LIVES IN THE RENAISSANCE

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INTRODUCTION[1]

Europe rediscovers past knowledge

The Renaissance (meaning “Re-birth”) was a period of excitement and innovation during which Europe rediscovered the knowledge that had been lost with the burning of the Great Library of Alexandria and the decline of the brilliant Greek and Hellenistic civilizations.

The Renaissance owes much to the Islamic civilization of the middle ages which preserved the writings of such great ancient figures as Plato, Aristotle, Socrates, Hypocrites and Galen and transmitted them to the west.

Paper and printing, both invented in China, were brought. to the west during the Renaissance, and they paved the way for the explosion of knowledge which took place.

In the 12th Century, the city of Toledo in Spain was a center of translation of Greek classical manuscripts from Arabic to Latin. It was a period of tolerance in Spain, when the three Abrahamic religions, Judaism, Christianity and Islam, lived together in friendly cooperation.

Another route by which ancient knowledge was transmitted to Europe was through the Greek scholars who came to the west from Byzantium, bringing with them classical manuscripts.

The Renaissance started in Italy, especially in the trading cities of Florence and Venice. Figures such as Leonardo da Vinci, Galileo, Michelangelo and Raphael belong to the Italian Renaissance. Later, the Renaissance moved northward, producing great contributions to human culture from such men as Rembrandt, Shakespeare and Newton.

The Renaissance was a crucial step towards the creation of the modern world, as we know it today.

Human history as cultural history

We need to reform our teaching of history so that the emphasis will be placed on the gradual growth of human culture and knowledge, a growth to which all nations and ethnic groups have contributed.

This book is part of a series on cultural history. Here is a list of the other books in the series that have, until now, been completed:

[1]This book makes use of my previously-published book chapters, but much of the material is new.

- Lives in the Ancient World
- Lives in the 17th Century
- Lives in the 18th Century
- Lives in the 19th Century
- Lives in the 20th century
- Lives in Biology
- Lives of Some Great Novelists
- Lives in Mathematics
- Lives in Exploration
- Lives in Education
- Lives in Poetry
- Lives in Painting
- Lives in Engineering
- Lives in Astronomy
- Lives in Chemistry
- Lives in Medicine
- Lives in Ecology
- Lives in Physics
- Lives in Economics
- Lives in the Peace Movement

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Chapter 1

EAST-WEST EXCHANGES

1.1 Marco Polo (1254-1324)

Marco Polo (1254-1324) was born in Venice, into a very successful family of merchants. At the time of his birth, his father Niccolò Polo (c.1230-c.1294) and his uncle, Maffeo Polo (c.1230-c.1309) were away from Venice on a long journey during which they spent many years in the court of the Chinese emperor, Kublai Khan. Niccolò Polo did not see his son Marco until the boy was about 15 years old.

The two Polo brothers, Niccolò and Maffeo, had established trading companies Constantinople, and in Sudak in the Crimea, which was then in the western part of the Mongol Empire. They lived in the Venetian quarter of Constantinople, where Venetians then enjoyed tax advantages and other privileges. However, in 1259 or 1260, judging the political situation in Constantinople to be precarious, they moved their business to the Crimea. This decision proved to be very fortunate, since the government in Constantinople soon changed, and Venetians in the city were then subject to terrible persecution.

The Crimea was at that time a part of the Golden Horde, the western end of of the Mongol empire. After spending some years there, the Polo brothers moved still further eastward to the city of Bukhara, where they spent three years and further increased their trading profits. While they were in Bukhara, the brothers were invited to visit the court of the great Chinese emperor, Kublai Khan.

Kublai Khan was very much interested in what the Polo brothers had to tell him about European civilization and Christianity. He wrote a letter to the pope, requesting 100 educated people and missionaries who would come and teach his people about western customs and Christianity. He also asked for oil from the lamp of the Holy Sepulchure.

When the Polo brothers returned to Venice in 1269 or 1270, they were distressed to find that there was no pope to whom they could deliver Kublai Khan's letter and request. However, in 1261, Pope Gregory X was elected, and the brothers were able to fulfil their commission. Pope Gregory sent a letter and gifts to the great Khan, but only two missionaries rather than 100. The Polo brothers took these with them when they returned to China. They also took Niccolò 's young son, Marco Polo.

Figure 1.1: **Niccolò and Maffeo Polo leaving Constantinople for the east, in 1259.**

Figure 1.2: **Niccolò and Maffeo in Bukhara, where they stayed for three years. They were invited by an envoy of Hulagu (right) to travel east to visit Kublai Khan.**

Figure 1.3: **Niccolò and Maffeo Polo remitting a letter from Kublai Khan to Pope Gregory X in 1271.**

Figure 1.4: **Rialto Bridge, Venice.**

Figure 1.5: **The Doge's Palace, Venice.**

Marco travels to China with his father and uncle

In 1271, at the age of 17, Marco Polo set off with his his father and uncle on an epic journey to the court of Kublai Khan. It would be 24 years before they returned to Venice.

In the service of Kublai Khan

Once again they were welcomed by the great Khan, who took a special interest in the young Marco Polo, who by this time was 21 years old, because of his intelligence and humility. Marco Polo also entertained the emperor with stories of the countries which he had visited. Kublai Khan was so pleased that he decided to appoint Marco as a diplomat to the various parts of his empire, for example present-day Burma, India, Indonesia, Sri Lanka, and Vietnam.

In addition to these diplomatic missions, Marco Polo also lived and travelled extensively inside China (then known as Cathay). He observed many things that were previously unknown to Europeans, for example, the use of paper money and coal.

Return to Europe

Kublai Khan several times refused to allow the Polos to return to Europe because they were useful to him. However, in 1291 he granted the Polos permission, as their last service, to accompany the Mongol princess Kököchin, to Persia, where she was to marry Arghun Khan. After performing this mission, the Polos finally returned to Venice, arriving there with many riches 24 years after they had departed on their epic journey.

Figure 1.6: **Marco Polo dressed as a Tartar.**

Figure 1.7: **Mosaic of Marco Polo displayed in the Palazzo Doria-Tursi, in Genoa, Italy.**

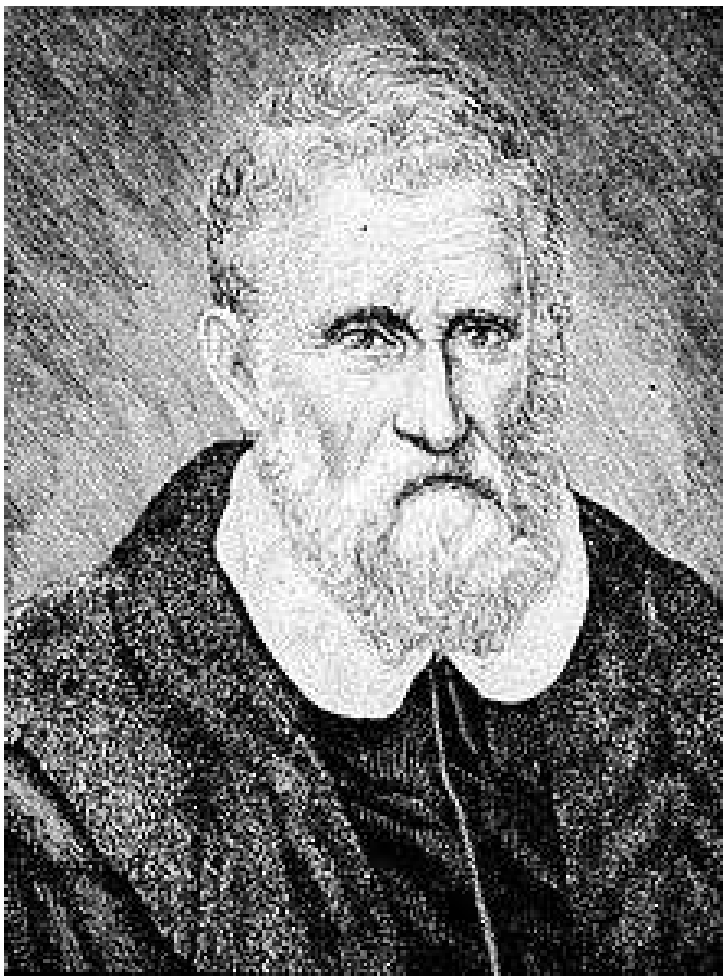

Figure 1.8: **16th century portrait of Marco Polo.**

Figure 1.9: **Portrait of Kublai Khan (1215-1294). His white robes are those of a shaman. He was the grandson and heir of Genghis Khan.**

Figure 1.10: **Portrait of young Kublai by Anige, a Nepali artist in Kublai's court.**

Figure 1.11: **The Yuan Dynasty of China, over which Kublai Khan became emperor.**

Return to Venice and capture by the Genoans

When Marco Polo returned to Venice in 1295, the city was at war with Genoa. Marco purchased a ship and participated in the naval war. However, he was captured and imprisoned for three years.

Marco dictates his book to a cell-mate

While in prison, Marco Polo dictated a book of his recollections from his epic travels in Asia to a cell-mate, Rustichello da Pisa, who happened to be a successful author of romances. The result was the famous book whose English title is *The Travels of Marco Polo*, while the French title was *Livre des merveilles*. The book became immensely popular, and it opened the eyes of Europeans to the great wealth and knowledge of countries in Asia, thus initiating the Age of Exploration.

Xanadu (Shangdu)

In Marco Polo's book describing of his travels, he gives the following description of Kublai Khan's summer palace:

"And when you have ridden three days from the city last mentioned, between north-east and north, you come to a city called Chandu, which was built by the Khan now reigning. There is at this place a very fine marble palace, the rooms of which are all gilt and painted with figures of men and beasts and birds, and with a variety of trees and flowers, all executed with such exquisite art that you regard them with delight and astonishment.

"Round this Palace a wall is built, inclosing a compass of 16 miles, and inside the Park there are fountains and rivers and brooks, and beautiful meadows, with all kinds of wild animals (excluding such as are of ferocious nature), which the Emperor has procured and placed there to supply food for his gerfalcons and hawks, which he keeps there in mew. Of these there are more than 200 gerfalcons alone, without reckoning the other hawks. The Khan himself goes every week to see his birds sitting in mew, and sometimes he rides through the park with a leopard behind him on his horse's croup; and then if he sees any animal that takes his fancy, he slips his leopard at it, and the game when taken is made over to feed the hawks in mew. This he does for diversion.

"Moreover at a spot in the Park where there is a charming wood he has another Palace built of cane, of which I must give you a description. It is gilt all over, and most elaborately finished inside. It is stayed on gilt and lacquered columns, on each of which is a dragon all gilt, the tail of which is attached to the column whilst the head supports the architrave, and the claws likewise are stretched out right and left to support the architrave. The roof, like the rest, is formed of canes, covered with a varnish so strong and excellent that no amount of rain will rot them. These canes are a good 3 palms in girth, and from 10 to 15 paces in length. They are cut across at each knot, and then the pieces are split so as to form from each two hollow tiles, and with these the house is roofed; only every such tile of cane has to be nailed down to prevent the wind from lifting it. In short, the whole Palace is built of these canes, which I may mention serve also for a great variety of other useful purposes. The construction of the Palace is so devised that it can be taken down and put up again with great celerity; and it can all be taken to pieces and removed whithersoever the Emperor may command. When erected, it is braced against mishaps from the wind by more than 200 cords of silk.

"The Khan abides at this Park of his, dwelling sometimes in the Marble Palace and sometimes in the Cane Palace for three months of the year, to wit, June, July and August; preferring this residence because it is by no means hot; in fact it is a very cool place..."

Coleridge's poem

In 1797, after reading a description of Shangdu, Samuel Taylor Coleridge fell asleep, and while asleep composed the poem which starts with the lines:

In Xanadu did Kublai Khan
A stately pleasure-dome decree:
Where Alph, the sacred river, ran
Through caverns measureless to man
Down to a sunless sea.

Figure 1.12: **French *Livre des merveilles* front page. At a time before printed books, it nevertheless became a best-seller!**

So twice five miles of fertile ground
With walls and towers were girdled round:
And there were gardens bright with sinuous rills,
Where blossomed many an incense-bearing tree;
And here were forests ancient as the hills,
Enfolding sunny spots of greenery...

Figure 1.13: **Handwritten notes by Christopher Columbus on the Latin edition of Marco Polo's *Le livre des merveilles*. By making Europeans conscious of the wealth and knowledge of eastern civilizations, Marco Polo's book initiated the Age of Exploration.**

1.2 The invention of paper

Paper of the type which we use today was not invented until 105 A.D.. This enormously important invention was made by a Chinese eunuch named Tsai Lun. The kind of paper invented by Tsai Lun could be made from many things: for example, bark, wood, hemp, rags, etc.. The starting material was made into a pulp, mixed together with water and binder, spread out on a cloth to partially dry, and finally heated and pressed into thin sheets. The art of paper-making spread slowly westward from China, reaching Baghdad in 800 A.D.. It was brought to Europe by the crusaders returning from the Middle East. Thus paper reached Europe just in time to join with Gütenberg's printing press to form the basis for the information explosion which has had such a decisive effect on human history.)

Many centers of paper production were established throughout the Muslim world, and their techniques were eventually transmitted to Christian Europe. Not only was paper convenient to use, transport, and store, it was, most importantly, considerably cheaper than papyrus and parchment, probably partly because of the use of recycled rags as raw material in its manufacture. Whereas an early Qur'an copy on parchment is reckoned to have required the skins of about 300 sheep, an equivalent amount of paper could be produced much more rapidly, in much greater quantities, and at much lower cost. This transformed the economics of book production, and made possible a greatly increased production of manuscript books, on a scale which was unprecedented and unmatched in Europe at that time.

The career of Leonardo da Vinci illustrates the first phase of the "information explosion" which has produced the modern world: During Leonardo's lifetime, inexpensive paper was being manufactured in Europe, and it formed the medium for Leonardo's thousands of pages of notes. His notes and sketches would never have been possible if he had been forced to use expensive parchment as a medium. On the other hand, the full force of

Figure 1.14: **Papyrus**

Leonardo's genius and diligence was never felt because his notes were not printed.

Copernicus, who was a younger contemporary of Leonardo, had a much greater effect on the history of ideas, because his work was published. Thus, while paper alone made a large contribution to the information explosion, it was printing combined with paper which had an absolutely decisive and revolutionary impact: The modern scientific era began with the introduction of printing.

Figure 1.15: **Paper is a Chinese invention**

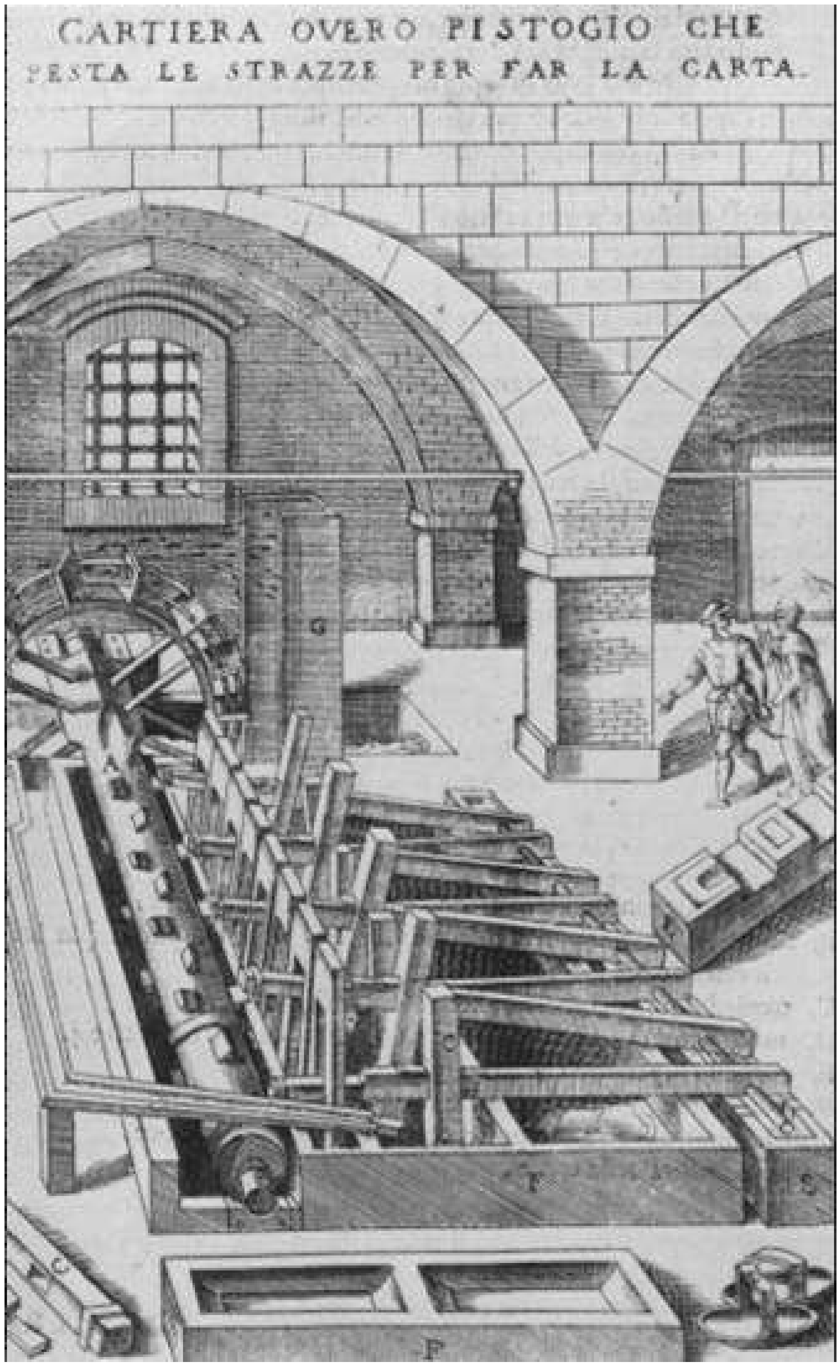

Figure 1.16: **Italian paper-mill, probably from the 16th century.**

Figure 1.17: **The impact of Leonardo da Vinci's genius would have been far greater if his thousands of pages of notes had been printed.**

1.3 Printing

It was during the T'ang period that the Chinese made an invention of immense importance to the cultural evolution of mankind. This was the invention of printing. Together with writing, printing is one of the key inventions which form the basis of human cultural evolution.

Printing was invented in China in the 8th or 9th century A.D., probably by Buddhist monks who were interested in producing many copies of the sacred texts which they had translated from Sanskrit. The act of reproducing prayers was also considered to be meritorious by the Buddhists.

The Chinese had for a long time followed the custom of brushing engraved official seals with ink and using them to stamp documents. The type of ink which they used was made from lamp-black, water and binder. In fact, it was what we now call "India ink". However, in spite of its name, India ink is a Chinese invention, which later spread to India, and from there to Europe.

We mentioned that paper of the type which we now use was invented in China in the first century A.D.. Thus, the Buddhist monks of China had all the elements which they needed to make printing practical: They had good ink, cheap, smooth paper, and the tradition of stamping documents with ink-covered engraved seals. The first block prints which they produced date from the 8th century A.D.. They were made by carving a block of wood the size of a printed page so that raised characters remained, brushing ink onto the block, and pressing this onto a sheet of paper.

The oldest known printed book, the "Diamond Sutra", is dated 868 A.D.., and it consists of only six printed pages. In was discovered in 1907 by an English scholar who obtained permission from Buddhist monks in Chinese Turkestan to open some walled-up monastery rooms, which were said to have been sealed for 900 years. The rooms were found to contain a library of about 15,000 manuscripts, among which was the Diamond Sutra.

Block printing spread quickly throughout China, and also reached Japan, where woodblock printing ultimately reached great heights in the work of such artists as Hiroshige and Hokusai. The Chinese made some early experiments with movable type, but movable type never became popular in China, because the Chinese written language contains 10,000 characters. However, printing with movable type was highly successful in Korea as early as the 15th century A.D..

The unsuitability of the Chinese written language for the use of movable type was the greatest tragedy of the Chinese civilization. Writing had been developed at a very early stage in Chinese history, but the system remained a pictographic system, with a different character for each word. A phonetic system of writing was never developed.

The failure to develop a phonetic system of writing had its roots in the Chinese imperial system of government. The Chinese empire formed a vast area in which many different languages were spoken. It was necessary to have a universal language of some kind in order to govern such an empire. The Chinese written language solved this problem admirably.

Suppose that the emperor sent identical letters to two officials in different districts.

Figure 1.18: **The Diamond Sutra, 868 A.D., is the first known printed book.**

Reading the letters aloud, the officials might use entirely different words, although the characters in the letters were the same. Thus the Chinese written language was a sort of “Esperanto” which allowed communication between various language groups, and its usefulness as such prevented its replacement by a phonetic system.

The invention of block printing during the T’ang dynasty had an enormously stimulating effect on literature, and the T’ang period is regarded as the golden age of Chinese lyric poetry. A collection of T’ang poetry, compiled in the 18th century, contains 48,900 poems by more than 2,000 poets.

1.4 Islamic civilization and printing

Some Islamic contributions to civilization

In the 5th century A.D., there was a split in the Christian church of Byzantium;and the Nestorian church, separated from the official Byzantine church. The Nestorians were bitterly persecuted by the Byzantines, and therefore they migrated, first to Mesopotamia, and later to south-west Persia. (Some Nestorians migrated as far as China.)

During the early part of the middle ages, the Nestorian capital at Gondisapur was a great center of intellectual activity. The works of Plato, Aristotle, Hippocrates, Euclid, Archimedes, Ptolemy, Hero and Galen were translated into Syriac by Nestorian scholars, who had brought these books with them from Byzantium.

Among the most distinguished of the Nestorian translators were the members of a family called Bukht-Yishu (meaning "Jesus hath delivered"), which produced seven generations of outstanding scholars. Members of this family were fluent not only in Greek and Syriac, but also in Arabic and Persian.

