走的一些資料，就是和運動有關的著作，包括了《兩種新科學》第三天的內容。這些資料的雛型都在伽利略離家前往羅馬之前，就已寫就。當時伽利略雖然認為這些資料不足以牽累到他，但仍然不願意見到資料遭到摧毀。

第三天探討的是等速運動和加速運動。這正是在帕多瓦期間，費了無限時間和苦心，仔細觀察小銅球在傾斜平面上的凹槽以加速度滾下的結果。因為無法隨心所欲地以自由落體進行實驗，伽利略自製了這些斜面，以便控制物體的降落、隨意停止運動、精確測量時間和距離。薩爾維亞蒂宣稱曾經偶爾幫助伽利略進行實驗，對其他兩位敘述實驗的情形：

我們把球沿著溝槽滾下，量度下降所需的時間。為求時間的誤差不超過一次心跳的十分之一，這樣的動作經常一再重複。獲得可靠的結果之後，溝槽的長度縮為四分之一，結果量得的時間確為原來的一半。然後再以各種不同的距離測量，之後再以其一半、三分之二、四分之三的距離測量，重複上百次。結果發現經過的距離和時間平方成正比。而且這種情況適用於各種斜面。


▲圖30-2　伽利略斜面的技術說明

當年伽利略沒有利用望遠鏡就能辨識太陽的形狀，如今伽利略在沒有可靠的單位或精確的鐘錶情況下，又發現了時間和距離的基本關係。十七世紀的義大利還沒國家標準的度量衡，距離的丈量方式和單位五花八門，毫不一致。佛羅倫斯、羅馬和威尼斯各自使用不同的單位，因此伽利略實驗時使用的單位，也是自訂的。相互換算之後，他照樣能夠建立基本的關係。

薩爾維亞蒂繼續描述：「為求精確測量時間，我們在高處放置一大桶水，底部接連一支小口徑的水管，以玻璃杯承接每次下降時流下的水量，然後以非常精確的天秤秤出水的重量。水的重量差異和比例，相當於時間的差異和比例。這個方法相當精確，所以同樣的實驗重複多次，結果仍然不會出現覺察得到的差異。」

薩爾維亞蒂的敘述展現一樣新奇驚人的實驗，將爲此後的科學開啓一片新的窗戶。但他無法擺脫新近養成引經據典的賣弄習氣，這種習慣極可能使科學和宗教——至少在科學和詩歌——之間出現無可彌補的裂痕。

斜面滾銅球的實驗，對於落體的研究提供了雖然瑣碎卻是勝利的前奏。伽利略將之寫進《兩種新科學》，成爲系列的定理。他以幾何比例的方式，利用散文配合圖表發表他的發現，相似於古希臘數學家使用的方式。他沒有利用傳統的代數解析，但是後來還是藉助於代數而利用少數幾個符號寫成公式。

《兩種新科學》第三天所討論的運動，因爲沒有施以諸如拋擲等的外力，所以都是「自然」的運動。第四天才討論到子彈或拋射物等的猛烈運動（這部分直到一六三七年才完成）。這一部分，伽利略顯現了他過人的見識，把運動分割成爲部分，逐一探討。他指出射出的砲彈或箭矢，都結合兩個向量：等速的推進力量和自由落體的加速度。

薩格雷多說，「這是無可否認的新論證，精密而具有論證力。依據這個假設一水平運動是等速，垂直運動則是等加速運動，和時間的平方成正比，而且運動和速度各自獨立，

不會互相干擾或妨礙一物體沿拋物線前進的運動軌跡不會變化。」

無論物體的重量或加於其上的外力如何，物體在空中的運動路線，都成拋物線。但如果垂直向上或向下發射，則情況又有不同。這點他們也加以討論。

薩爾維亞蒂多次提到拋物線，但因爲薩格雷多和辛普利西奧擔憂過度討論拋物線不能迅速了解，所以話題轉到圓錐體，因爲拋物線就源於圓錐體。辛普利西奧抱怨：「你的說明過快，而且一直假設我們對於歐幾里德的幾何和你一樣熟悉，可是事實並不如此。」

一旦他們兩位熟悉了基本的形狀之後，討論繼續進行的情況就輕易而和諧多了。內容甚至於包括了重砲在不同發射角度時效率變化的分析。利用幾何證明四十五度之所以優於其他角度的原因。因爲這樣的拋物線的射程最大，所以砲彈射得最遠。