In the 7th century A.D., the Islamic religion suddenly emerged as a conquering and proselytizing force. Inspired by the teachings of Mohammad (570 A.D. - 632 A.D.), the Arabs and their converts rapidly conquered western Asia, northern Africa, and Spain. During the initial stages of the conquest, the Islamic religion inspired a fanaticism in its followers which was often hostile to learning. However, this initial fanaticism quickly changed to an appreciation of the ancient cultures of the conquered territories; and during the middle ages, the Islamic world reached a very high level of culture and civilization.

Thus, while the century from 750 to 850 was primarily a period of translation from Greek to Syriac, the century from 850 to 950 was a period of translation from Syriac to Arabic. It was during this latter century that Yuhanna Ibn Masawiah (a member of the Bukht-Yishu family, and medical advisor to Caliph Harun al-Rashid) produced many important translations into Arabic.

The skill of the physicians of the Bukht-Yishu family convinced the Caliphs of the value of Greek learning; and in this way the family played an extremely important role in the preservation of the western cultural heritage. Caliph al-Mamun, the son of Harun al-Rashid, established at Baghdad a library and a school for translation, and soon Baghdad replaced Gondisapur as a center of learning.

The English word "chemistry" is derived from the Arabic words *"al-chimia"*, which mean "the changing". The earliest alchemical writer in Arabic was Jabir (760-815), a friend of Harun al-Rashid. Much of his writing deals with the occult, but mixed with this is a certain amount of real chemical knowledge. For example, in his *Book of Properties*, Jabir gives the following recipe for making what we now call lead hydroxycarbonate (white lead), which is used in painting and pottery glazes: "Take a pound of litharge, powder it well and heat it gently with four pounds of vinegar until the latter is reduced to half its original volume. The take a pound of soda and heat it with four pounds of fresh water until the volume of the latter is halved. Filter the two solutions until they are quite clear, and then gradually add the solution of soda to that of the litharge. A white substance is formed, which settles to the bottom. Pour off the supernatant water, and leave the residue to dry. It will become a salt as white as snow."

Another important alchemical writer was Rahzes (c. 860 - c. 950). He was born in the ancient city of Ray, near Teheran, and his name means "the man from Ray". Rahzes studied medicine in Baghdad, and he became chief physician at the hospital there. He wrote the first accurate descriptions of smallpox and measles, and his medical writings include methods for setting broken bones with casts made from plaster of Paris. Rahzes was the first person to classify substances into vegetable, animal and mineral. The word *"al-kali"*, which appears in his writings, means "the calcined" in Arabic. It is the source of our word "alkali", as well as of the symbol K for potassium.

The greatest physician of the middle ages, Avicenna, (Abu-Ali al Hussein Ibn Abdullah Ibn Sina, 980-1037), was also a Persian, like Rahzes. More than a hundred books are at-

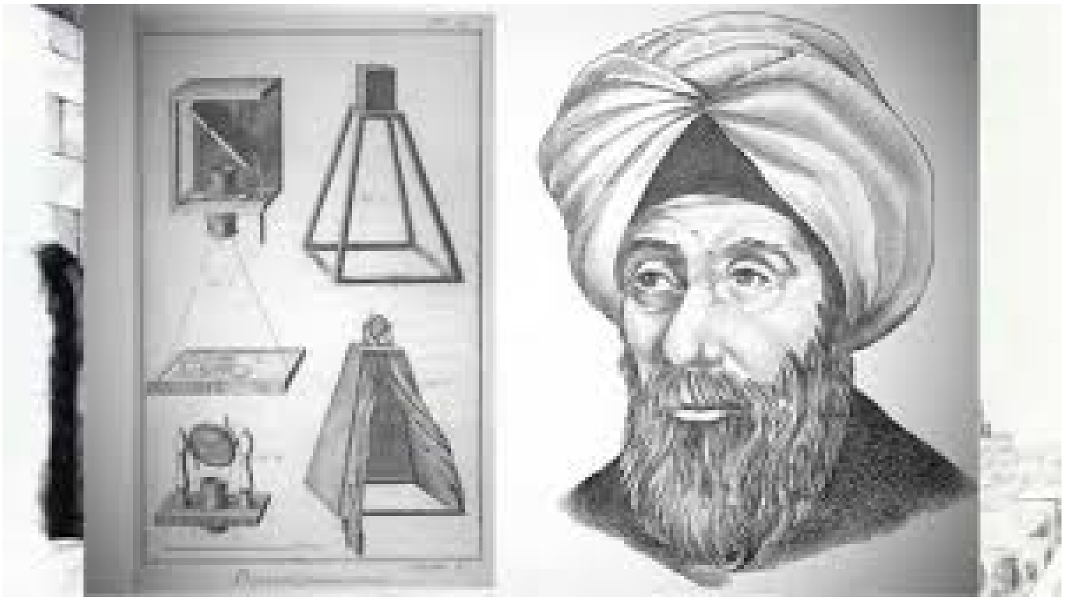

Figure 1.19: **Al-Hazen invented the camera-obscura during the years 1012-1021. It was a forerunner of the modern camera.**

tributed to him. They were translated into Latin in the 12th century, and they were among the most important medical books used in Europe until the time of Harvey. Avicenna also wrote on alchemy, and he is important for having denied the possibility of transmutation of elements.

In mathematics, one of the most outstanding Arabic writers was al-Khwarizmi (c. 780 - c. 850). The title of his book, *Ilm al-jabr wa'd muqabalah*, is the source of the English word "algebra". In Arabic *al-jabr* means "the equating". Al-Khwarizmi's name has also become an English word, "algorism", the old word for arithmetic. Al-Khwarizmi drew from both Greek and Hindu sources, and through his writings the decimal system and the use of zero were transmitted to the west.

One of the outstanding Arabic physicists was al-Hazen (965-1038). He made the mistake of claiming to be able to construct a machine which could regulate the flooding of the Nile. This claim won him a position in the service of the Egyptian Caliph, al-Hakim. However, as al-Hazen observed Caliph al-Hakim in action, he began to realize that if he did not construct his machine immediately, he was likely to pay with his life! This led al-Hazen to the rather desperate measure of pretending to be insane, a ruse which he kept up for many years. Meanwhile he did excellent work in optics, and in this field he went far beyond anything done by the Greeks.

Al-Hazen studied the reflection of light by the atmosphere, an effect which makes the stars appear displaced from their true positions when they are near the horizon; and he calculated the height of the atmospheric layer above the earth to be about ten miles. He also studied the rainbow, the halo, and the reflection of light from spherical and parabolic mirrors. In his book, *On the Burning Sphere*, he shows a deep understanding of the properties of convex lenses. Al-Hazen also used a dark room with a pin-hole opening to study the image of the sun during an eclipses. This is the first mention of the *camera obscura*, and it is perhaps correct to attribute the invention of the *camera obscura* to al-Hazen.

Another Islamic philosopher who had great influence on western thought was Averröes, who lived in Spain from 1126 to 1198. His writings took the form of thoughtful commentaries on the works of Aristotle. He shocked both his Moslem and his Christian readers by maintaining that the world was not created at a definite instant, but that it instead evolved over a long period of time, and is still evolving.

Like Aristotle, Averröes seems to have been groping towards the ideas of evolution which were later developed in geology by Steno, Hutton and Lyell and in biology by Darwin and Wallace. Much of the scholastic philosophy which developed at the University of Paris during the 13th century was aimed at refuting the doctrines of Averröes; but nevertheless, his ideas survived and helped to shape the modern picture of the world.

Muslims in Egypt and probably elsewhere were using printing to mass-produce texts as early as the 10th century. Dozens of examples of their output are preserved in museums and libraries, but have, until recently, been overlooked and neglected by scholars. This phenomenon is yet another example of the 1000-year missing history of science and technology.

It is, however, true that Muslims did not use printing to produce books, nor extended texts in any form, until the 18th century. This challenge was taken up by Europeans from the 15th century onwards, and it would not have been possible there, without the availability of another gift from the Muslims, paper, which had earlier reached Europe from the Muslim world, via Spain and Italy.

Figure 1.20: **A handwritten Islamic manuscript: Qazwini, 'Ajaib al-makhluqat, MS probably from Mosul, ca.1305. British Library.**

1.5 Gutenberg

Johannes Gensfleisch zur Laden zum Gutenberg (c.1400-1468) was born in the German city of Mainz. He was the youngest son of an upper-class merchant, Friele Gensfleisch zur Laden, whose long-established family traced its roots back to the 13th century.

Johannes Gutenberg was educated as a goldsmith and blacksmith, and may also have attended the University of Erfurt. In 1440, while he was living in Strassburg. he is said to have perfected and unveiled his system of printing with movable type.

By 1448, he was back in Mainz, where he took a loan from his brother-on-law to meet the expenses of setting up a printing press.In 1450, the press was in operation, and Gutenberg took a further loan, 800 guilders, from the moneylender Johann Fust. Peter Schöffer, who became Fust's son-in-law also joined the enterprise, and is believed to have designed the type faces.

Among the many technical innovations introduced by Gutenberg are the invention of a process for mass-producing movable type; the use of oil-based ink for printing books; adjustable molds; mechanical movable type; and the use of a wooden printing press similar to the agricultural screw presses of the period. The alloy which he used was a mixture of lead, tin, and antimony that melted at a relatively low temperature for faster and more economical casting, cast well, and created a durable type. The combination of all these elements made the mass production of books both practical and economically feasible.

Gutenberg's greatest artistic achievement was his printed Bible, but this project also cost so much that it left him with debts of more than 20,000 guilders. A court order gave Fust control of the Bible printing project, and half of the printed Bibles.

Although he had suffered bankruptcy, the aging Gutenberg's greatness was acknowledged in 1465. He was given the tithe "Hofmann" (Gentleman of the Court) and awarded a yearly stipend, as well as 2,180 liters of grain and 2,000 liters of wine tax-free. He died in 1468, having enjoyed this official recognition for only three years.

Printing quickly affected both religion and science in Europe. By 1517, when Martin Luther posted his Ninety-Five Theses on the door of All Saint's Church in Wittenburg, many cities has printing presses. The theses were quickly reprinted and translated, and they spread throughout Europe. This initiated a pamphlet war, in which both sides used printing to spread their views. The impact of Luther's German translation of the Bible was greatly increased by the fact that inexpensive printed copies were widely available.

Science was similarly revolutionized. Nicolaus Copernicus (1473-1543) had a far greater impact on the history of science than his near contemporary Leonardo da Vinci (1452-1519) because of printing. Leonardo's thousands of pages of notes and his innovations in virtually all the fields of human knowledge have only recently become available in printed form. By contrast, the publication Copernicus' great book, *De revolutionibus orbium coelestium* (On the Revolutions of the Celestial Spheres) initiated a sequence of discoveries by Tycho Brahe, Galileo, Johannes Kepler and Isaac Newton, discoveries upon which the modern world is built.

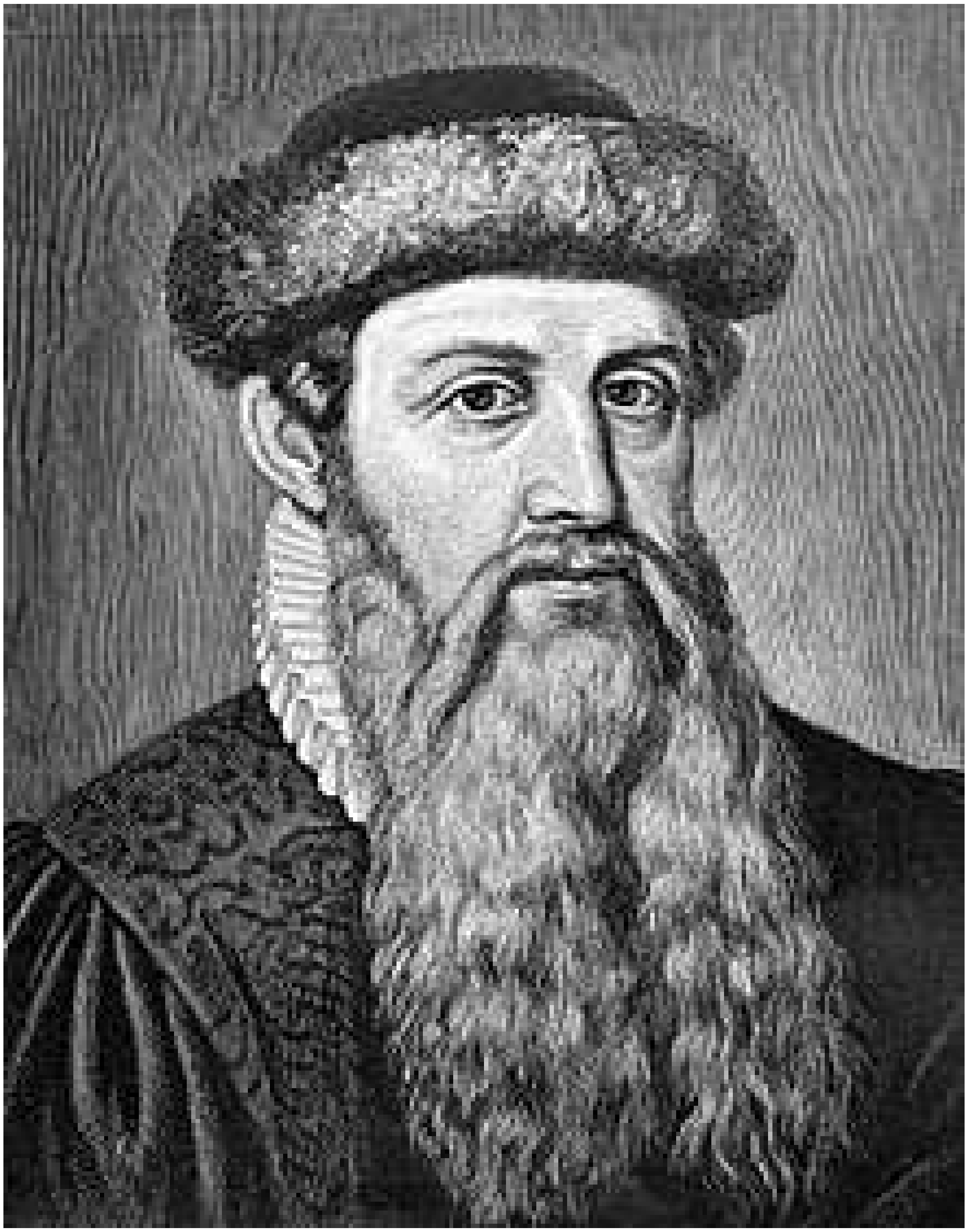

Figure 1.21: **Gutenberg is credited with introducing printing with movable type into Europe, with many improvements of technique. His inventions were a turning point in European history, and ushered in the modern era, the Reformation, the Age of Reason and the Industrial Revolution.**

Figure 1.22: **Gutenberg's printing press**

Figure 1.23: **Gutenberg's bible**

1.6 The Nestorians and Islam

After the burning of the great library at Alexandria and the destruction of Hellenistic civilization, most of the books of the classical Greek and Hellenistic philosophers were lost. However, a few of these books survived and were translated from Greek, first into Syriac, then into Arabic and finally from Arabic into Latin. By this roundabout route, fragments from the wreck of the classical Greek and Hellenistic civilizations drifted back into the consciousness of the west.

We mentioned that the Roman empire was ended in the 5th century A.D. by attacks of barbaric Germanic tribes from northern Europe. However, by that time, the Roman empire had split into two halves. The eastern half, with its capital at Byzantium (Constantinople), survived until 1453, when the last emperor was killed vainly defending the walls of his city against the Turks.

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The skill of the physicians of the Bukht-Yishu family convinced the Caliphs of the value of Greek learning; and in this way the family played an extremely important role in the preservation of the western cultural heritage. Caliph al-Mamun, the son of Harun al-Rashid, established at Baghdad a library and a school for translation, and soon Baghdad replaced Gondisapur as a center of learning.

1.7 Outstanding Islamic contributions to civilization

The English word "chemistry" is derived from the Arabic words *"al-chimia"*, which mean "the changing". The earliest alchemical writer in Arabic was Jabir (760-815), a friend of Harun al-Rashid. Much of his writing deals with the occult, but mixed with this is a certain amount of real chemical knowledge. For example, in his *Book of Properties*, Jabir gives the following recipe for making what we now call lead hydroxycarbonate (white lead), which is used in painting and pottery glazes:

"Take a pound of litharge, powder it well and heat it gently with four pounds of vinegar until the latter is reduced to half its original volume. The take a pound of soda and heat it with four pounds of fresh water until the volume of the latter is halved. Filter the two

Figure 1.24: **A painting of Caliph Harun al-Rashid.**

solutions until they are quite clear, and then gradually add the solution of soda to that of the litharge. A white substance is formed, which settles to the bottom. Pour off the supernatant water, and leave the residue to dry. It will become a salt as white as snow."

Another important alchemical writer was Rahzes (c. 860 - c. 950). He was born in the ancient city of Ray, near Teheran, and his name means "the man from Ray". Rhazes studied medicine in Baghdad, and he became chief physician at the hospital there. He wrote the first accurate descriptions of smallpox and measles, and his medical writings include methods for setting broken bones with casts made from plaster of Paris. Rahzes was the first person to classify substances into vegetable, animal and mineral. The word *"al-kali"*, which appears in his writings, means "the calcined" in Arabic. It is the source of our word "alkali", as well as of the symbol K for potassium.

The greatest physician of the middle ages, Avicenna, (Abu-Ali al Hussain Ibn Abdullah Ibn Sina, 980-1037), was also a Persian, like Rahzes. More than a hundred books are attributed to him. They were translated into Latin in the 12th century, and they were among the most important medical books used in Europe until the time of Harvey. Avicenna also wrote on alchemy, and he is important for having denied the possibility of transmutation of elements.

In mathematics, one of the most outstanding Arabic writers was al-Khwarizmi (c. 780 - c. 850). The title of his book, *Ilm al-jabr wa'd muqabalah*, is the source of the English word "algebra". In Arabic *al-jabr* means "the equating". Al-Khwarizmi's name has also become an English word, "algorism", the old word for arithmetic. Al-Khwarizmi drew from both Greek and Hindu sources, and through his writings the decimal system and the

Figure 1.25: **In mathematics, one of the most outstanding Arabic writers was al-Khwarizmi (c.780 - c.850), commemorated here on a Russian stamp Public domain, Wikimedia Commons**

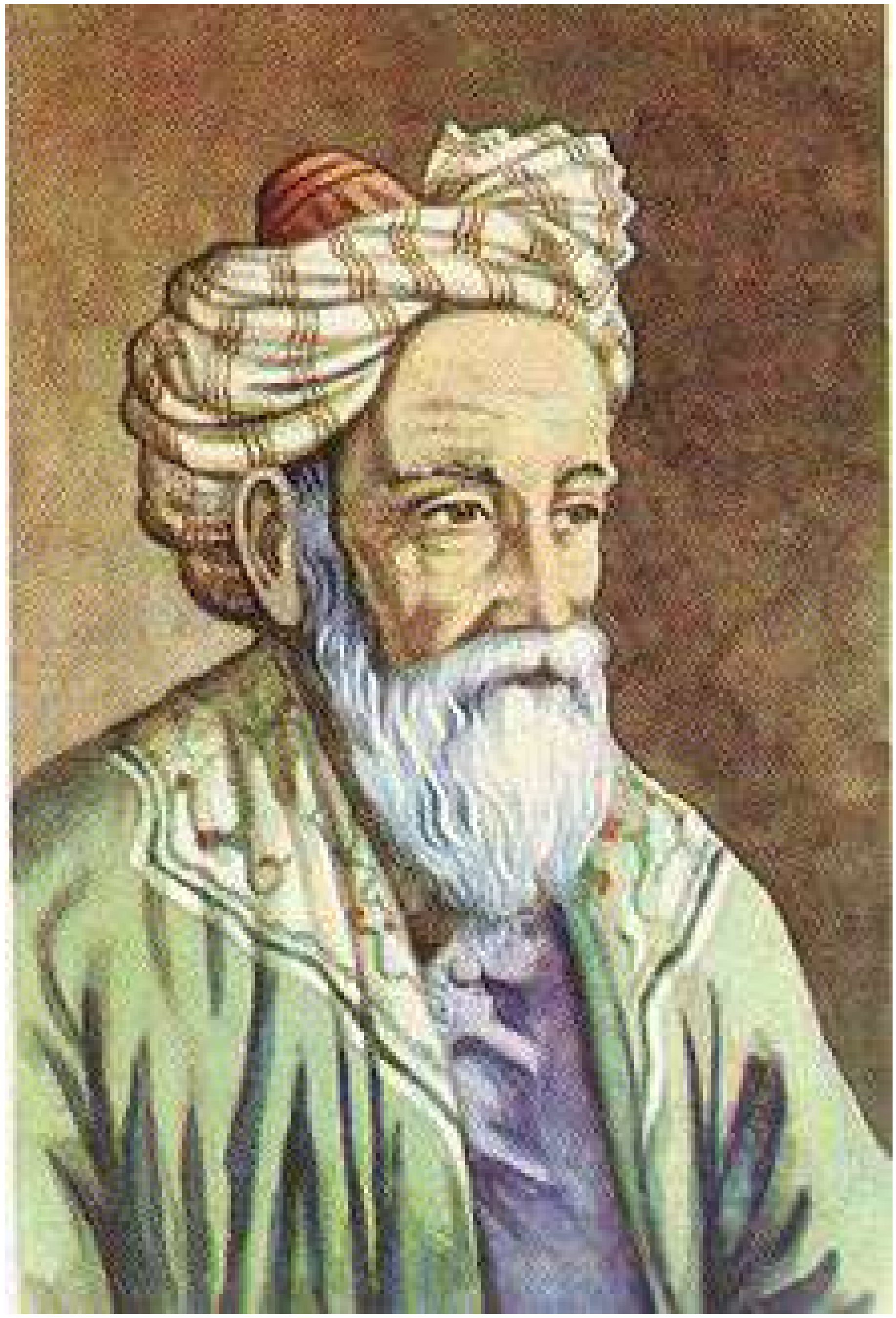

Figure 1.26: **Omar Khayyam (1048-1131) was a Persian mathematician, astronomer and poet. His work in mathematics was notable for his solutions to cubic equations, his understanding of the binomial theorem, and his discussions of the axioms of Euclid. As an astronomer, he directed the building of an observatory to reform the Persian calendar. Omar Khayyam's long poem, *Rubaiyat*, is known to western readers through Edward Fitzgerald's brilliant translation.**

use of zero were transmitted to the west.

Another Islamic philosopher who had great influence on western thought was Averröes, who lived in Spain from 1126 to 1198. His writings took the form of thoughtful commentaries on the works of Aristotle. He shocked both his Moslem and his Christian readers by maintaining that the world was not created at a definite instant, but that it instead evolved over a long period of time, and is still evolving.

Like Aristotle, Averröes seems to have been groping towards the ideas of evolution which were later developed in geology by Steno, Hutton and Lyell and in biology by Darwin and Wallace. Much of the scholastic philosophy which developed at the University of Paris during the 13th century was aimed at refuting the doctrines of Averröes; but nevertheless, his ideas survived and helped to shape the modern picture of the world.

Figure 1.27: **Avicenna (c.980-1037) was a Persian astronomer, philosopher, and physician. He was one of the most influential thinkers of the Islamic Golden Age. Of the 450 works he is believed to have written, around 240 have survived, including 150 on philosophy and 40 on medicine. Avicenna's famous book. "The Canon of Medicine", was a standard medical text in many midievil European universities, and was still in use as late as 1650. The statue of Avicenna shown here is in the United Nations Office in Vienna.**

Figure 1.28: **Ulugh Beg (1394-1449), whose statue is shown here, was the ruler of the Samarkand region of present-day Uzbekistan. He was also a notable astronomer and mathematician. Ulugh Beg made important contributions to spherical geometry and trigonometry. For example, he made tables of trigonometric functions which are accurate to five significant figures. He spoke five languages, including Arabic, Persian, Turkic, Mongolian, and a little Chinese.**

1.8 Translations from Arabic to Latin in Toledo

In the 12th century, parts of Spain, including the city of Toledo, were reconquered by the Christians. Toledo had been an Islamic cultural center, and many Muslim scholars, together with their manuscripts, remained in the city when it passed into the hands of the Christians. Thus Toledo became a center for the exchange of ideas between east and west; and it was in this city that many of the books of the classical Greek and Hellenistic philosophers were translated from Arabic into Latin.

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In the 12th century, the translation was confined to books of science and philosophy. Classical Greek literature was forbidden by both the Christian and Moslem religions; and the beautiful poems and dramas of Homer, Sophocles and Euripides were not translated into Latin until the time of the Renaissance Humanists.

It is interesting and inspiring to visit Toledo. A tourist there can see ample evidence of

Figure 1.29: **Mosaics at the Alhambra**

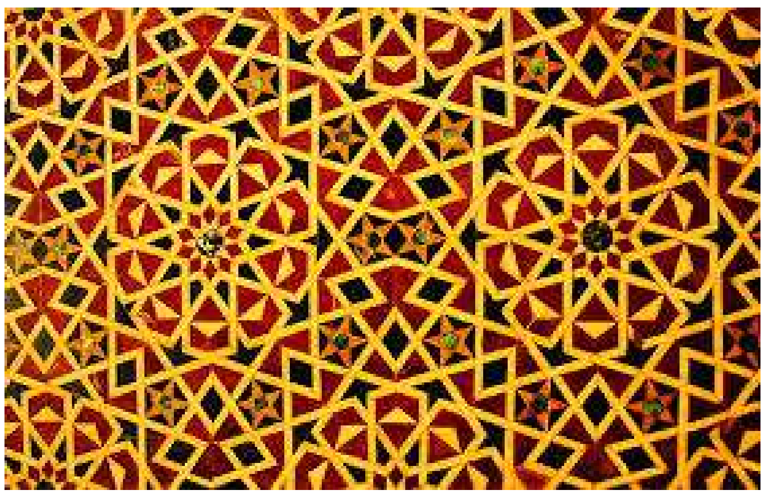

Figure 1.30: **Mosaics at the Alhambra**

a period of tolerance and enlightenment, when members of the three Abrahamic religions, Christianity, Judaism and Islam , lived side by side in harmony and mutual respect, exchanging important ideas which were to destined to become the foundations of our modern civilization. One can also see a cathedral, a mosque and a synagogue, in each of which craftsmen from all three faiths worked cooperatively to produce a beautiful monument to human solidarity.

Figure 1.31: **A view of Toledo**

1.9 East-west contacts during the Renaissance

Towards the end of the middle ages, Europe began to be influenced by the advanced Islamic civilization. European scholars were anxious to learn, but there was an "iron curtain" of religious intolerance which made travel in the Islamic countries difficult and dangerous for Christians. However, in the 12th century, parts of Spain, including the city of Toledo, were reconquered by the Christians. Toledo had been an Islamic cultural center, and many Moslem scholars, together with their manuscripts, remained in the city when it passed into the hands of the Christians. Thus Toledo became a center for the exchange of ideas between east and west; and it was in this city that many of the books of the classical Greek and Hellenistic philosophers were translated from Arabic into Latin.

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During the Mongol period (1279-1328), direct contact between Europe and China was possible because the Mongols controlled the entire route across central Asia; and during this period Europe received from China three revolutionary inventions: printing, gunpowder and the magnetic compass.

Another bridge between east and west was established by the crusades. In 1099, taking advantage of political divisions in the Moslem world, the Christians conquered Jerusalem and Palestine, which they held until 1187. This was the first of a series of crusades, the last of which took place in 1270. European armies, returning from the Middle East, brought with them a taste for the luxurious spices, textiles, jewelry, leatherwork and fine steel weapons of the orient; and their control of the Mediterranean sea routes made trade with the east both safe and profitable. Most of the profit from this trade went to a few cities, particularly to Venice and Florence.

At the height of its glory as a trading power, the Venetian Republic maintained six fleets of nationally owned ships, which could be chartered by private enterprise. All the ships of this fleet were of identical construction and rigged with identical components, so that parts could be replaced with ease at depots of the Venetian consular service abroad. The ships of these fleets could either serve as merchant ships, or be converted into warships by the addition of guns. Protected by a guard of such warships, large convoys of Venetian merchant ships could sail without fear of plunder by pirates.

In 1420, at the time of Venice's greatest commercial expansion, the doge, Tommaso Mocenigo, estimated the annual turnover of Venetian commerce to be ten million ducats, of which two million was profit. With this enormous income to spend, the Venetians built a city of splendid palaces, which rose like a shimmering vision above the waters of the lagoon.

The Venetians were passionately fond of pleasure, pageantry and art. The cross-shaped church of Saint Mark rang with the music of great composers, such as Gabrieli and Palestrina; and elegant triumphal music accompanied the doge as he went each year to throw a golden ring into the waters of the lagoon, an act which symbolized the marriage of Venice to the sea.

Like the Athenians after their victory in the Persian war, the Venetians were both rich and confident. Their enormous wealth allowed them to sponsor music, art, literature and science. The painters Titian, Veronese, Giorgione and Tintoretto, the sculptor Verrocchio and the architect Palladio all worked in Venice at the height of the city's prosperity.

The self-confidence of the Venetians produced a degree of intellectual freedom which was not found elsewhere in Europe at that time, except in Florence. At the University of Padua, which was supported by Venetian funds, students from all countries were allowed to study regardless of their religious beliefs. It was at Padua that Copernicus studied, and there Andreas Vesalius began the research which led to his great book on anatomy. At one point in his career, Galileo also worked at the University of Padua.

The prosperity of 15th century Florence, like that of Venice, was based on commerce. In the case of Florence, the trade was not by sea, but along the main north-south road of Italy, which crossed the Arno at Florence. In addition to this trade, Florence also had an important textile industry. The Florentines imported wool from France, Flanders, Holland and England. They wove the wool into cloth and dyed it, using superior techniques, many of which had come to them from India by way of the Islamic civilization. Later, silk weaving (again using eastern techniques) became important. Florentine banking was also highly developed, and our present banking system is derived from Florentine commercial practices.

1.10 Leonardo da Vinci

Against this background, it may seem strange that Lorenzo the Magnificent did not form a closer relationship with Leonardo da Vinci, the most talented student of Verrocchio's school in Florence. One might have expected a close friendship between the two men, since

Lorenzo, only four years older than Leonardo, was always quick to recognize exceptional ability.

The explanation probably lies in Leonardo's pride and sensitivity, and in the fact that, while both men were dedicated to knowledge, they represented different points of view. Lorenzo was full of enthusiasm for the revival of classical learning, while Leonardo had already taken the next step: Rejecting all blind obedience to authority, including the authority of the ancients, he relied on his own observations. Lorenzo was fluent in Latin and Greek, and was widely educated in Greek philosophy, while Leonardo was ignorant of both languages and was largely self-taught in philosophy and science (although he had studied mathematics at the school of Benedetto d'Abacco).

While he did not form a close friendship with Lorenzo the Magnificent, Leonardo was lucky in becoming the friend and protegé of the distinguished Florentine mathematician, physician, geographer and astronomer, Paolo Toscanelli, who was also the friend and advisor of Columbus. (Toscanelli furnished Columbus with maps of the world and encouraged him in his project of trying to reach India and China by sailing westward. Toscanelli's maps mistakenly showed the Atlantic Ocean with Europe on one side, and Asia on the other!)

Gradually, under Toscanelli's influence, young Leonardo's powerful and original mind was drawn away from the purely representational aspects of art, and he became more and more involved in trying to understand the underlying structure and mechanism of the things which he observed in nature - the bodies of men and animals, the flight of birds, the flow of fluids and the features of the earth.

Both in painting and in science, Leonardo looked directly to nature for guidance, rather than to previous masters. He wrote:

"The painter will produce pictures of small merit if he takes as his standard the pictures of others; but if he will study from natural objects, he will produce good fruits... And I would say about these mathematical studies, that those who study the authorities and not the works of nature are descendents but not sons of nature."

In another place, Leonardo wrote:

"But first I will test with experiment before I proceed further, because my intention is to consult experience first, and then with reasoning to show why such experience is bound to operate in such a way. And that is the true rule by which those who analyze the effects of nature must proceed; and although nature begins with the cause and ends with the experience, we must follow the opposite course, namely (as I said before) begin with the experience and by means of it investigate the cause."

Lorenzo the Magnificent finally did help Leonardo in a backhanded way: In 1481, when Leonardo was 29 years old, Lorenzo sent him as an emissary with a gift to the Duke of Milan, Ludovico Sforza. Although Milan was far less culturally developed than Florence, Leonardo stayed there for eighteen years under the patronage of Sforza. He seemed to work better in isolation, without the competition and criticism of the Florentine intellectuals.

In Milan, Leonardo began a series of anatomical studies which he developed into a book, intended for publication. Leonardo's anatomical drawings make previous work in this field seem like the work of children, and in many respects his studies were not surpassed for hundreds of years. Some of his anatomical drawings were published in a book by Fra Pacioli, and they were very influential; but most of the thousands of pages of notes which Leonardo wrote have only been published in recent years.

The notebooks of Leonardo da Vinci cover an astonishing range of topics: mathematics, physics, astronomy, optics, engineering, architecture, city planing, geology, hydrodynamics and aerodynamics, anatomy, painting and perspective, in addition to purely literary works. He was particularly interested in the problem of flight, and he made many studies of the flight of birds and bats in order to design a flying machine. Among his notes are designs for a helicopter and a parachute, as well as for a propeller-driven flying machine.

In astronomy, Leonardo knew that the earth rotates about its axis once every day, and he understood the physical law of inertia which makes this motion imperceptible to us except through the apparent motion of the stars. In one of his notebooks, Leonardo wrote: "The sun does not move." However, he did not publish his ideas concerning astronomy. Leonardo was always planning to organize and publish his notes, but he was so busy with his many projects that he never finished the task. At one point, he wrote what sounds like a cry of despair: "Tell me, tell me if anything ever was finished!"

Leonardo ended his life in the court of the king of France, Francis I. The king gave him a charming chateau in which to live, and treated him with great respect. Francis I visited Leonardo frequently in order to discuss philosophy, science and art; and when Leonardo died, the king is said to have wept openly.

1.11 Some of Leonardo's engineering drawings

According to Wikipedia,

Leonardo was a master of mechanical principles. He utilized leverage and cantilevering, pulleys, cranks, gears, including angle gears and rack and pinion gears; parallel linkage, lubrication systems and bearings. He understood the principles governing momentum, centripetal force, friction and the aerofoil and applied these to his inventions. His scientific studies remained unpublished with, for example, his manuscripts describing the processes governing friction predating the introduction of Amontons' laws of friction by 150 years.

It is impossible to say with any certainty how many or even which of his inventions passed into general and practical use, and thereby had impact over the lives of many people. Among those inventions that are credited with passing into general practical use are the strut bridge, the automated bobbin winder, the rolling mill, the machine for testing the tensile strength of wire and the lens-grinding machine pictured at right. In the lens-grinding machine, the hand rotation of the grinding wheel operates an angle-gear, which rotates a shaft, turning a geared dish in which sits the glass or crystal to be ground. A single action rotates both surfaces at a fixed speed ratio determined by the gear.