薩格雷多不禁感慨萬分，「這種只利用數學證明的強烈力量，讓我深感驚訝和樂趣。我早從射擊者口中獲悉，利用四十五度的角度發射，可使砲彈射得最遠。然而了解其基本原因，其意義遠較旁人的證詞或親自重複實驗來得重大。」

自古以來，形上學考慮事情的原因時，一向忽略科學的實際運用和價值。伽利略對於它們的強調，使他不同於同時代的其他科學家。亞里斯多德派的學者奢談精華和自然地位，伽利略卻追逐諸如時間、距離和加速度等可量化的事物。同時代的對話式論著，對談者都安排在大學校園中。伽利略的《兩種新科學》卻以造船廠爲背景。而且對話者根本捨棄追求科學界一向奉爲圭臬的原始起因。薩爾維亞蒂說：「自由落體加速度的起因，不必

薩爾維亞蒂繼續描述：「為求精確測量時間，我們在高處放置一大桶水，底部接連一支小口徑的水管，以玻璃杯承接每次下降時流下的水量，然後以非常精確的天秤秤出水的重量。水的重量差異和比例，相當於時間的差異和比例。這個方法相當精確，所以同樣的實驗重複多次，結果仍然不會出現覺察得到的差異。」

薩爾維亞蒂的敘述展現一樣新奇驚人的實驗，將爲此後的科學開啓一片新的窗戶。但他無法擺脫新近養成引經據典的賣弄習氣，這種習慣極可能使科學和宗教——至少在科學和詩歌——之間出現無可彌補的裂痕。

斜面滾銅球的實驗，對於落體的研究提供了雖然瑣碎卻是勝利的前奏。伽利略將之寫進《兩種新科學》，成爲系列的定理。他以幾何比例的方式，利用散文配合圖表發表他的發現，相似於古希臘數學家使用的方式。他沒有利用傳統的代數解析，但是後來還是藉助於代數而利用少數幾個符號寫成公式。

《兩種新科學》第三天所討論的運動，因爲沒有施以諸如拋擲等的外力，所以都是「自然」的運動。第四天才討論到子彈或拋射物等的猛烈運動（這部分直到一六三七年才完成）。這一部分，伽利略顯現了他過人的見識，把運動分割成爲部分，逐一探討。他指出射出的砲彈或箭矢，都結合兩個向量：等速的推進力量和自由落體的加速度。

薩格雷多說，「這是無可否認的新論證，精密而具有論證力。依據這個假設一水平運動是等速，垂直運動則是等加速運動，和時間的平方成正比，而且運動和速度各自獨立，

不會互相干擾或妨礙，物體沿拋物線前進的運動軌跡不會變化。」

無論物體的重量或加於其上的外力如何，物體在空中的運動路線，都成拋物線。但如果垂直向上或向下發射，則情況又有不同。這點他們也加以討論。

薩爾維亞蒂多次提到拋物線，但因爲薩格雷多和辛普利西奧擔憂過度討論拋物線不能迅速了解，所以話題轉到圓錐體，因爲拋物線就源於圓錐體。辛普利西奧抱怨：「你的說明過快，而且一直假設我們對於歐幾里德的幾何和你一樣熟悉，可是事實並不如此。」

一旦他們兩位熟悉了基本的形狀之後，討論繼續進行的情況就輕易而和諧多了。內容甚至於包括了重砲在不同發射角度時效率變化的分析。利用幾何證明四十五度之所以優於其他角度的原因。因爲這樣的拋物線的射程最大，所以砲彈射得最遠。

薩格雷多不禁感慨萬分，「這種只利用數學證明的強烈力量，讓我深感驚訝和樂趣。我早從射擊者口中獲悉，利用四十五度的角度發射，可使砲彈射得最遠。然而了解其基本原因，其意義遠較旁人的證詞或親自重複實驗來得重大。」

自古以來，形上學考慮事情的原因時，一向忽略科學的實際運用和價值。伽利略對於它們的強調，使他不同於同時代的其他科學家。亞里斯多德派的學者奢談精華和自然地位，伽利略卻追逐諸如時間、距離和加速度等可量化的事物。同時代的對話式論著，對談者都安排在大學校園中。伽利略的《兩種新科學》卻以造船廠爲背景。而且對話者根本捨棄追求科學界一向奉爲圭臬的原始起因。薩爾維亞蒂說：「自由落體加速度的起因，不必