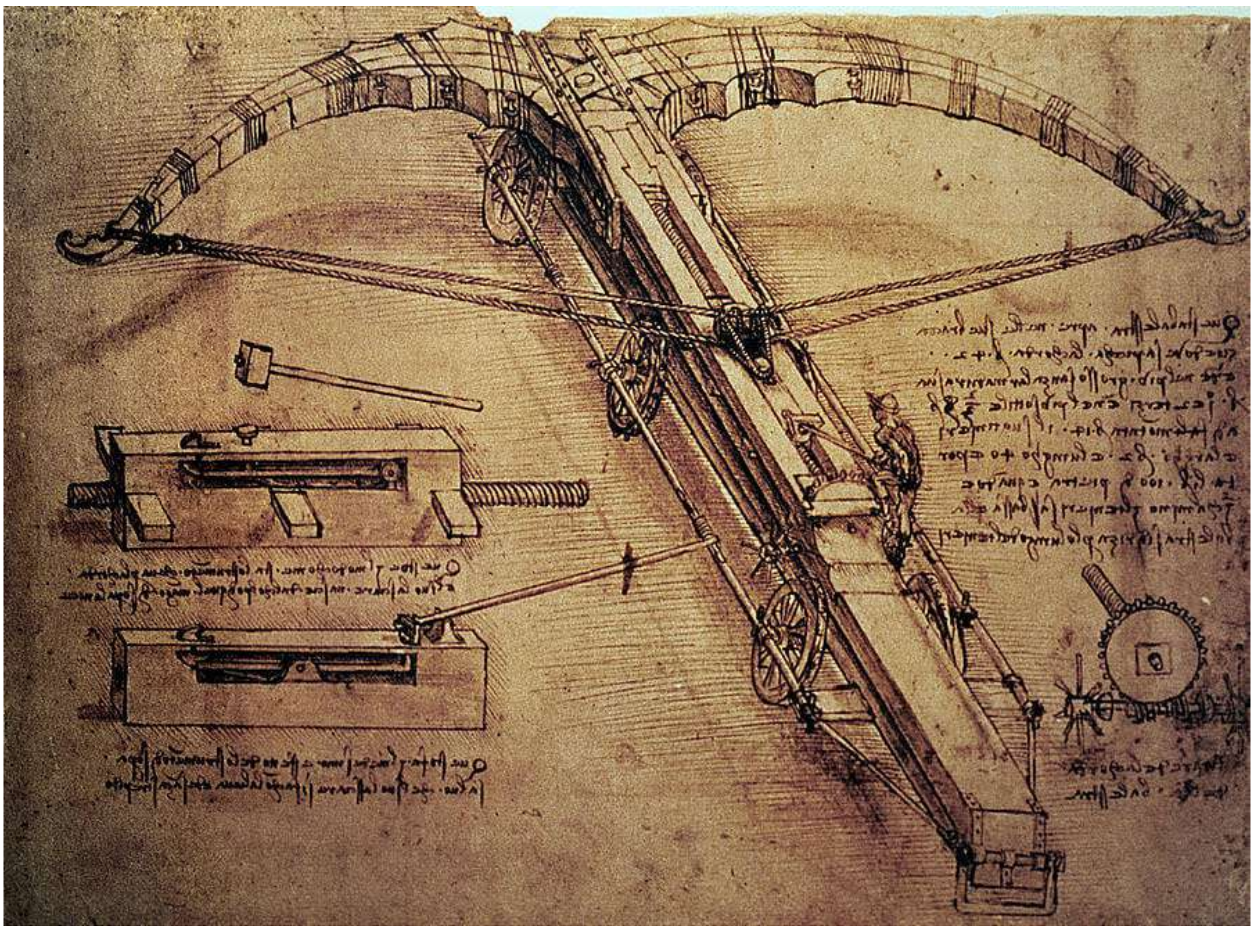

Figure 1.32: **Design for a crossbow.**

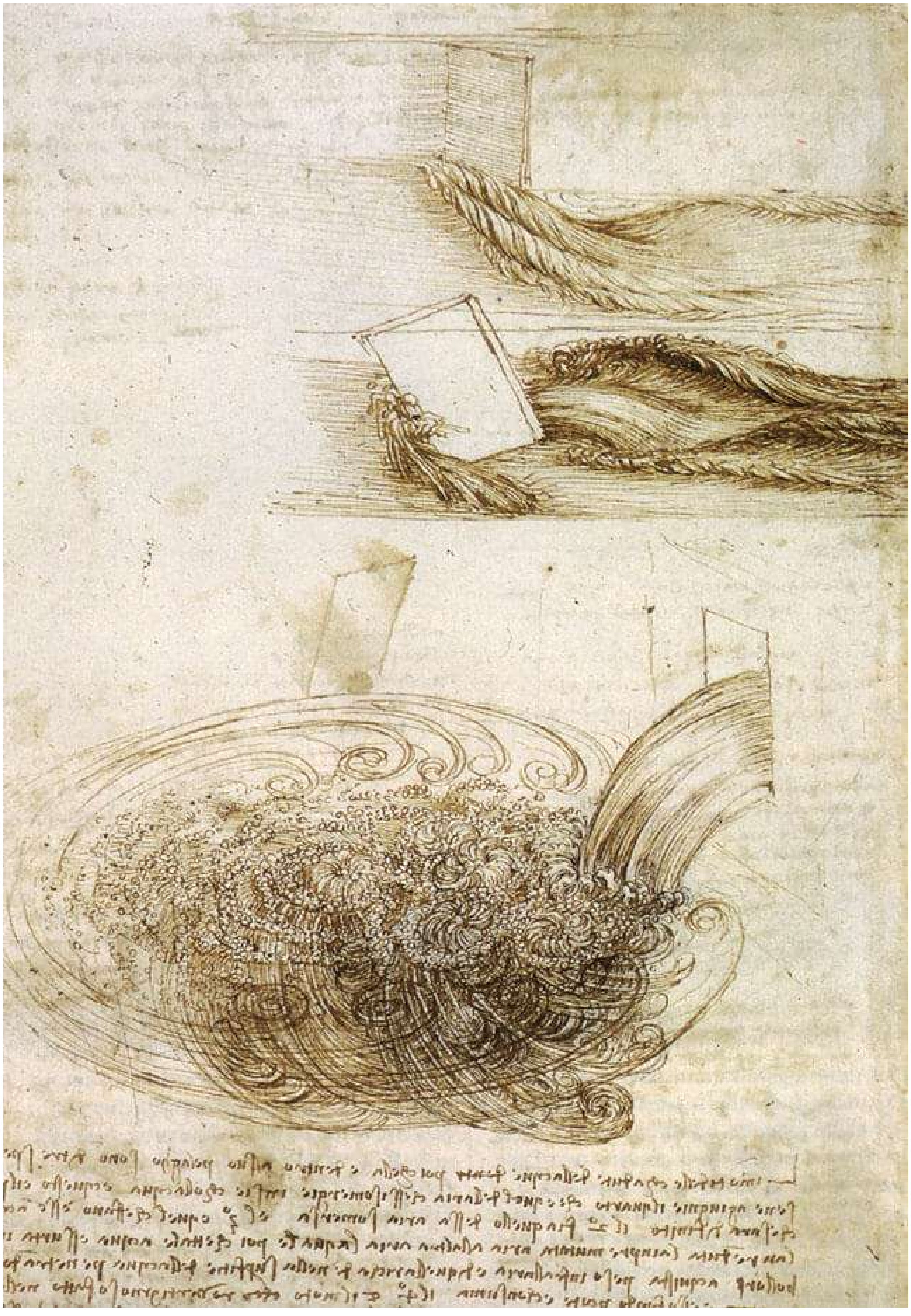

Figure 1.33: **Studies of Water Passing Obstacles.**

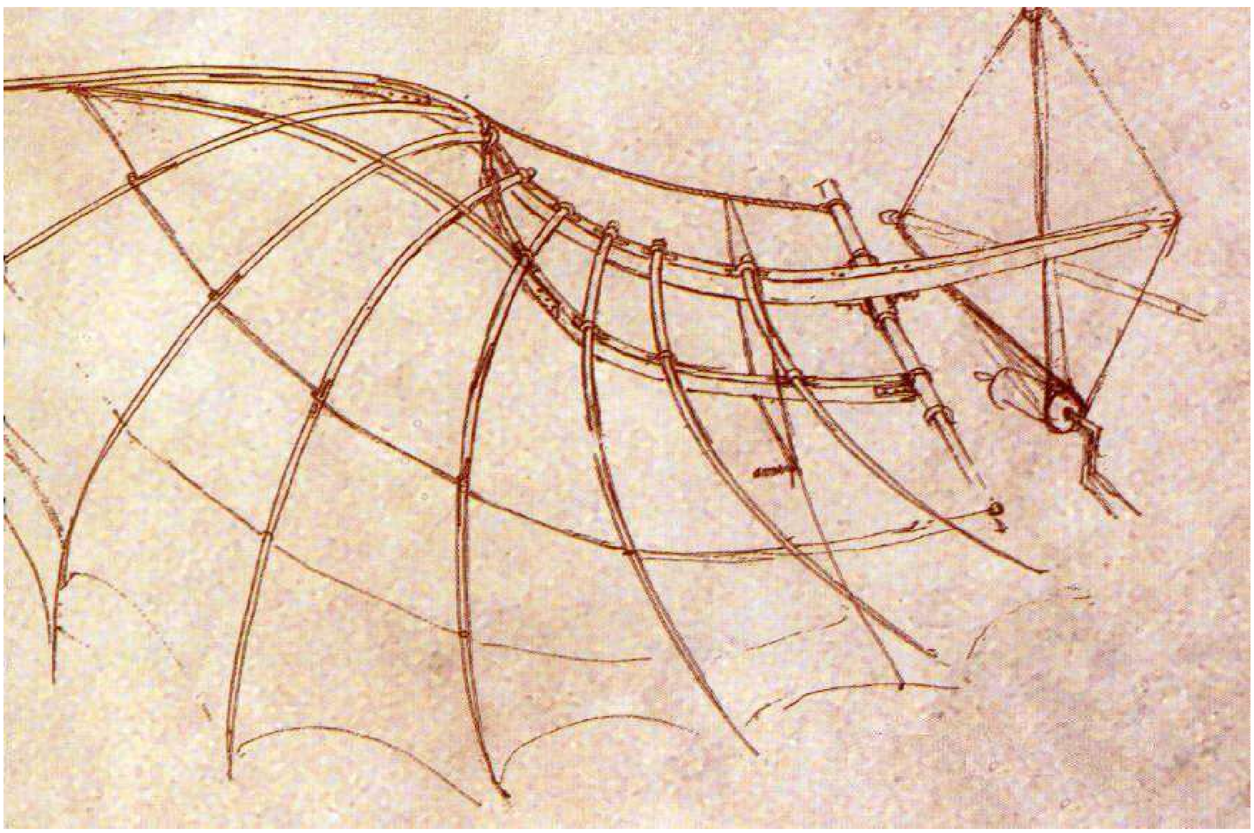

Figure 1.34: **Wing Construction with Engineering Design.**

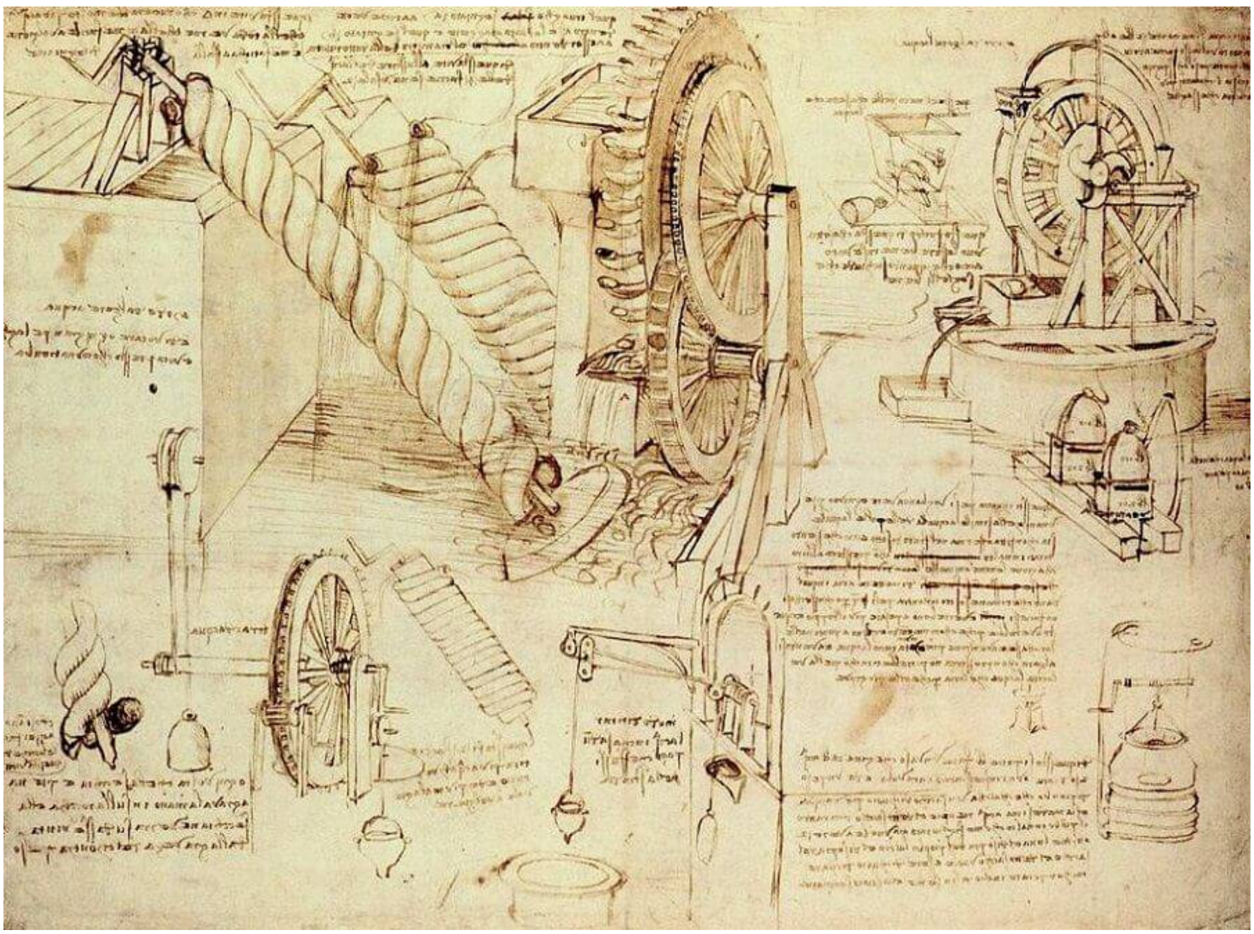

Figure 1.35: **Water Lifting Devices.**

Figure 1.36: **A Plan of Imola.**

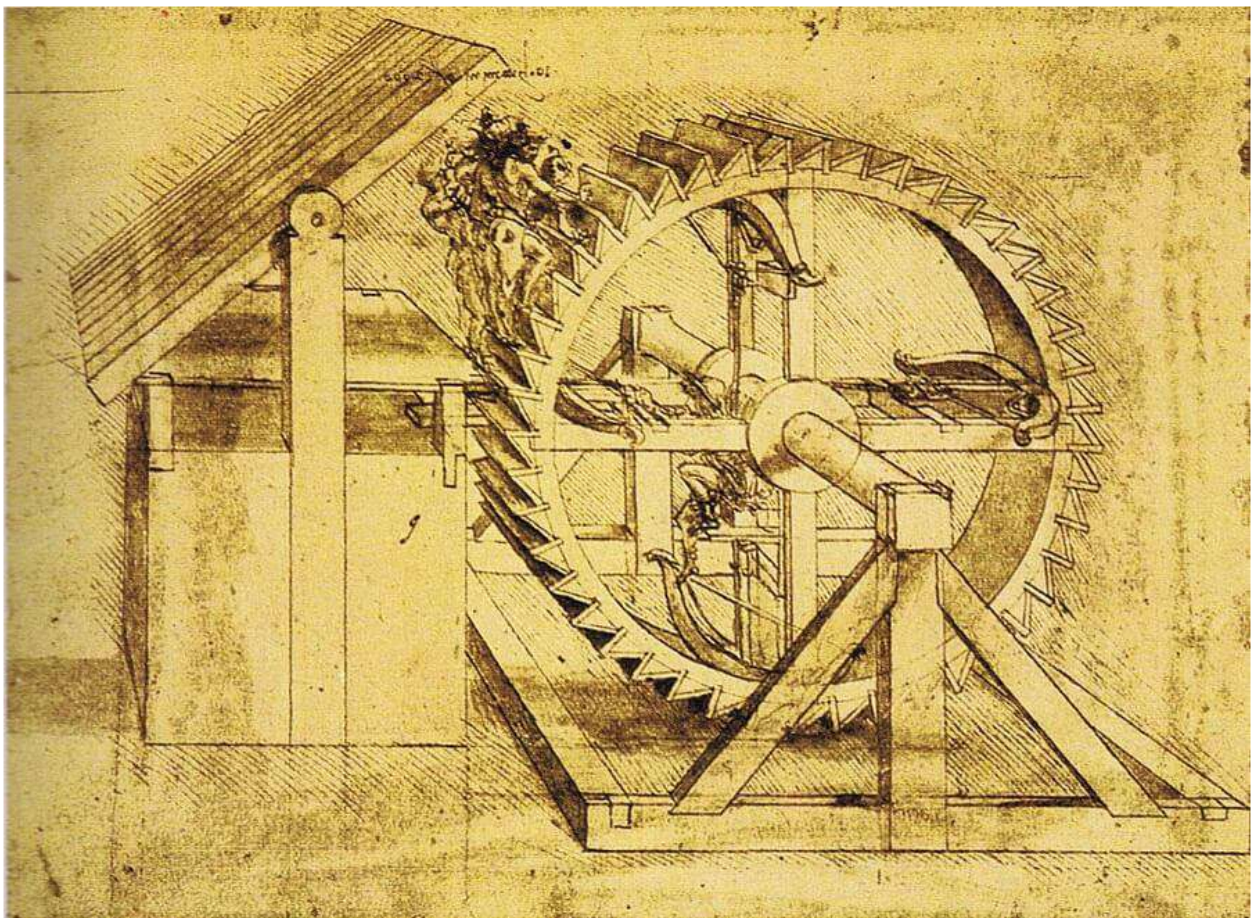

Figure 1.37: **Machine Gun.**

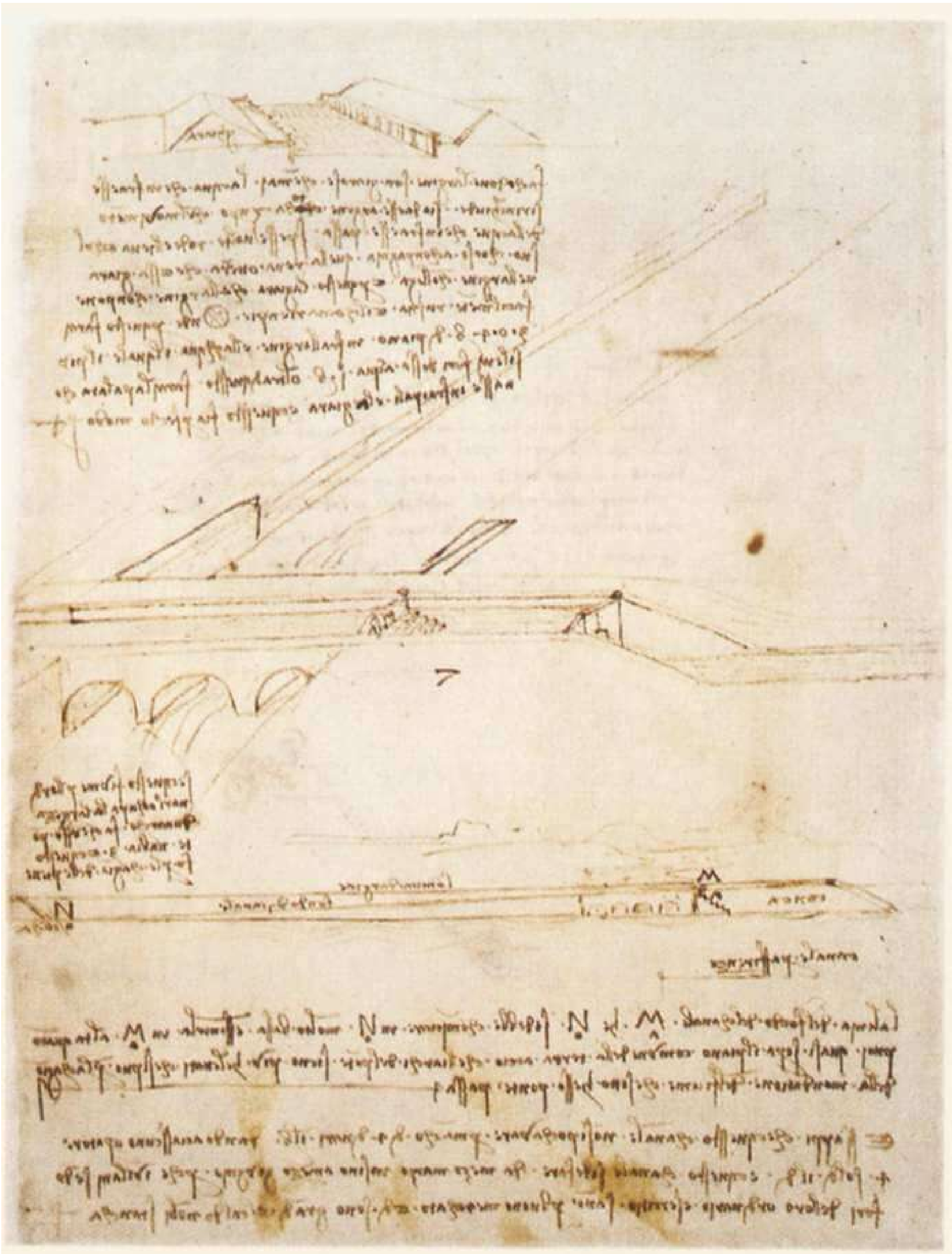

Figure 1.38: **Canal bridge.**

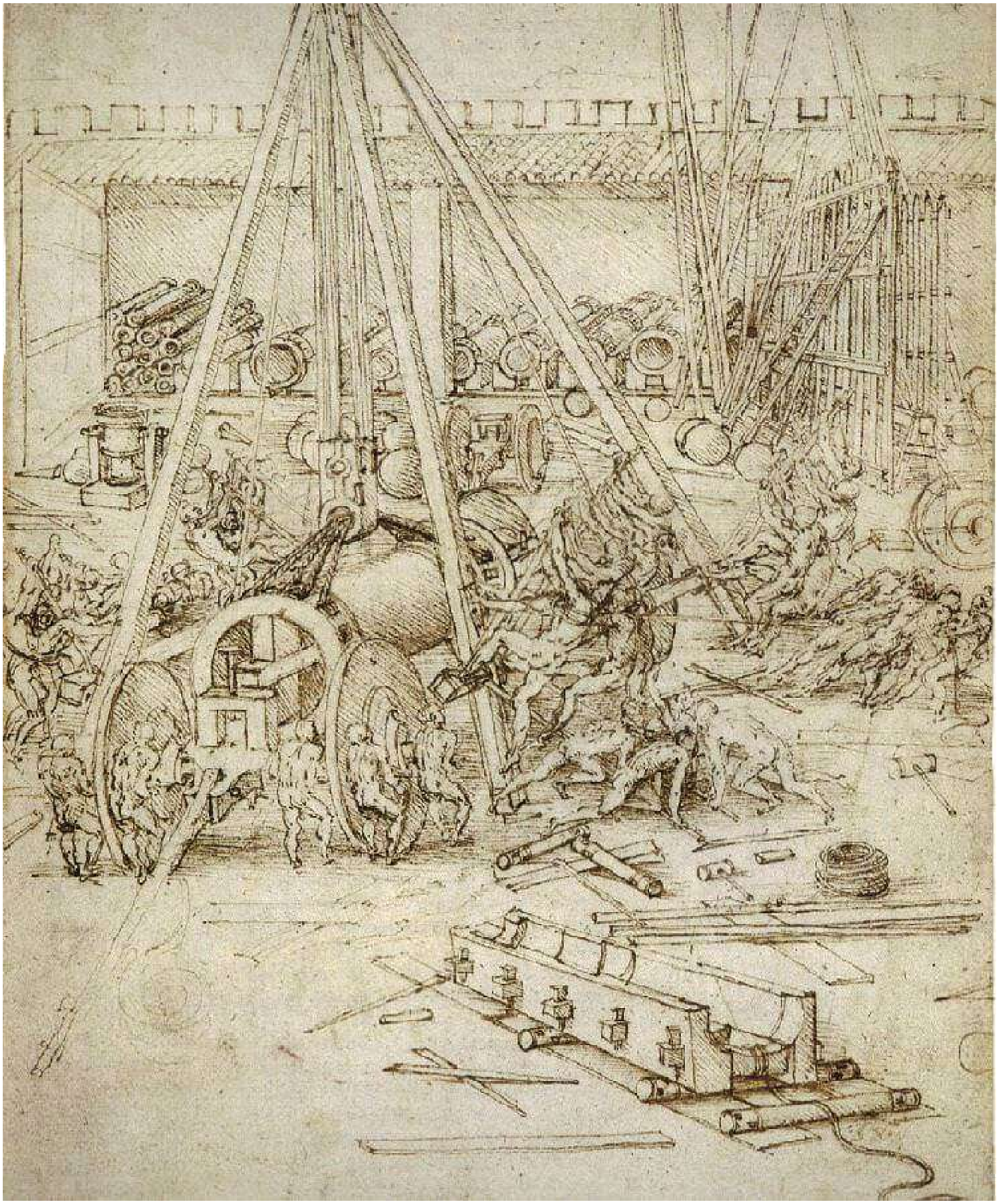

Figure 1.39: **Cannon Foundry, 1488.**

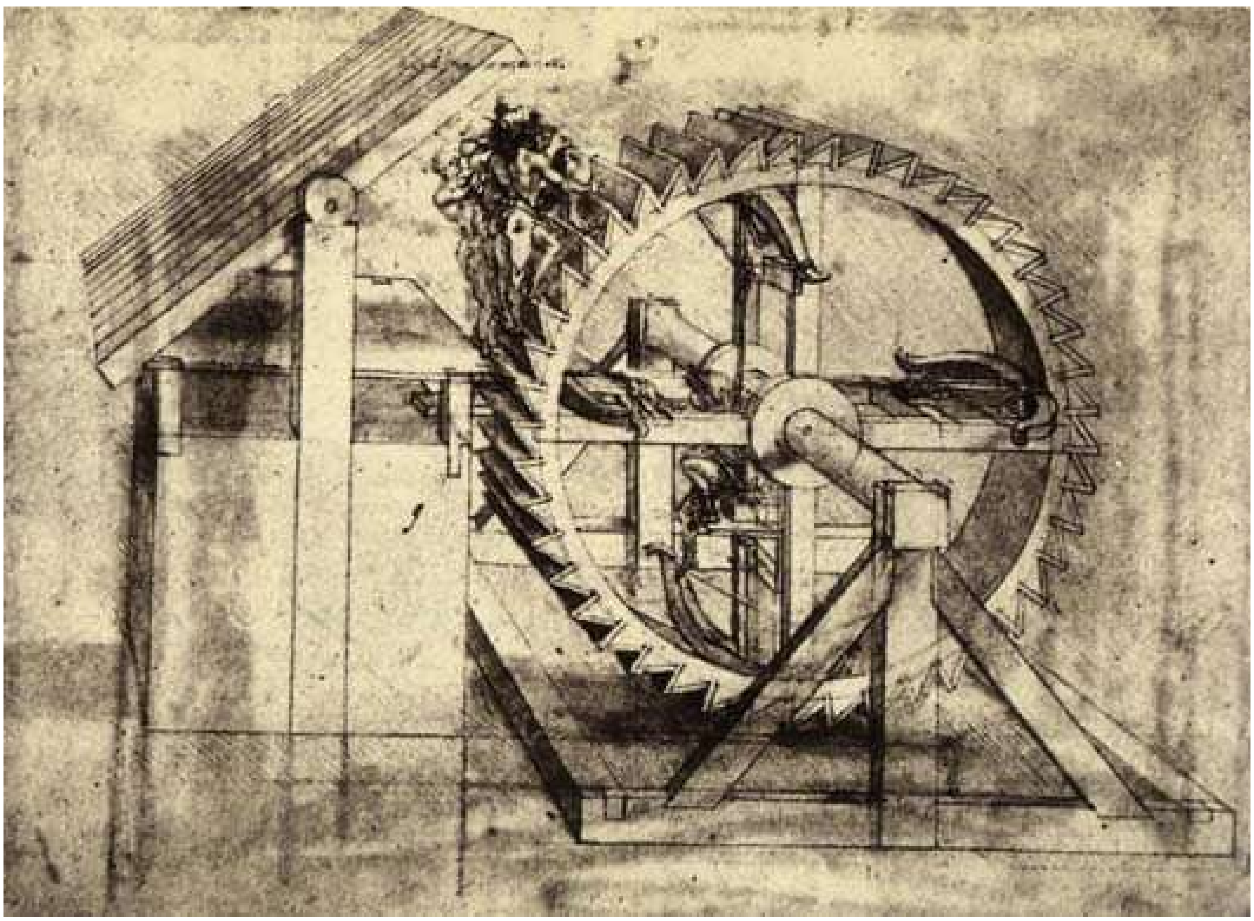

Figure 1.40: **Crossbow machine.**

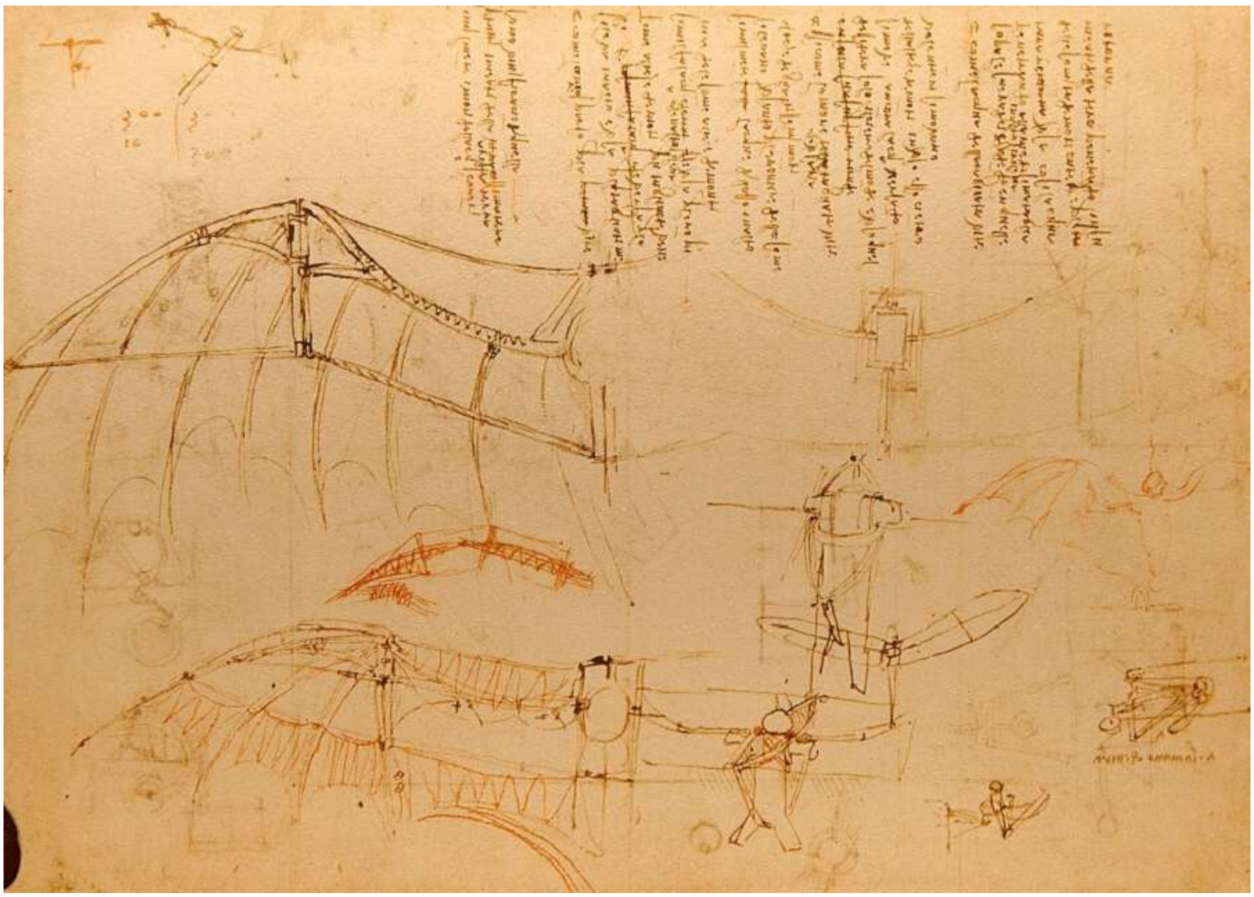

Figure 1.41: **Design for a flying machine.**

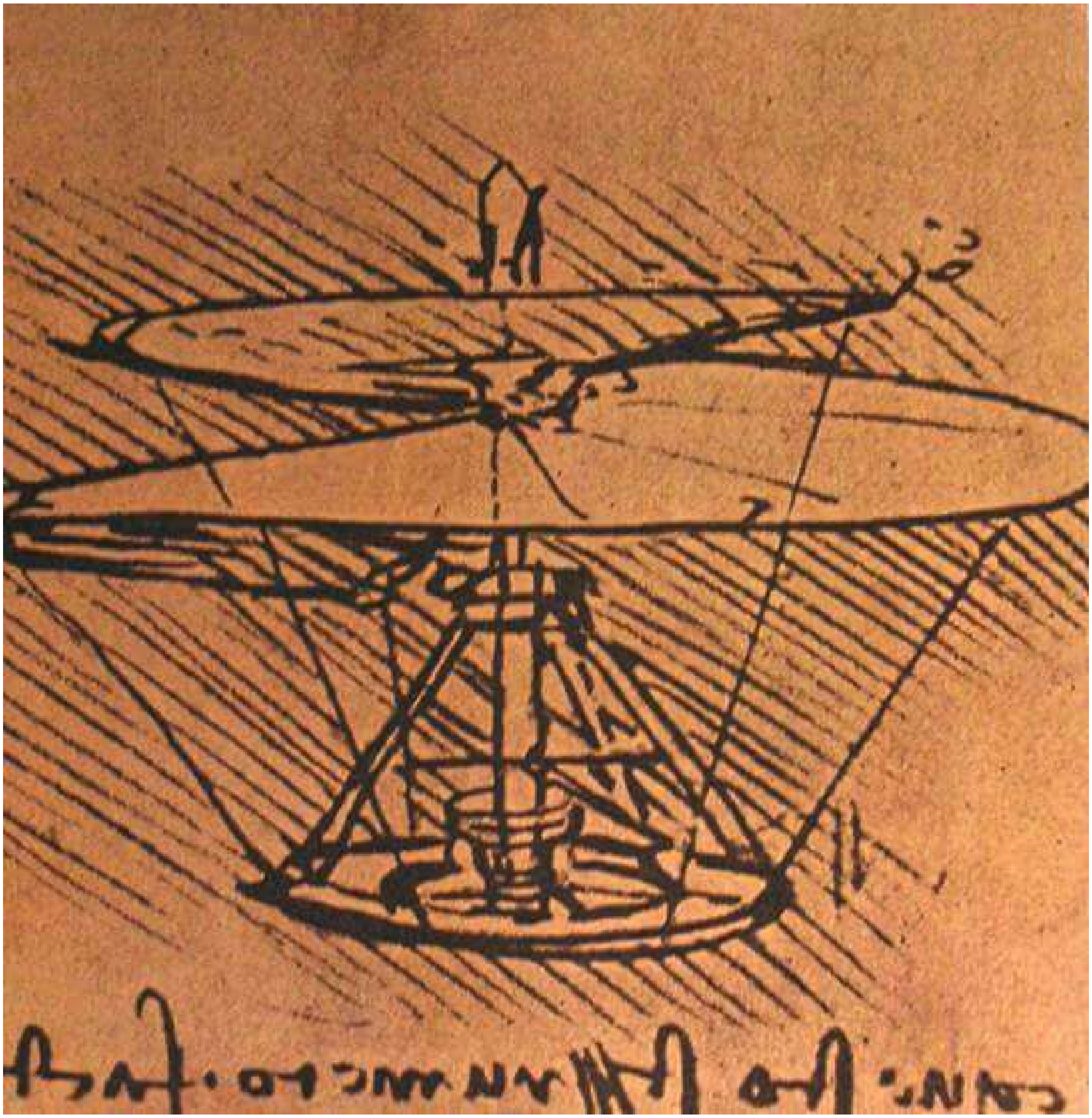

Figure 1.42: **Design for a helicopter.**

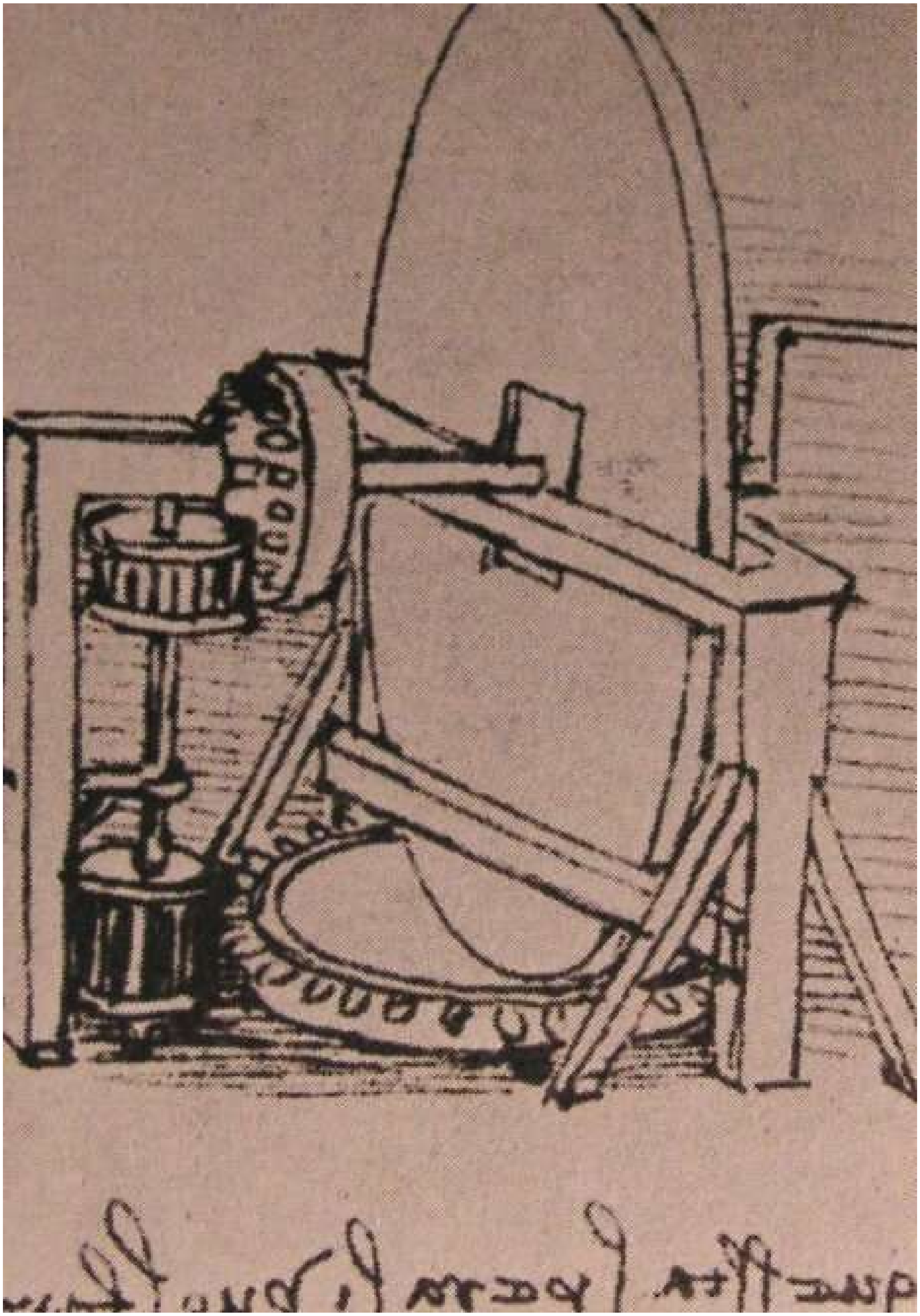

Figure 1.43: **Design for a machine for grinding convex lenses.**

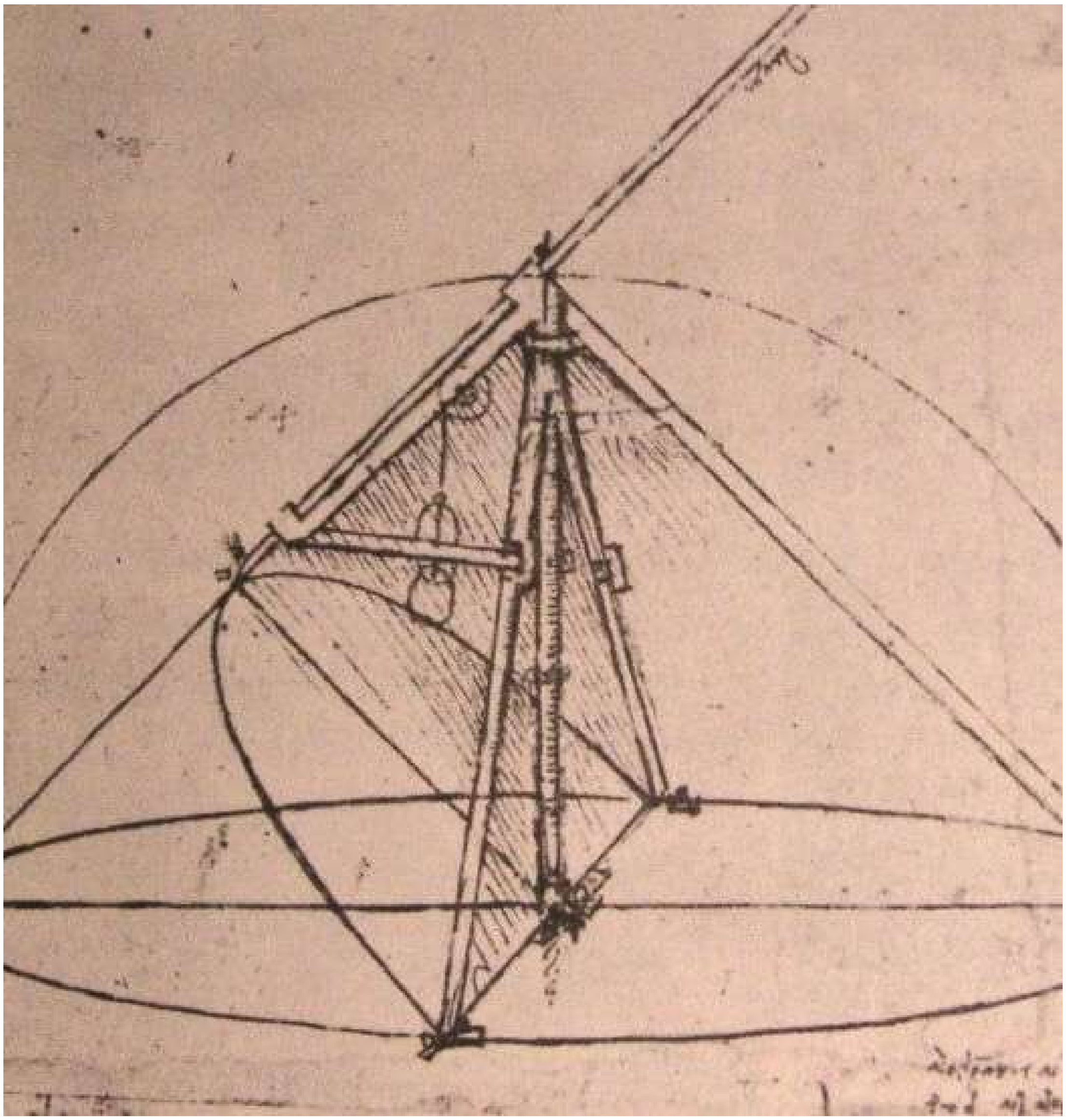

Figure 1.44: **Design for a parabolic compass.**

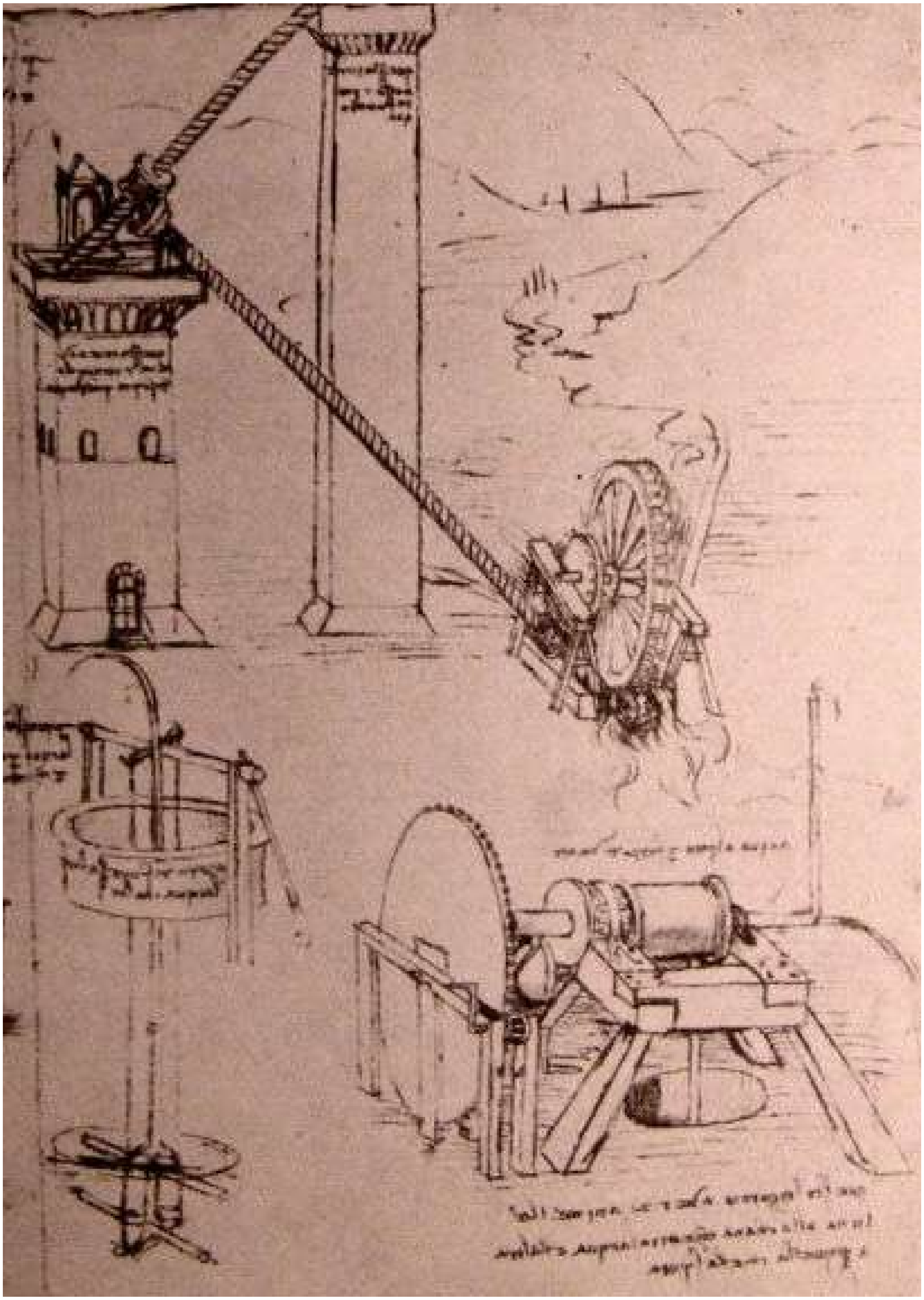

Figure 1.45: **Drawings of machines.**

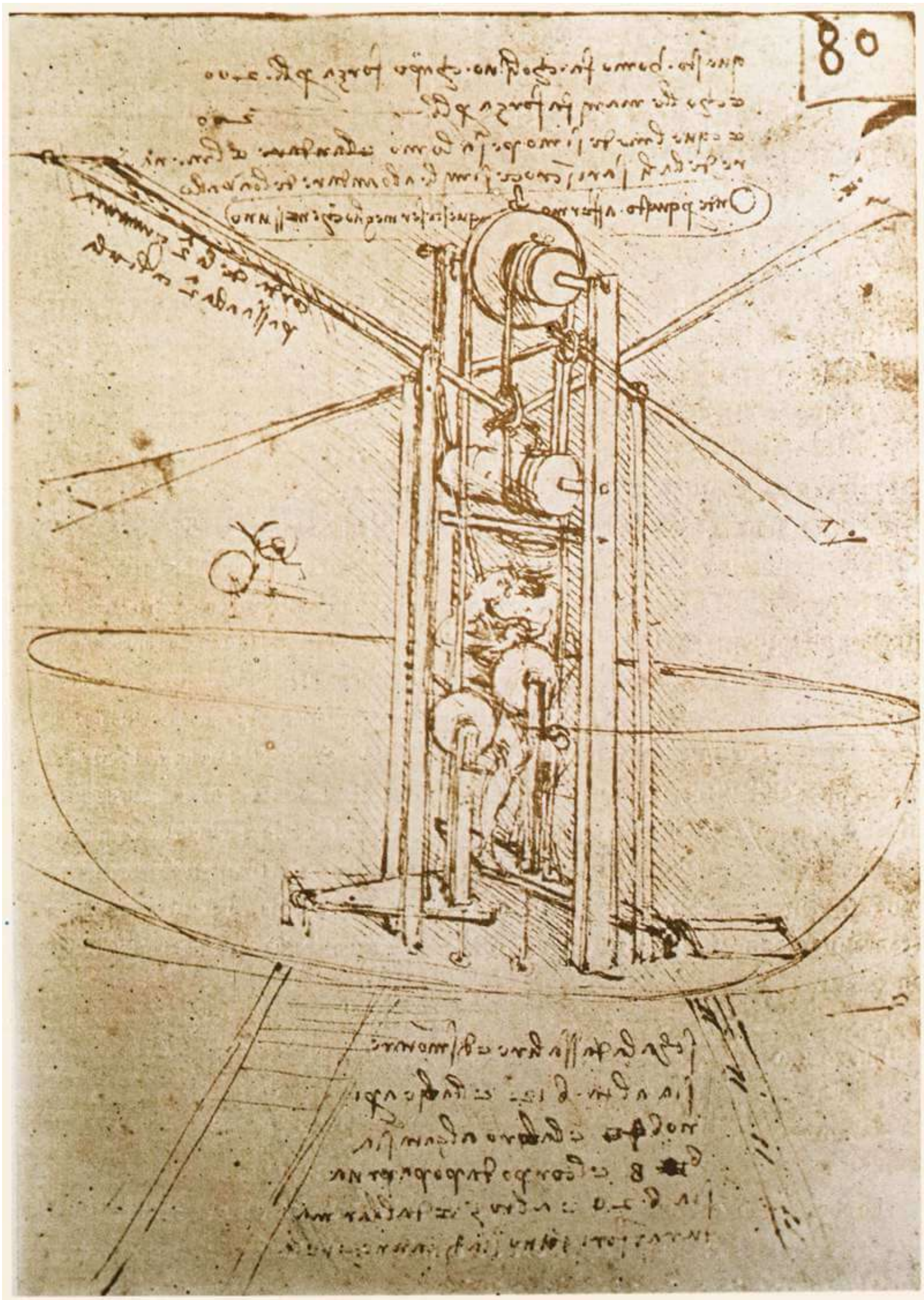

Figure 1.46: **Flying machine.**

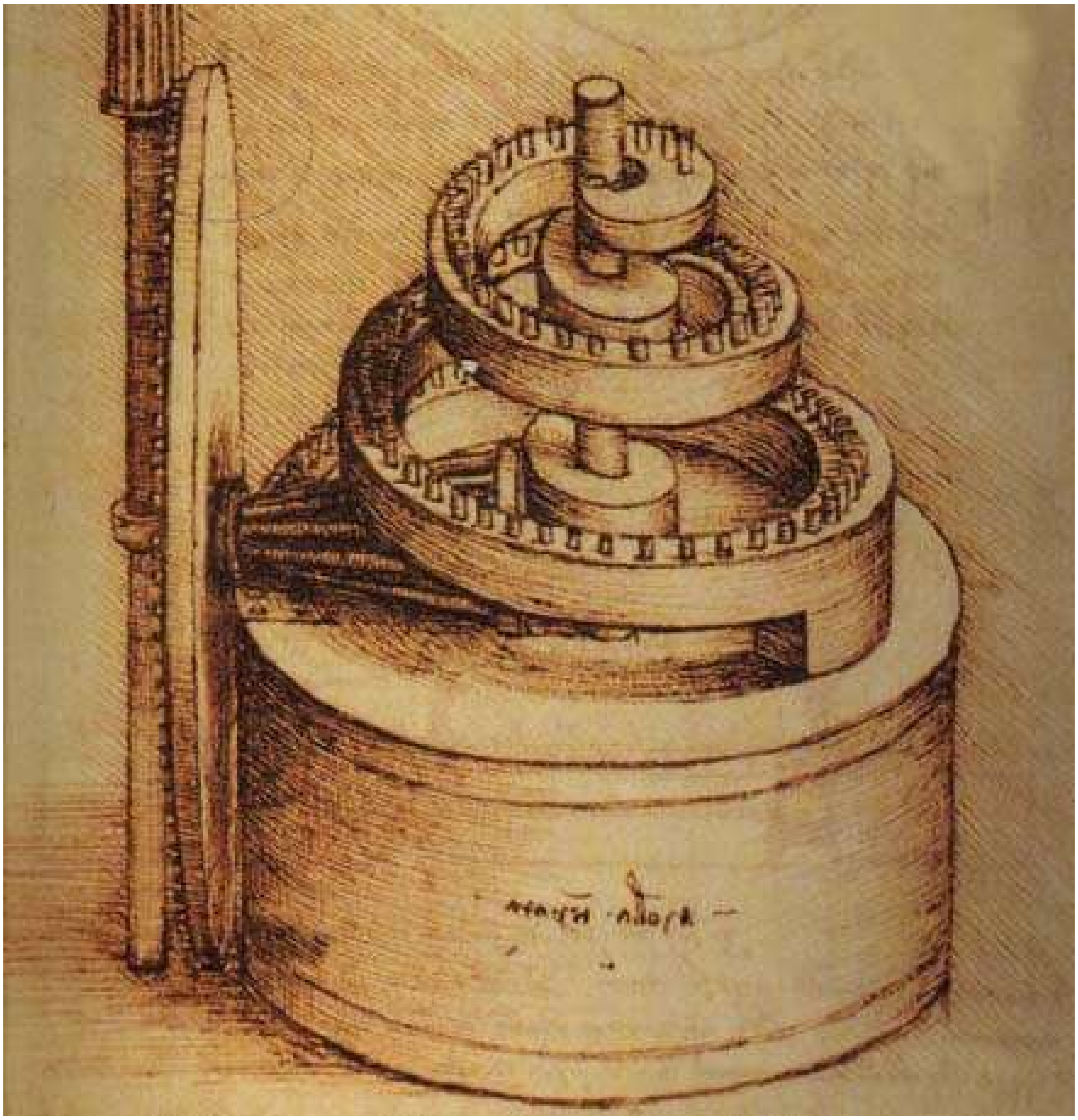

Figure 1.47: **Spring device.**

Suggestions for further reading

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Chapter 2

THE MEDICIS

2.1 Early history of banking

The Wikipedia article on the history of banking states that "The history of banking began with the first prototype banks which were the merchants of the world, who made grain loans to farmers and traders who carried goods between cities. This was around 2000 BC in Assyria, India and Sumeria. Later, in ancient Greece and during the Roman Empire, lenders based in temples made loans, while accepting deposits and performing the change of money. Archaeology from this period in ancient China and India also shows evidence of money lending." However, banking practices of the modern type first began in Renaissance Italy.

2.2 Trading cities in Italy

Towards the end of the middle ages, Europe began to be influenced by the advanced Islamic civilization. European scholars were anxious to learn, but there was an "iron curtain" of religious intolerance which made travel in the Islamic countries difficult and dangerous for Christians. However, in the 12th century, parts of Spain, including the city of Toledo, were reconquered by the Christians. Toledo had been an Islamic cultural center, and many Moslem scholars, together with their manuscripts, remained in the city when it passed into the hands of the Christians. Thus Toledo became a center for the exchange of ideas between east and west; and it was in this city that many of the books of the classical Greek and Hellenistic philosophers were translated from Arabic into Latin.

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The prosperity of 15th century Florence, like that of Venice, was based on commerce. In the case of Florence, the trade was not by sea, but along the main north-south road of Italy, which crossed the Arno at Florence. In addition to this trade, Florence also had an important textile industry. The Florentines imported wool from France, Flanders, Holland and England. They wove the wool into cloth and dyed it, using superior techniques, many of which had come to them from India by way of the Islamic civilization. Later, silk weaving (again using eastern techniques) became important. Florentine banking was also highly developed, and our present banking system is derived from Florentine commercial practices.

2.3 Giovanni di Bicci de' Medici

By enormously expanding the family bank, and establishing branches throughout Europe, Giovanni de Bicci di' Medici (1360-1429) brought his family to power and great wealth. The Medicis controlled the politics of Florence for many generations, and they became great patrons of learning and the arts.

Under Giovanni's guidance the Medici's bank became entrusted with the finances of the Papacy. This was during the time of the Western Schism when there were two rival popes, one in Rome and another in Avignon. Giovanni supported the Roman Pope, and when the Council of Constance in 1417 established the permanent papacy in Rome, Pope Martin V rewarded Giovanni by giving the Medici bank control of the Apostolic Chamber. Subsequent popes made use of the Medici bank, also for tax collecting purposes.

Although they were extremely wealthy, Giovanni and his family lived modestly, and dressed in the manner of the working people of Florence. Their modesty was rewarded by affection and popularity among the Florentines.

Giovanni de' Medici is portrayed by Dustin Hoffman in the 2016 television series, *Medici: Masters of Florence.*

Florentine banking practices

The Medici banks pioneered several practices that are still in use today. One of these was double-entry accounting. In this system, a credit in one account must always be matched by a debit in another account. For example, when something is sold, the credit in the cash account must be matched by a debit in the inventory account.

Another important practice of the Medici banks was the letter of credit. A letter of credit is a promise to pay at a particular location and time an amount of money for goods or services received. Letters of credit were useful to the Medicis for two reasons: Firstly, transport of money over large distances was dangerous at the time. But with letters of credit the Medicis could order their London branch to pay for some transaction instead of sending money to London. Secondly, usury, the taking of interest on a loan, was considered to be a sin by the Catholic Church. Letters of credit helped to disguise the fact that usury had taken place.

The Medicis also introduced the first holding companies. The Medici banks had branches in Milan, Venice, Rome, London, Geneva, Lyon, Avignon, Barcelona, and Bruges.

Each of its branches was a partnership, held under the central holding company in Florence.

Figure 2.1: **Giovanni de Bicci de' Medici, (1360-1429), in a portrait by Christofano dell'Altissimo.**

2.4 The Medicis and Humanism

In the 15th and 16th centuries, Florence was ruled by a syndicate of wealthy merchant families, the greatest of whom were the Medicis. Cosimo de' Medici, the unofficial ruler of Florence from 1429 to 1464, was a banker whose personal wealth exceeded that of most contemporary kings. In spite of his great fortune, Cosimo lived in a relatively modest style, not wishing to attract attention or envy; and in general, the Medici influence tended to make life in Florence more modest than life in Venice.

Cosimo de' Medici is important in the history of ideas as one of the greatest patrons of the revival of Greek learning. In 1439, the Greek Patriarch and the Emperor John Palaeologus attended in Florence a council for the reunification of the Greek and Latin churches. The Greek-speaking Byzantine scholars who accompanied the Patriarch brought with them a number of books by Plato which excited the intense interest and admiration of Cosimo de' Medici.

Cosimo immediately set up a Platonic Academy in Florence, and chose a young man named Marsilio Ficino as its director. In one of his letters to Ficino, Cosimo says:

"Yesterday I came to the villa of Careggi, not to cultivate my fields, but my soul. Come to us, Marsilio, as soon as possible. Bring with you our Plato's book *De Summo Bono*. This, I suppose, you have already translated from the Greek language into Latin, as you promised. I desire nothing so much as to know the road to happiness. Farewell, and do not come without the Orphian lyre!"

Cosimo's grandson, Lorenzo the Magnificent, continued his grandfather's policy of reviving classical Greek learning, and he became to the golden age of Florence what Pericles had been too the golden age of Athens. Among the artists whom Lorenzo sponsored were Michelangelo, Botticelli and Donatello. Lorenzo established a system of bursaries and prizes for the support of students. He also gave heavy financial support to the University of Pisa, which became a famous university under Lorenzo's patronage. (It was later to be the university of Galileo and Fermi.)

At Florence, Greek was taught by scholars from Byzantium; and Poliziano, who translated Homer into Latin could say with justice: "Greek learning, long extinct in Greece itself, has come to life and lives again in Florence. There Greek literature is taught and studied, so that Athens, root and branch, has been transported to make her abode - not in Athens in ruins and in the hands of barbarians, but in Athens as she was, with her breathing spirit and her very soul."

Figure 2.2: **Cosimo di Giovanni de' Medici (1389-1464) was the son of Giovanni di Bicca de' Medici. His great wealth allowed him to control the politics of Florence for a long period, and he sponsored the revival of classical Greek learning in Florence.**

Figure 2.3: **Lorenzo the Magnificent (1449-1492), patron of such artists as Botticelli and Michelangelo. He was the grandson of Cosimo di Giovanni de' Medici.**

Figure 2.4: **Detail from Botticelli's painting, *The Birth of Venus*.**

Figure 2.5: **Michelangelo's *Pieta*.**

Figure 2.6: **Florence as it looks today.**

Figure 2.7: **Cosimo I di' Medici (1519-1574) Grand Duke of Tuscany, in his coronation robes. He was the great-great-great grandson of Giovanni de Bicca di' Medici.**

Suggestions for further reading

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Chapter 3

PAINTERS OF THE RENAISSANCE

3.1 Giotto

Giotto painted from living models

Giotto de Bondonne (c.1267-1337) was an Italian painter who broke with the traditions of the Middle ages, and began to paint figures of humans from life, rather that from previous paintings. This paved the way for the realistic paintings of the Italian Renaissance. Giotto was also a renounced architect.

Giotto's life

Very little is known about Giotto's early life. It is not even known for certain where he was born. There is a legend that as a boy, Giotto was working as a shepherd, and made strikingly realistic drawings of his sheep on a rock. According to the legend, the drawings were noticed by the painter Cimabue (c.1240-1302), who then made Giotto one of his apprentices. However, truth of the legend is disputed. It is certain, however, that Giotto was recognized as a great painter during his own lifetime.

The Scrovegni Chapel

The frescos decorating the Scrovegni Chapel in Padua, which Giotto began to paint in 1305, are his most famous and influential works. They depict *The Life of Christ*, and *The Life of the Blessed Virgin Mary*, and their general theme is Salvation. Another theme is the Annunciation. On the western wall of the chapel, Giotto painted *The Last Judgement*.