然是研究的部分。」此後，物理就起了根本變化。

馬利亞於十一月十三日星期天早上，在給父親一週綜合報告的信尾附言說：「大雨不停，您的信差喬萬尼今早無法動身，所以女兒得到了和您多聊的時間。女兒最近拔掉一顆大臼齒，疼痛不堪。更可怕的是，還有幾顆同樣情況的牙齒，也都必須在最近拔掉。」多年以來，她都自行拔牙，顯示了勇氣和果決。廿七歲時她就自認已經未老先衰掉光牙齒。

附言繼續說：「您告知女兒工作有益於健康，女兒完全同意。雖然有時難免覺得瑣碎無聊甚至於難以忍受，但是女兒仍覺得勞動確是健康的基礎，尤以您遠離在外，女兒頓失依靠時，更是如此。上帝有意考驗，女兒內心難得有片刻安寧，卻也因此您的遠離才不至於讓女兒灰心喪志。否則的話，不但對女兒有害，恐怕也會增添您的憂慮。」

馬利亞在週日上午雨中寫信的時候，羅馬的尼可里尼大使再度晉見教宗，要求讓伽利略返回阿切特里。烏爾班仍然不做決定，會面的時候既不答應也不拒絕大使的請求。只是故意透露伽利略獲得同志們的支持、衛護、友誼和通訊。烏爾班毫不掩飾對這些人的厭惡，並且告訴大使，羅馬教廷正在監視他們。西恩那總主教也名列其中。

時間又過了一週，而伽利略仍然沒有回家的消息，馬利亞再度寫信：「如果運氣好可以找到灰松雞的話，女兒可能會為了那位可憐的年輕姊妹而興奮不已。她在上次月圓時就已病危接受了臨終塗油，幸而最近稍有好轉，但是她對於其他食物毫無食欲，只想吃松雞。昨夜女兒整夜陪她，餵她食物的時候，她說，『快死的人居然能夠像我這樣進食，實在難以想像。只是我願意看到上帝的願望實現，沒有恢復健康的欲望。』」

馬利亞必然多次利用手背測試她的發燒情況，可是沒有辦法量度她的體溫。[1]她只能根據病人臉上的紅暈、脈搏速度和呼吸情況，粗略估計病人的體溫。

不到一週，一天傍晚當太陽在第廿四小時快要下山的時候，從西恩那來了一位信差，帶來一籃子的鳥類：

裡面有十二隻畫眉，和您信中所說的數目差了四隻，恐怕是被小貓偷吃掉了。因為遍找不著，而且布蓋上面有個大洞。還好，灰松雞和山鶉都放在下面。女兒以兩隻畫眉和一隻松雞送給生病的那位修女，她非常高興，對您更是感激莫名。另外以兩隻畫眉送給隆迪內里先生，其餘的就和朋友們分享了。

女兒把鳥隻分送大家，真是快樂無比。千辛萬苦才獲得的東西，值得和朋友分享。只是畫眉有點老，只好燉煮。女兒整整燉了一天，也忘形的狼吞虎嚥大吃一頓。

[1]原註：伽利略在一五九三年前後發明了溫度計的雛型，可以大略量度室溫。一七一四年才由德國人華倫海（Fahrenheit, Daniel. 1686-1736）加以改善，裝進水銀並在管上刻好度數，世稱「華氏溫度計」。

科学家介绍

伽　利　略

（Galileo Galilei，1564—1642 年）

伽利略

DISCORSI
E
DIMOSTRAZIONI
MATEMATICHE,
intorno à due nuoue scienze
Attenenti alla
MECANICA & i MOVIMENTI LOCALI;
del Signor
GALILEO GALILEI LINCEO,
Filosofo e Matematico primario del Serenissimo
Grand Duca di Toscana
Con una Appendice del centro di grauità d'alcuni Solidi.

IN LEIDA,
Appresso gli Elsevirii. M. D. C. XXXVIII.