Giotto's figures are three-dimensional, and they sometimes are shown with their backs turned to the viewer, creating an illusion of space. Their clothes are not stylized, but hang naturally, and their faces show real emotion. For example, the face of the soldier who drags a baby from its mother's arms in *The Massacre of the Innocents* is averted and shows his shame at the act. This depiction of emotions sets Giotto apart from his contemporaries.

Figure 3.1: **Details of figures from the *Raising of Drusiana*, by Giotto de Bondonne, Peruzzi Chapel, Florence, Italy.**

Figure 3.2: ***Lamentation of Christ*, c. 1305, by Giotto de Bondonne, fresco from the Scrovegni Chapel, Padua, Italy.**

3.2 Botticelli

Sandro Botticelli studies with Fra Filiippo Lippi

Sandro Botticelli (c.1445-1510) was born in Florence and he spent almost his entire life there, never moving more than a few minutes walk from the street of his birth. Botticelli was originally trained as a goldsmith, but in about 1461, at the age of 16, he was apprenticed to the painter Fra Filippo Lippi, who was one of the top painters of the day, often patronized by the Medicis. Lippi was rather conservative, but he gave Botticelli a solid training in technique.

Botticelli's paintings based on classical mythology

Botticelli's two masterpieces, *Primavera* (c.1482) and *The Birth of Venus* (c,1485) are among the most famous paintings in the world. These iconic paintings, both of which are now at the Uffizi Gallery in Florence, come to mind whenever we think of the Italian Renaissance.

The visual appeal of the two paintings, and their portrayal of the joy of life, account for their enormous popularity. Their subjects were influenced by the neo-Platonism introduced in Florence by the Medici family.

Figure 3.3: ***Primavera*****, c. 1482, by Sandro Botticelli, Uffizi Gallery, Florence.**

Figure 3.4: ***The Birth of Venus*, c. 1485, by Sandro Botticelli, Uffizi Gallery, Florence.**

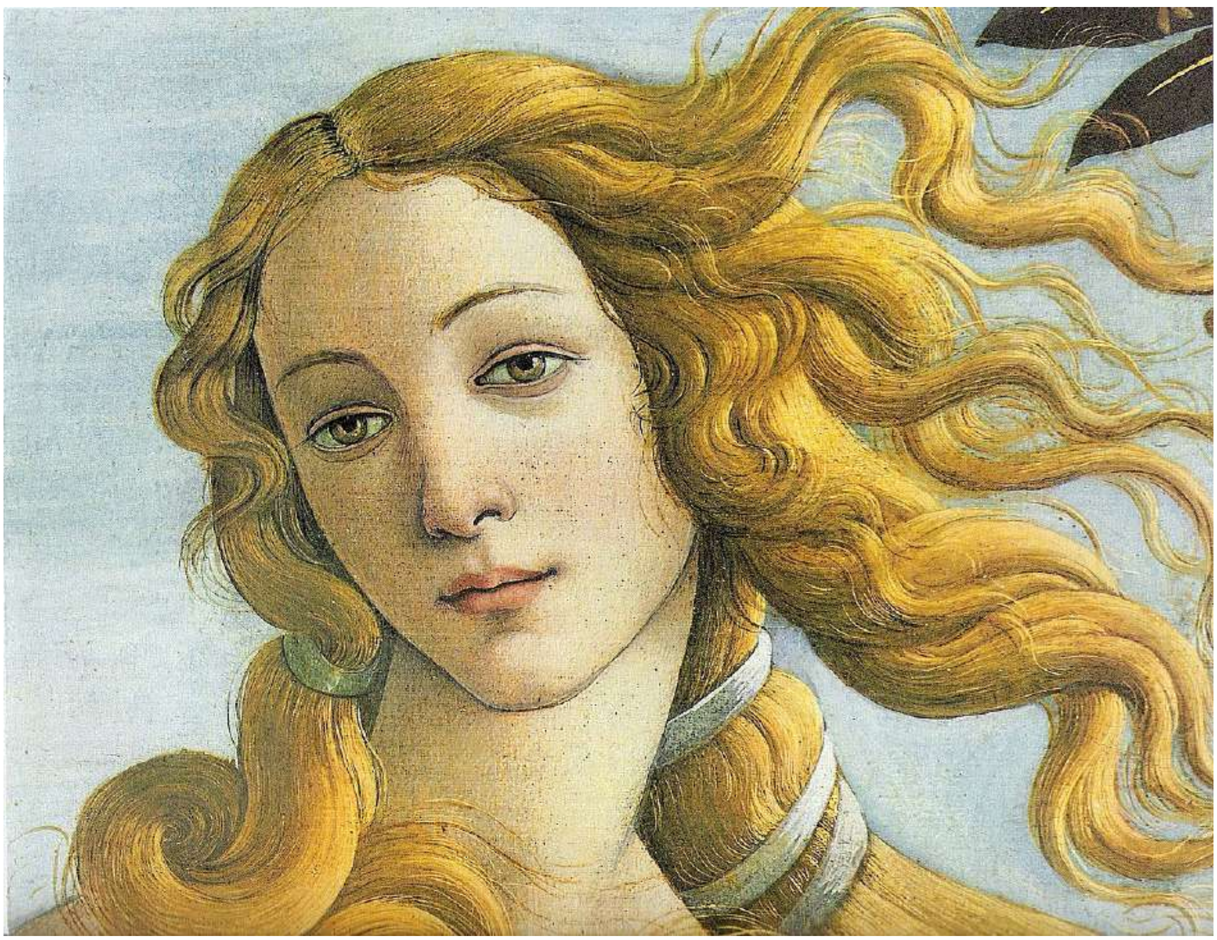

Figure 3.5: **Detail from *The Birth of Venus*, c. 1485, by Sandro Botticelli, Uffizi Gallery, Florence.**

3.3 Leonardo da Vinci

Leonardo da Vinci (1452-1519) was an astonishing universal genius. His range of interest and work, which has perhaps never been matched before or since, included invention, drawing, painting, sculpture, architecture, science, music, mathematics, engineering, literature, anatomy, geology, astronomy, botany, paleontology, and cartography. Altough only 13 of his paintings have survived, Leonardo is generally considered to be one of the greatest painters of all time.

Leonardo was the illegitimate son of a notary, Piero da Vinci and a peasant girl. At an early age, he was apprenticed to the important Florentine painter Andrea del Verrocchio.

Both in painting and in science, Leonardo looked directly to nature for guidance, rather than to previous masters. He wrote:

"The painter will produce pictures of small merit if he takes as his standard the pictures of others; but if he will study from natural objects, he will produce good fruits... And I would say about these mathematical studies, that those who study the authorities and not the works of nature are descendents but not sons of nature."

Leonardo's paintings

Wikipedia states that:

Leonardo is renowned primarily as a painter. The Mona Lisa is the most famous of his works and the most popular portrait ever made. The Last Supper is the most reproduced religious painting of all time, and his Vitruvian Man drawing is regarded as a cultural icon as well. Salvator Mundi was sold for a world record $450.3 million at a Christie's auction in New York, 15 November 2017, the highest price ever paid for a work of art. Leonardo's paintings and preparatory drawings - together with his notebooks, which contain sketches, scientific diagrams, and his thoughts on the nature of painting - compose a contribution to later generations of artists rivalled only by that of his contemporary Michelangelo.

Figure 3.6: **Leonardo's portrait of a lady with an ermine, painted in 1489-1490. The painting is now at the National Museum in Krakow, Poland.**

Figure 3.7: **Head of a Woman, a drawing by Leonardo da Vinci.**

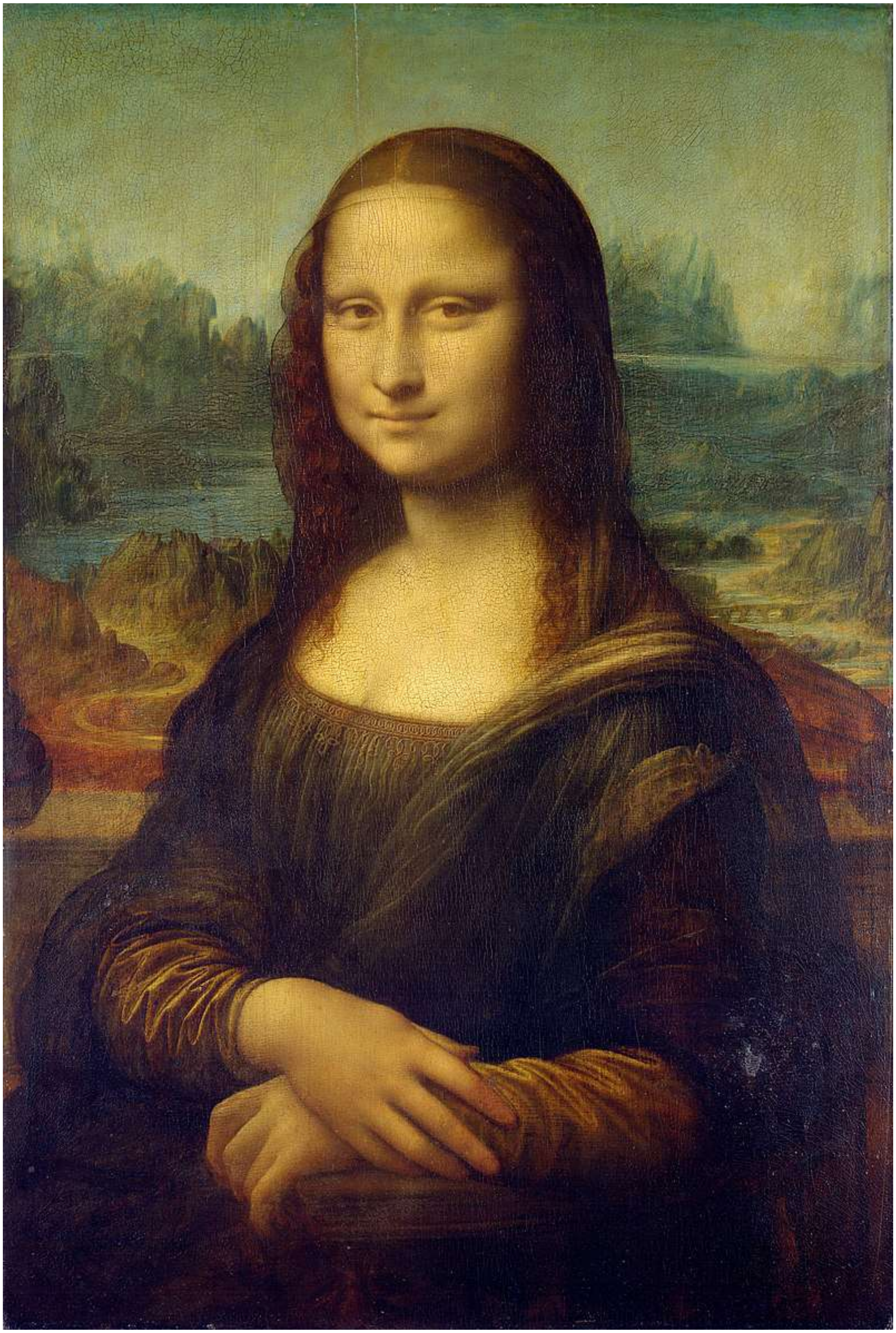

Figure 3.8: ***Mona Lisa*, 1503-1507, by Leonardo da Vinci, Louvre, Paris.**

3.4 Michelangelo

Sculptor, painter, architect and poet

Michelangelo di Lodovico Buonarroti Simoni (1475-1564), who is known today simply as Michelangelo, was truly a Renaissance man, He was not only a painter of genius, but a sculptor, architect and poet, excelling in all four fields. He is certainly one of the greatest artists of all time. Michelangelo was born in the Republic of Florence, in the town of Caprese, where his father was a local administrator. Michelangelo's mother died when he was only six years old, and he was brought up by a nanny whose husband was a stonecutter. Michelangelo wrote later, "Along with the milk of my nurse I received the knack of handling chisel and hammer, with which I make my figures." As an adult, Michelangelo was so devoted to his work that he neglected his appearance. It was said of him that he was indifferent to food and drink, eating "more out of necessity than of pleasure", and that he "often slept in his clothes and ... boots." His biographer Paolo Giovio wrote that, "His nature was so rough and uncouth that his domestic habits were incredibly squalid, and deprived posterity of any pupils who might have followed him."

Helped by the Medicis

Michelangelo was one of the artists who were greatly helped by members of the Medeci family. The Medeci's were the de facto rulers of Florence, and also members of the family became popes. Together, they commissioned Michelangelo's great works of painting, sculpture and architecture, for example, the statue Pietà (1498-99), the statue of David, completed in 1504, the ceiling of the Sistine Chapel, (1508-1512), the statue of Moses for the tomb of Pope Julius II, and St Peter's Basilica, (1546-1564).

In 1494, the Medicis were expelled from Florence by a rebellion incited by the puritanical Dominican friar Girolamo Savonarola (1452-1498), who believed that works of art and literature were "vanities" that distracted attention from pure religion. Under Savonarola, there occurred a "bonfire of vanities", during which paintings and books were burned. The situation was complicated by a French invasion of Italy. Savonarola sided with the French, while the pope called on Christians in Italy to oppose them. In 1497, the pope excommunicated Savonarola. Finally, Savonarola was overthrown and hanged, and his body burned in the main square of Florence. The Medicis then returned to the city, where they continued their patronage of Michelangelo.

During his own lifetime Michelangelo was called *Il Devino* ("The Divine One"). He inspired a sense of awe in those who saw his works. Two biographies of Michelangelo were published while he was still alive.

Raphael was directly influenced by Michelangelo, for example in Raphael's fresco, *The School of Athens*. However, the two artist were bitter rivals, and their personalities were very different. Michelangelo was aloof and refrained from social contacts, while the younger Raphael was sociable and gregarious.

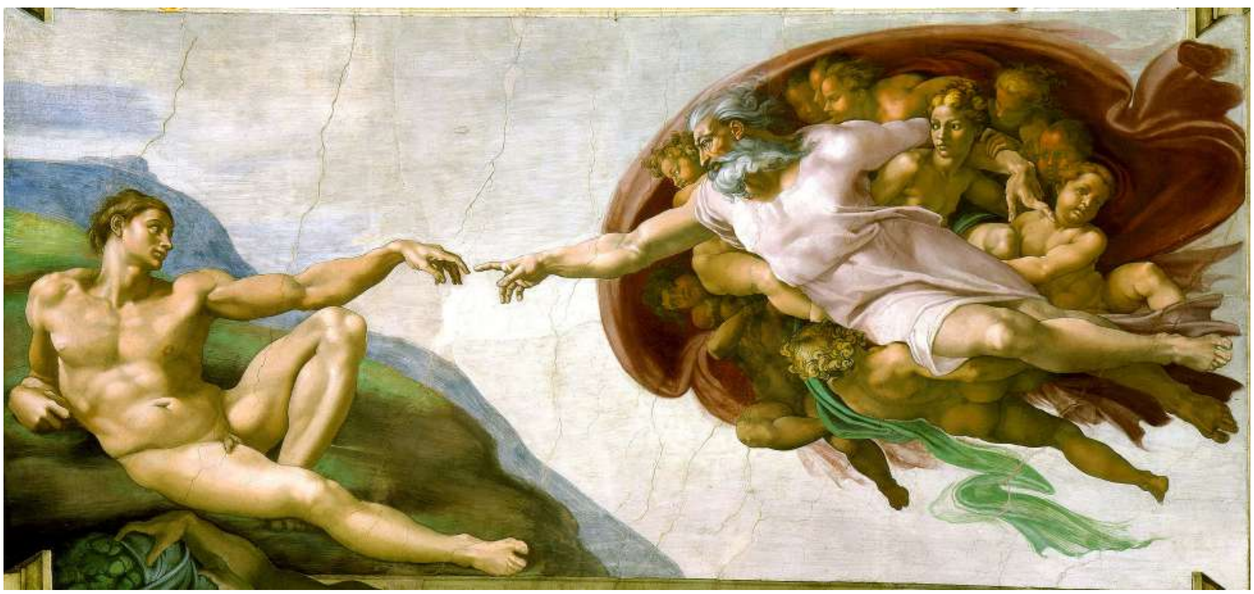

Figure 3.9: ***The Creation of Adam*, 1510, by Michelangelo, St. Peter's Cathedral, Vatican, Rome.**

Figure 3.10: ***The Libyan Sibyl*, 1511, by Michelangelo, St. Peter's Cathedral, Vatican, Rome.**

3.5 Raphael

Student of the Umbrian master, Pietro Perugino

Raffaello Sanzio da Urbino (1483-1520), known as Raphael, was the son of the Umbrian painter and poet Gievanni Santi, court painter to the Duke of Urbino. Raphael grew up in the court, and acquired the easy manners that allowed him to move easily in the highest circles later in life.

Raphael showed his great talent as a very young boy. According to one account, he was apprenticed to the pioneering Umbrian painter Pietro Perugino at the age of eight, "despite the tears of his mother". What is known for certain is that Raphael was a student of Perugino, and was greatly influenced by the master's innovations, such as the scientific use of perspective.

Perugia is the capital of Umbria. This ancient Etruscan city is built on a hill, and at the top of the hill, there is a wide and very long open space called the "Corso Vannucci", where people go to walk in the evenings. (Today they eat ice cream.) The famous painter Pietro Vannucci, nicknamed Pietro Perugino, painted a series of of frescos, and his paintings can also be seen on the Corso Vannucci. Raphael produced eight of his early paintings in Perugia. He also began a fresco in a chapel at the end of the Corso, but before he had finished it, he had become so famous that he was called to Rome by the pope, and the fresco had to be finished by painters in Raphael's workshop. Raphael also spent some time in Florence, and was influenced by Leonardo da Vinci's dynamic treatment of figures, and pyramidal style of composition, which can be seen in such paintings as the Mona Lisa. Raphael acknowledged his debt to Leonardo by giving the figure of Plato in his *School of Athens* a face that resembled Leonardo's.

Raphael's rooms at the Vatican

In 1508, Raphael was called to Rome by Pope Julius II, who immediately commissioned him to paint frescos in rooms that were intended to become the pope's private apartments at the Vatican. The "Stanze" or "Raphael Rooms", are among the most famous of Raphael's works. After Raphael's early death at the age of 37, the project rooms were finished by his assistants. The Raphael Rooms, now a museum, are as follows:

1. Sala di Constantino, containing The Vision of the Cross, The Battle of Milvian Bridge, The Baptism of Constantine and The Donation of Constantine.

2. Stanza di Eliodoro, containing The Expulsion of Heliodorus from the Temple, The Mass at Bolsena, The Meeting of Leo the Great and Attila and Deliverance of Saint Peter.

3. Stanza della Segnatura, containing Disputation of the Holy Sacrament, The Parnassus, The School of Athens and The Cardinal Virtues.

4. Stanza dell'incendio del Borgo, containing The Oath of Leo III, The Coronation of Charlemagne, Fire in the Borgo and The Battle of Ostia.

Together with Leonardo and Michelangelo, Raphael was one of the three greatest painters of the Italian Renaissance.

Figure 3.11: ***Self-portrait of Raphael, aged approximately 23*, 1503.**

Figure 3.12: ***The Miraculous Draught of Fishes*, 1515, by Raphael, Victoria and Albert Museum, London.**

Figure 3.13: **Detail from Raphael's *The School of Athens* showing Plato (on the left) and Aristotle. Plato's features resemble those of Leonardo da Vinci.**

3.6 The Northern Renaissance

Dürer, Bruegel father and son, Holbein, Rubens, Vermeer and Rembrandt belong to the Northern Renaissance, which occurred slightly later than the Renaissance in Italy. The trial of Galileo cast a chill over the Renaissance in Italy, but inspiration was moving northward.

3.7 Dürer

Dürer's early life

Albrecht Dürer (1471-1528) was born in Nuremberg in the Holy Roman Empire. His father was a prosperous goldsmith, who wanted his son to become a goldsmith too. However, Albrecht showed an amazing talent for drawing, and instead became an artist, printmake and theoretician. His work influenced the entire Northern Renaissance.

Wikipedia says of him: **"Dürer's vast body of work includes engravings, his preferred technique in his later prints, altarpieces, portraits and self-portraits, watercolors and books. The woodcuts, such as the Apocalypse series (1498), are more Gothic than the rest of his work. His well-known engravings include the Knight, Death and the Devil (1513), Saint Jerome in his Study (1514) and Melencolia I (1514), which has been the subject of extensive analysis and interpretation. His watercolors also mark him as one of the first European landscape artists, while his ambitious woodcuts revolutionized the potential of that medium."**

Nuremberg was the center of the new printing industry that revolutionized Europe, and Dürer's prints and books were produced in many copies, spreading his influence very widely. In making woodblock prints, Dürer either drew directly on the block, or else pasted a drawing onto the block. Afterwards, an assistant did the actual cutting.

Inspiration from Italy

Dürer communicated with the major Italian artists of his time. These included Raphael, Giovanni Bellini and Leonardo da Vinci. He also traveled th Venice, and was greatly inspired by the paintings that he saw there. However, although influenced by Italian Renaissance painters, he developed his own unique style.

Figure 3.14: ***Self portrait at the Age of 26*, by Albrecht Dürer, Prado, Madrid.**

Figure 3.15: ***Portrait of Maximilian I*, 1519 by Albrecht Dürer, Kunsthistorisches Museum, Vienna. From 1512 onwards, Dürer was patronized by Emperor Maximillion.**

Figure 3.16: ***Great Piece of Turf*, 1507, by Albrecht Dürer, watercolor, pen and ink, Albertina Museum, Vienna.**

Figure 3.17: ***Praying Hands*, 1508, by Albrecht Dürer, pen and ink drawing.**

3.8 Bruegel, father and son

Pieter Bruegel the Elder

Pieter Bruegel the Elder (c.1527-1569) was one of the most important and influential painters and printmakers of the Dutch and Flemish Renaissance. Little is known for certain about the exact date and place of his birth, or the circumstances of his family. Earlier it was thought that he was of peasant origin, but modern researchers now believe that he was a townsman, and moved in intellectual humanist circles.

During his short life, Pieter Bruegel the Elder began by producing large numbers of prints. Later, he turned to painting. His paintings, often showing scenes of peasant life, were extremely popular and were collected by wealthy patrons. He also painted portraits. Thus, he abandoned religious subjects, which had until then, been the main themes in painting.

In 1551, Pieter Bruegel the Elder set off for Italy, probably by way of France. He traveled the entire length of Italy, sketching on the way, and even reached Sicily.

Returning from Italy, he was married in 1563 in Brussels, and he spent the remainder of his short life in that city. Two of his sons from this marriage became well-known painters: Pieter Bruegel th Younger, and Jan Bruegel the Elder. Before his death, Bruegel asked his wife to burn a number of his unpublished prints. This seems to have been because they so satirical as to have been dangerous, and he wished to protect his wife from retribution.

Pieter Bruegel the Younger

Pieter Brueghel the Younger (1564-1638) was orphaned by the early death of his father, and the death of his mother in 1578. Together with his brother, Jan Bruegel the Elder and his sister Marie, he went to live with his grandmother, Myjen Verhulst. The grandmother was the widow of a well-known painter, Pieter Coecke van Aelst, and she was also an accomplished artist in her own right. It is probable that her two orphaned grandsons received their first instruction in painting from her.

Because of the enormous popularity of his father's paintings, Pieter Bruegel the Younger set up a workshop which made copies of them for both local and foreign markets. This was remunerative work, but he nevertheless had financial troubles, probably because of his excessive entertaining and drinking.

Besides copying his fathers works, he also made many original paintings. Wikipedia says of him: **"Pieter Brueghel the Younger created original works largely in the idiom of his father which are energetic, bold and bright and adapted to the 17th-century style. One of the artist's most successful original designs was the painting of The Village Lawyer (sometimes also called the Tax Collector's Office, the Payment of the Tithe, the Lawyer of Bad Cases"**

He was married and had a number of children, among whom, Pieter Bruegel III was also a painter.

Figure 3.18: ***The Peasant Wedding*, 1566-1569, by Pieter Bruegel the Elder.**

Figure 3.19: ***The Peasant Dance*, 1568, by Pieter Bruegel the Elder, Kunsthistorisches Museum, Vienna.**

Figure 3.20: ***Winter Landscape With A Bird Trap*, copied by Pieter Bruegel the Younger from his father's original painting.**

3.9 Holbein

Early life

Hans Holbein the Younger (c.1497-1543) is considered to be one of the greatest portrait painters of the 16th century. He was born in Ausberg, Germany, and was the son of an accomplished painter, Hans Holbein the Elder, from whom he undoubtedly received his first instruction in painting. As a young artist, Holbein worked mainly in Basil, where he painter murals, designed stained glass windows, and printed books. When the Reformation reached Basil, Holbein painted for both Protestant and Catholic clients, and the effort to pleas both resulted in a unique style.

Holbein's career in England

Holbein first achieved fame with his portrait of the humanist philosopher, Erasmus of Rotterdam. He traveled to England in 1526, carrying with him a recommendation from Erasmus, and as a result of this recommendation he was welcomed warmly into the humanist circle of Sir Thomas More. There he quickly built a high reputation as a portrait painter. Holbein's portraits were famous for their exact likeness to the people whom they represent; but he also somehow managed to communicate the character of the portrayed person as well.

In 1528, Holbein returned to Basil, in order to maintain his citizenship, since he had only been granted a two-year leave of absence. Enriched by his financial success in England, he bought a second house in the city. At this time, he painted an emotionally moving portrait of his wife and two children.

During the period 1532-1540, Holbein returned to England, where the Protestant Reformation was reaching a new stage. Henry VIII was on the verge of repudiating his marriage to Catherine of Aragon, in order to marry Anne Boleyn. Since the political situation was now changed, Holbein changed with the times. He distanced himself from his former patron, Sir Thomas More, who steadfastly opposed Henry's marriage to Anne Boleyn. Sir Thomas More was soon to be executed because of this opposition. Holbein now found a new patrons in Anne Boleyn's family and Thomas Cromwell, the powerful Chancellor of England. By 1536, Holbein as employed as the King's Painter on a steady salary. Besides painting members of the court, he also painted merchants of the Hanseatic League, who had rooms at the steelyards near London's docks.

No Holbein portraits of Anne Boleyn survive. Perhaps they were destroyed after her famous execution at the order of Henry VIII. Holbein traveled to Denmark to paint the recently-widowed Christina of Denmark, whom Henry was considering as a possible new wife. He also made a portrait of Anne of Cleves, another possible choice to be Henry's new wife. Henry married Anne of Cleves, but was enraged when he found that her beauty was much less than he had expected. Henry's rage fell on Thomas Cromwell, who then fell from power. The loss of Cromwell's patronage greatly damaged Holbein's prospects in England. He died in Aldgate in 1543, at the age of 45.

Figure 3.21: ***Portrait of Erasmus of Rotterdam*, 1523. by Hans Holbein the Younger.**

Figure 3.22: ***Portrait of Sir Thomas More*, 1527. by Hans Holbein the Younger, Frick Collection, New York.**

Figure 3.23: ***Portrait Henry VIII*, 1536. by Hans Holbein the Younger, Tyssen-Bornemisza Museum, Madrid.**

3.10 Rubens

Rubens' early life

Sir Peter Paul Rubens (1577-1640) was born in the German Westphalian town of Siegen, where his parents had fled to avoid religious persecution. His father was a prominent lawyer, Jan Rubens, and his mother, Maria Pypelinckx, an author. Jan Rubens had been the legal advisor to Anna of Saxony, with whom he had an affair and an illegitimate daughter. Anna was the second wife of William the Silent of Holland. As a result of the scandal, Jan Rubens was locked up in Dillenburg Castle, where he feared he would be executed. However his wife, Maria, pleaded for his life, and he was released, following payment of a large bail, on the condition that he should not leave Siegen. Thus Peter Paul Rubens was born in the town.

Following the death of his father in 1587, Peter Paul Rubens and his mother moved to Antwerp, where he was raised as a devout Catholic. Here he received a humanist education, studying classical literature in Latin. At the age of 14 he began his training as an artist, as an apprentice with Tobias Verhaech.

Diplomat and artist

Wikipedia says of Rubens, **"He is considered the most influential artist of Flemish Baroque tradition. Ruben's highly charged compositions reference erudite aspects of classical and Christian history. His unique and immensely popular Baroque style emphasized movement, colour, and sensuality, which followed the immediate, dramatic artistic style promoted in the Counter-Reformation. Rubens specialized in making altarpieces, portraits, landscapes, and history paintings of mythological and allegorical subjects.**

"In addition to running a large studio in Antwerp that produced paintings popular with nobility and art collectors throughout Europe, Rubens was a classically educated humanist scholar and diplomat who was knighted by both Philip IV of Spain and Charles I of England. Rubens was a prolific artist. The catalogue of his works by Michael Jaffé lists 1,403 pieces, excluding numerous copies made in his workshop."

Rubens spent the years 1600-1608 in Italy, where he was very much influenced by great painters of the Italian Renaissance, especially by Leonardo da Vinci, Michelangelo and Raphael. He also studied Roman and Greek art, and was especially influenced by the dramatic statue of *Lacoön and His Sons.* On a visit to Venice, he saw paintings by Titian, Veronese and Tintorino. At the end of this period Rubens received news that his mother was very ill. He hurried back to Antwerp, only to find that his mother had died before his arrival.

Rubens was now so financially successful that in 1635 he was able to buy an estate with castle, Chateau de Steen, where he spent the last five years of his life.

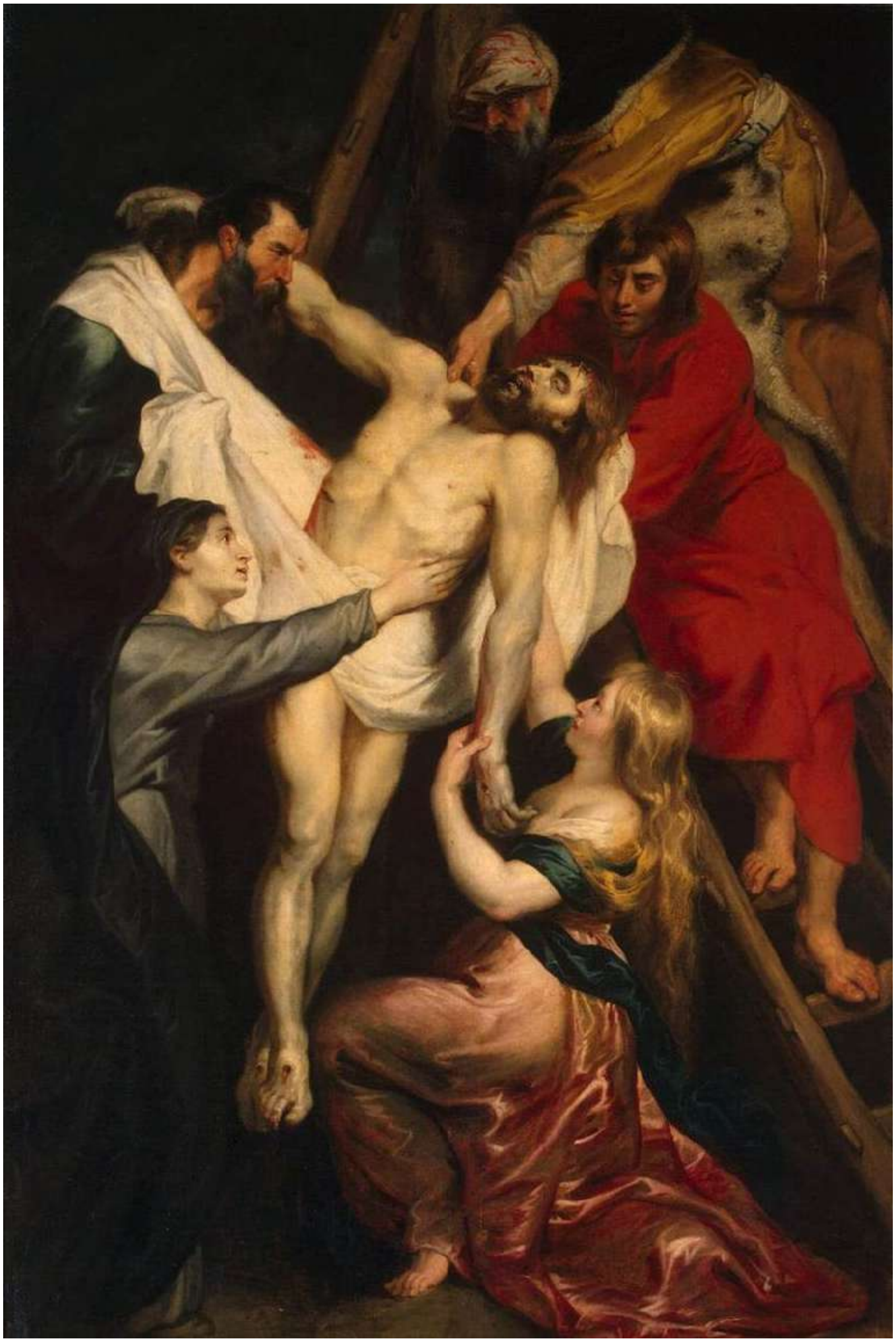

Figure 3.24: ***Descent from the Cross*, 1618, by Peter Paul Rubens, Hermitage Museum.**

Figure 3.25: ***Portrait of Anna of Austria, Queen of France*, c. 1622, by Peter Paul Rubens.**

Figure 3.26: ***Portrait of the Artist*, 1623, by Peter Paul Rubens, Picture Gallery, Buckingham Palace.**

3.11 Vermeer

Artist, art dealer, father and innkeeper in Delft

Johannes Vermeer (1632-1675) was a Dutch painter who lived his entire life in Delft. He is today renowned for his masterly treatment of light and color, and for his portrayal of intimate domestic scenes. He worked very slowly and carefully, and partly for that reason produced very few paintings, only about 66, and of these only 34 survive today. Besides his very slow and careful way of working, the other reason why Vermeer produced so few paintings was that his life was full of many other activities. He was the father of 13 children, of whom 10 survived infancy. He was also an innkeeper and an art dealer.