《两门新科学》一书的扉页

伽利略 1564 年出生于意大利比萨城的一个没落贵族家庭。他从小表现聪颖，17 岁时被父亲送入比萨大学学医，但他对医学不感兴趣。由于受到一次数学演讲的启发，开始热衷于数学和物理学的研究。1585 年辍学回家。此后曾在比萨大学和帕多瓦大学任教，在此期间他在科学研究上取得了不少成绩。由于他反对当时统治知识界的亚里士多德世界观和物理学，同时又由于他积极宣扬违背天主教教义的哥白尼太阳中心说，所以不断受到教授们的排挤以及教士们和罗马教皇的激烈反对，最后终于在 1633 年被罗马宗教裁判所强迫在写有“我悔恨我的过失，宣传了地球运动的邪说”的“悔罪书”上签字，并被判刑入狱（后不久改为在家监禁）。这使他的身体和精神都受到很大的摧残。但他仍致力于力学的研究工作。1637 年双目失明。1642 年他由于寒热病在孤寂中离开了人世，时年 78 岁。（时隔 347 年，罗马教皇多余地于 1980 年宣布承认对伽利略的压制是错误的，并为他“恢复名誉”。）

伽利略的主要传世之作是两本书。一本是 1632 年出版的《关于两个世界体系的对话》，简称《对话》，主旨是宣扬哥白尼的太阳中心说。另一本是 1638 年出版的《关于力学和局部运动两门新科学的谈话和数学证明》，简称《两门新科学》，书中主要陈述了他在力学方面研究的成果。伽利略在科学上的贡献主要有以下几方面：

(1) 论证和宣扬了哥白尼学说，令人信服地说明了地球的公转、自转以及行星的绕日运动。他还用自制的望远镜仔细地观测了木星的 4 个卫星的运动，在人们面前展示了一个太阳系的模型，有力地支持了哥白尼学说。

(2) 论证了惯性运动，指出维持运动并不需要外力。这就否定了亚里士多德的“运动必须推动”的教条。不过伽利略对惯性运动理解还没有完全摆脱亚里士多德的影响，他也认为“维持宇宙完善秩序”的惯性运动“不可能是直线运动，而只能是圆周运动”。这个错误理解被他的同代人笛卡儿和后人牛顿纠正了。

(3) 论证了所有物体都以同一加速度下落。这个结论直接否定了亚里士多德的重物比轻物下落得快的说法。两百多年后，从这个结论萌发了爱因斯坦的广义相对论。

(4) 用实验研究了匀加速运动。他通过使小球沿斜面滚下的实验测量验证了他推出的公式：从静止开始的匀加速运动的路程和时间的平方成正比。他还把这一结果推广到自由落体运动，即倾角为 90°的斜面上的运动。

(5) 提出运动合成的概念，明确指出平抛运动是相互独立的水平方向的匀速运动和竖直方向的匀加速运动的合成，并用数学证明合成运动的轨迹是抛物线。他还根据这个概念计算出了斜抛运动在仰角 45°时射程最大，而且比 45°大或小同样角度时射程相等。

(6) 提出了相对性原理的思想。他生动地叙述了大船内的一些力学现象，并且指出船以任何速度匀速前进时这些现象都一样地进行，从而无法根据它们来判断船是否在动。这个思想后来被爱因斯坦发展为相对性原理而成了狭义相对论的基本假设之一。

(7) 发现了单摆的等时性并证明了单摆振动的周期和摆长的平方根成正比。他还解释了共振和共鸣现象。

此外，伽利略还研究过固体材料的强度、空气的重量、潮汐现象、太阳黑子、月亮表面的隆起与凹陷等问题。

除了具体的研究成果外，伽利略还在研究方法上为近代物理学的发展开辟了道路，是他首先把实验引进物理学并赋予重要的地位，革除了以往只靠思辨下结论的恶习。他同时也很注意严格的推理和数学的运用，例如他用消除摩擦的极限情况来说明惯性运动，推论大石头和小石块绑在一起下落应具有的速度来使亚里士多德陷于自相矛盾的困境，从而否定重物比轻物下落快的结论。这样的推理就能消除直觉的错误，从而更深入地理解现象的本质。爱因斯坦和英费尔德在《物理学的进化》一书中曾评论说：“伽利略的发现以及他所应用的科学的推理方法，是人类思想史上最伟大的成就之一，而且标志着物理学的真正开端。”

伽利略一生和传统的错误观念进行了不屈不挠的斗争，他对待权威的态度也很值得我们学习。他说过：“老实说，我赞成亚里士多德的著作，并精心地加以研究。我只是责备那些使自己完全沦为他的奴隶的人，变得不管他讲什么都盲目地赞成，并把他的话一律当作丝毫不能违抗的圣旨一样，而不深究其他任何依据。”