Vermeer's father, Reijnier Vermeer, was a middle-class dealer in silk and wool, who also owned a large inn. When he died in 1652, his son, Johannes Vermeer took over both businesses. In 1653. he married a Catholic girl, Catherina Bolenes, and converted to Catholicism. His new mother-in-law was much wealthier than he, and as a consequence, the young couple moved into her house.

Vermeer had meanwhile finished his apprenticeship in painting, and had become a highly respected figure within the art world of Delft. His paintings were much sought after by the collectors of the city, who are thought to have supplied him with the very expensive pigments that he used. The fact that all of his paintings were bought by local collectors prevented his reputation from spreading beyond Delft.

The year 1672 was known as the "year of disaster for Holland. In that year, Holland was invaded by the French army of Louis XIV, and as a result there was a severe economic downturn. Vermeer found himself unable to sell not only his own paintings, but also the paintings of others that he had in his collection. As a result, he became desperate and depressed, and he died in 1675 after a short illness. His wife described his death in the following words: "..during the ruinous war with France he not only was unable to sell any of his art but also, to his great detriment, was left sitting with the paintings of other masters that he was dealing in. As a result and owing to the great burden of his children having no means of his own, he lapsed into such decay and decadence, which he had so taken to heart that, as if he had fallen into a frenzy, in a day and a half he went from being healthy to being dead."

Overlooked for two centuries, then rediscovered

Vermeer's work was overlooked by art historians for two centuries after his death, probably because his high reputation was confined to the city of Delft. He was unknown elsewhere. However, in the 1860's he was rediscovered. Wikipedia writes about this event: **"The Delft master's modern rediscovery began about 1860, when German museum director Gustav Waagen saw The Art of Painting in the Czernin gallery in Vienna and recognized the work as a Vermeer, though it was attributed to Pieter de Hooch at that time."**

Vermeer is now famous throughout the world.

Figure 3.27: ***The Milkmaid*, 1658. by Johannes Vermeer.**

Figure 3.28: ***Girl with a Pearl Earring*, 1665. by Johannes Vermeer.**

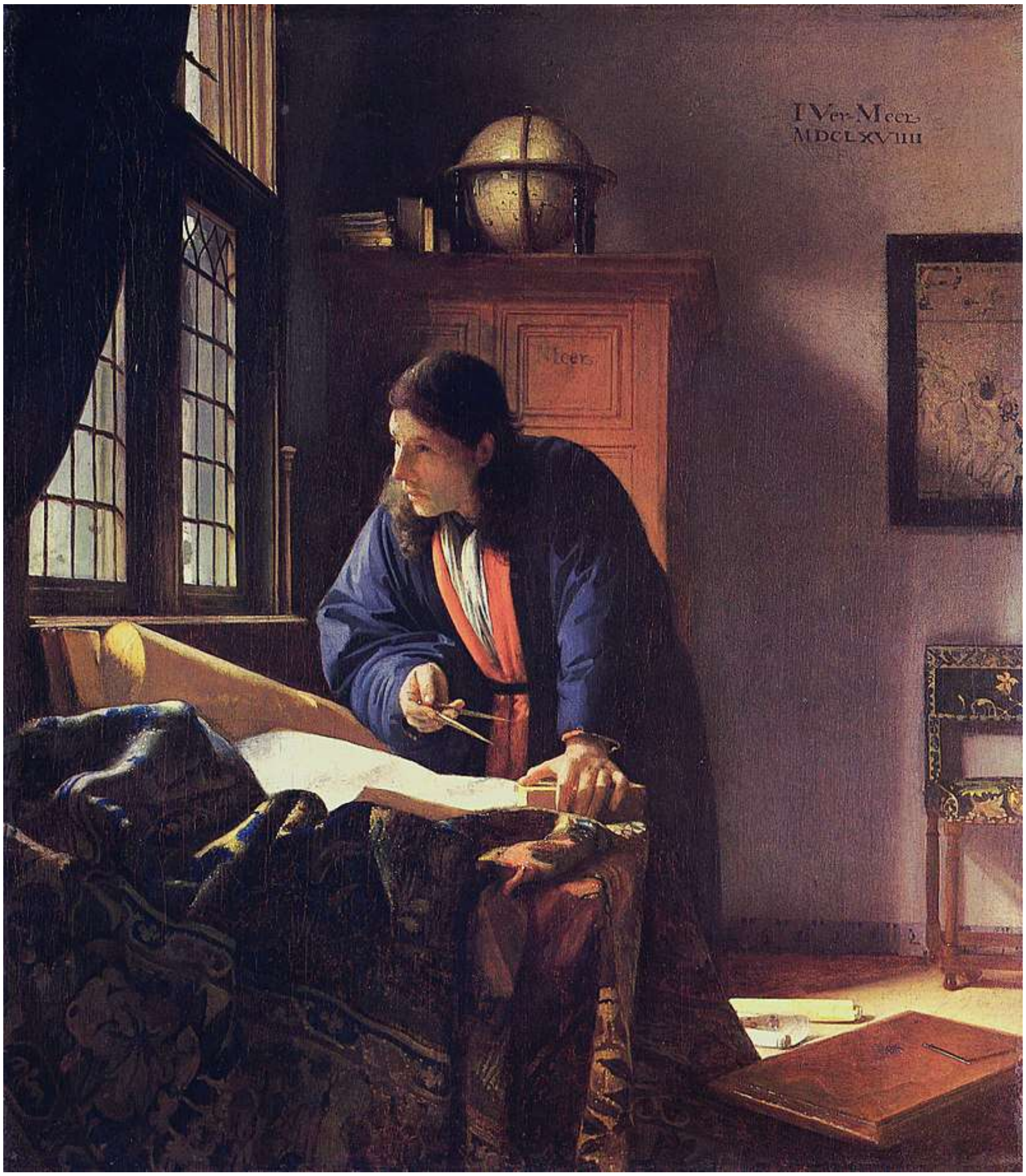

Figure 3.29: ***The Geographer*, 1669, by Johannes Vermeer.**

3.12 Rembrandt

Early success

Rembrandt Harmenszoon van Rijn (1606-1669) was born in Leiden, in the Dutch Republic. After briefly attending the University of Leiden, he was apprenticed to the Dutch historical painter, Jacob van Swanenburg, and afterwards Pieter Lastman in Amsterdam. He then started his own workshop. In 1631, Rembrandt began to practice as a portrait painter in Amsterdam. He achieved great popularity and his financial success allowed him to marry Saskia van Uylenburgh, whose father had been a lawyer and mayor of the city of Leeuwarden.

Overspending and personal tragedy

In 1639. Rembrandt and Saskia bought a very large house in Amsterdam (now a Rembrandt museum). To make this purchase, Rembrandt borrowed a large amount of money. He could easily have paid off his debt from his earnings, but instead he bought many works by other painters, and he may have made unsuccessful investments.

The family was then struck by tragedy. Three of their children died shortly after birth. Their fourth child, Titus, survived to become an adult, but in 1642, Saskia died, probably from tuberculosis.

In the late 1640's, Rembrandt began a relationship with a much younger woman, Hendrickje Stoffels. She became his long-time partner, and they had a daughter together, but Rembrandt was unable to marry her because of financial conditions related to his inheritance from Saskia.

Rembrandt continued to overspend and became bankrupt. According to the law, he was no longer allowed to deal in art. To get around this regulation a company was set up, "Hendrickje and Titus", with Rembrandt as an employee.

Rembrandt's legacy

Wikipedia says of Rembrandt: "**His reputation as the greatest etcher in the history of the medium was established in his lifetime and never questioned since... Because of his empathy for the human condition, he has been called 'one of the great prophets of civilization'. The French sculptor Auguste Rodin said, 'Compare me with Rembrandt! What sacrilege! With Rembrandt, the colossus of Art! We should prostrate ourselves before Rembrandt and never compare anyone with him!' Vincent van Gogh wrote, 'Rembrandt goes so deep into the mysterious that he says things for which there are no words in any language. It is with justice that they call Rembrandt - magician - that's no easy occupation.'"**

Figure 3.30: ***Self-Portrait*, by Rembrandt van Rijn.**

Figure 3.31: ***The Prodigal Son in a Tavern*, 1635, self-portrait with Saskia, by Rembrandt van Rijn, Gemäldegalerie Alte Meister, Dresden.**

Figure 3.32: ***The Night Watch or The Militia Company of Captain Frans Banning Cocq,*, 1642, by Rembrandt van Rijn, Rijksmuseum, Amsterdam.**

Figure 3.33: ***Rembrandt's Son Titus as a Monk*, 1660, by Rembrandt van Rijn, Rijksmuseum, Amsterdam.**

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Chapter 4

COPERNICUS, BRAHE, KEPLER AND GALILEO

4.1 Copernicus

The career of Leonardo da Vinci illustrates the first phase of the "information explosion" which has produced the modern world: Inexpensive paper was being manufactured in Europe, and it formed the medium for Leonardo's thousands of pages of notes. His notes and sketches would never have been possible if he had been forced to use expensive parchment as a medium. On the other hand, the full force of Leonardo's genius and diligence was never felt because his notes were not printed.

Copernicus, who was a younger contemporary of Leonardo, had a much greater effect on the history of ideas, because his work was published. Thus, while paper alone made a large contribution to the information explosion, it was printing combined with paper which had an absolutely decisive and revolutionary impact: The modern scientific era began with the introduction of printing.

Nicolas Copernicus (1473-1543) was orphaned at the age of ten, but fortunately for science he was adopted by his uncle, Lucas Watzelrode, the Prince-Bishop of Ermland (a small semi-independent state which is now part of Poland). Through his uncle's influence, Copernicus was made a Canon of the Cathedral of Frauenberg in Ermland at the age of twenty-three. He had already spent four years at the University of Krakow, but his first act as Canon was to apply for leave of absence to study in Italy.

At that time, Italy was very much the center of European intellectual activity. Copernicus stayed there for ten years, drawing a comfortable salary from his cathedral, and wandering from one Italian University to another. He studied medicine and church law at Padua and Bologna, and was made a Doctor of Law at the University of Ferrara. Thus, thanks to the influence of his uncle, Copernicus had an education which few men of his time could match. He spent altogether fourteen years as a student at various universities, and he experienced the bracing intellectual atmosphere of Italy at the height of the Renaissance.

Figure 4.1: **Nicolas Copernicus (1473-1543).**

In 1506, Bishop Lucas recalled Copernicus to Ermland, where the young Canon spent the next six years as his uncle's personal physician and administrative assistant. After his uncle's death, Copernicus finally took up his duties as Canon at the cathedral-fortress of Frauenberg on the Baltic coast of Ermland; and he remained there for the rest of his life, administering the estates of the cathedral, acting as a physician to the people of Ermland, and working in secret on his sun-centered cosmology.

Even as a student in Krakow, Copernicus had thought about the problem of removing the defects in the Ptolomeic system. In Italy, where the books of the ancient philosophers had just become available in the original Greek, Copernicus was able to search among their writings for alternative proposals. In Ptolemy's system, not all the "wheels within wheels" turn with a uniform velocity, although it is possible to find a point of observation called the *"punctum equans"* from which the motion seems to be uniform. Concerning this, Copernicus wrote:

"A system of this sort seems neither sufficiently absolute, nor sufficiently pleasing to the mind... Having become aware of these defects, I often considered whether there could be found a more reasonable arrangement of circles, in which everything would move uniformly about its proper center, as the rule of absolute motion requires.."

While trying to remove what he regarded as a defect in the Ptolemaic system by rearranging the wheels, Copernicus rediscovered the sun-centered cosmology of Aristarchus. However, he took a crucial step which went beyond Aristarchus: What Copernicus did during the thirty-one years which he spent in his isolated outpost on the Baltic was to develop the heliocentric model into a complete system, from which he calculated tables of planetary positions.

The accuracy of Copernicus' tables was a great improvement on those calculated from the Ptolemaic system, and the motions of the planets followed in a much more natural way. The inner planets, Mercury and Venus, stayed close to the sun because of the smallness of their orbits, while the occasional apparently retrograde motion of the outer planets could be explained in a very natural way by the fact that the more rapidly-moving earth sometimes overtook and passed one of the outer planets. Furthermore, the speed of the planets diminished in a perfectly regular way according to their distances from the sun.

According the the Copernican cosmology, the earth moves around the sun in an orbit whose radius is ninety-three million miles. As the earth moves in its enormous orbit, it is sometimes closer to a particular star, and sometimes farther away. Therefore the observed positions of the stars relative to each other ought to change as the earth moves around its orbit. This effect, called "stellar parallax", could not be observed with the instruments which were available in the 16th century.

The explanation which Copernicus gave for the absence of stellar parallax was that "Compared to the distance of the fixed stars, the earth's distance from the sun is negligibly small!" If this is true for the nearest stars, then what about the distance to the farthest stars?

Vast and frightening chasms of infinity seemed to open under the feet of those who understood the implications of the Copernican cosmology. Humans were no longer rulers of a small, tidy universe especially created for themselves. They were suddenly "lost in the stars", drifting on a tiny speck of earth through unimaginably vast depths of space. Hence the cry of Blaise Pascal: *"Le silence eternal de ce éspaces infinis m'effraie!"*, "The eternal silence of these infinite spaces terrifies me!"

4.2 Tycho Brahe

The next step in the Copernican revolution was taken by two men who presented a striking contrast to one another. Tycho Brahe (1546-1601) was a wealthy and autocratic Danish nobleman, while Johannes Kepler (1571-1630) was a neurotic and poverty-stricken teacher in a provincial German school. Nevertheless, in spite of these differences, the two men collaborated for a time, and Johannes Kepler completed the work of Tycho Brahe.

At the time when Tycho was born, Denmark included southern Sweden; and ships sailing to and from the Baltic had to pay a toll as they passed through the narrow sound between Helsingør (Elsinore) in Denmark, and Helsingborg in what is now Sweden. On each side of the sound was a castle, with guns to control the sea passage. Tycho Brahe's father, a Danish nobleman, was Governor of Helsingborg Castle.

Tycho's uncle was also a military man, a Vice-Admiral in the navy of the Danish king, Frederik II. This uncle was childless, and Tycho's father promised that the Vice-Admiral could adopt one of his own children. By a fortunate coincidence, twins were born to the Governor's wife. However, when one of the twins died, Tycho's father was unwilling to part with the survivor (Tycho). The result was that, in the typically high-handed style of the Brahe family, the Vice-Admiral kidnapped Tycho. The Governor at first threatened murder, but soon calmed down and accepted the situation with good grace.

The adoption of Tycho Brahe by his uncle was as fortunate for science as the adoption of Copernicus by Bishop Watzelrode, because the Vice-Admiral soon met his death in an heroic manner which won the particular gratitude of the Danish Royal Family:

Admiral Brahe, returning from a battle against the Swedes, was crossing a bridge in the company of King Frederik II. As the king rode across the bridge, his horse reared suddenly, throwing him into the icy water below. The king would have drowned if Admiral Brahe had not leaped into the water and saved him. However, the Admiral saved the king's life at the cost of his own. He caught pneumonia and died from it. The king's gratitude to Admiral Brahe was expressed in the form of special favor shown to his adopted son, Tycho, who had in the meantime become an astronomer (against the wishes of his family).

As a boy of fourteen, Tycho Brahe had witnessed a partial eclipse of the sun, which had been predicted in advance. It struck him as "something divine that men could know the motions of the stars so accurately that they were able a long time beforehand to predict their places and relative positions". Nothing that his family could say would dissuade him from studying astronomy, and he did so not only at the University of Copenhagen, but also at Leipzig, Wittenberg, Rostock, Basel and Augsberg.

During this period of study, Tycho began collecting astronomical instruments. His lifelong quest for precision in astronomical observation dated from his seventeenth year, when he observed a conjunction of Saturn and Jupiter. He found that the best tables available were a month in error in predicting this event. Tycho had been greatly struck by the fact that (at least as far as the celestial bodies were concerned), it was possible to predict the future; but here the prediction was in error by a full month! He resolved to do better.

Tycho first became famous among astronomers through his observations on a new star, which suddenly appeared in the sky in 1572. He used the splendid instruments in his collection to show that the new star was very distant from the earth - certainly beyond the sphere of the moon - and that it definitely did not move with respect to the fixed stars. This was, at the time, a very revolutionary conclusion. According to Aristotle, (who was still regarded as the greatest authority on matters of natural philosophy), all generation and decay should be confined to the region beneath the sphere of the moon. Tycho's result meant that Aristotle could be wrong!

Tycho thought of moving to Basel. He was attracted by the beauty of the town, and he wanted to be nearer to the southern centers of culture. However, in 1576 he was summoned to appear before Frederik II. Partly in recognition of Tycho's growing fame as an astronomer, and partly to repay the debt of gratitude which he owed to Admiral Brahe, the king made Tycho the ruler of Hven, an island in the sound between Helsingborg and Helsingør. Furthermore, Frederik granted Tycho generous funds from his treasury to construct an observatory on Hven.

With these copious funds, Tycho Brahe constructed a fantastic castle-observatory which he called Uranieborg. It was equipped not only with the most precise astronomical instruments the world had ever seen, but also with a chemical laboratory, a paper mill, a printing press and a dungeon for imprisoning unruly tenants.

Tycho moved in with a retinue of scientific assistants and servants. The only thing which he lacked was his pet elk. This beast had been transported from the Brahe estate at Knudstrup to Landskrona Castle on the Sound, and it was due to be brought on a boat to the island of Hven. However, during the night, the elk wandered up a stairway

Figure 4.2: **Tycho Brahe.**

in Landskrona Castle and found a large bowl of beer in an unoccupied room. Like its master, the elk was excessively fond of beer, and it drank so much that, returning down the stairway, it fell, broke its leg, and had to be shot.

Tycho ruled his island in a thoroughly autocratic and grandiose style, the effect of which was heightened by his remarkable nose. In his younger days, Tycho had fought a duel with another student over the question of who was the better mathematician. During the duel, the bridge of Tycho's nose had been sliced off. He had replaced the missing piece by an artificial bridge which he had made of gold and silver alloy, and this was held in place by means of a sticky ointment which he always carried with him in a snuff box.

Tycho entertained in the grandest possible manner the stream of scholars who came to Hven to see the wonders of Uranieborg. Among his visitors were King James VI of Scotland (who later ascended the English throne as James I), and the young prince who later became Christian IV of Denmark.

With the help of his numerous assistants, Tycho observed and recorded the positions of the sun, moon, planets and stars with an accuracy entirely unprecedented in the history of astronomy. He corrected both for atmospheric refraction and for instrumental errors,

Figure 4.3: **Tycho Brahe's large mural quadrant at Uranieborg.**

Figure 4.4: **Johannes Kepler**

with the result that his observations were accurate to within two minutes of arc. This corresponds to the absolute limit of what can be achieved without the help of a telescope.

Not only were Tycho's observations made with unprecedented accuracy - they were also made *continuously* over a period of 35 years. Before Tycho's time, astronomers had haphazardly recorded an observation every now and then, but no one had thought of making systematic daily records of the positions of each of the celestial bodies. Tycho was able to make a "motion picture" record of the positions of the planets because he could divide the work among his numerous assistants.

All went well with Tycho on the island of Hven for twelve years. Then, in 1588, Frederik II died (of alcoholism), and his son ascended the throne as Christian IV. Frederik II had been especially grateful to Admiral Brahe for saving his life, and he treated the Admiral's adopted son, Tycho, with great indulgence. However, Christian IV was unwilling to overlook the increasingly scandalous and despotic way in which Tycho was ruling Hven; and he reduced the subsidies which Tycho Brahe had been receiving from the royal treasury. The result was that Tycho, feeling greatly insulted, dismantled his instruments and moved them to Prague, together with his retinue of family, scientific assistants, servants and jester.

In Prague, Tycho became the Imperial Mathematician of the Holy Roman Emperor, Rudolph II. (We should mention in passing that royal patrons such as Rudolph were more interested in astrology than in astronomy: The chief duty of the Imperial Mathematician was to cast horoscopes for the court!) After the move to Prague, one of Tycho's senior scientific assistants became dissatisfied and left. To replace him, Tycho recruited a young German mathematician named Johannes Kepler.

4.3 Johannes Kepler

Two thousand years before the time of Kepler, Pythagoras had dreamed of finding mathematical harmony in the motions of the planets. Kepler and Newton were destined to fulfil his dream. Kepler was also a true follower of Pythagoras in another sense: Through his devotion to philosophy, he transcended the personal sufferings of a tortured childhood and adolescence. He came from a family of misfits whose neurotic quarrelsomeness was such that Kepler's father narrowly escaped being hanged, and his mother was accused of witchcraft by her neighbors. She was imprisoned, and came close to being burned.

At the age of 4, Kepler almost died of smallpox, and his hands were badly crippled. Concerning his adolescence, Kepler wrote: "I suffered continually from skin ailments, often severe sores, often from the scabs of chronic putrid wounds in my feet, which healed badly and kept breaking out again. On the middle finger of my right hand, I had a worm, and on the left, a huge sore."

Kepler's mental strength compensated for his bodily weakness. His brilliance as a student was quickly recognized, and he was given a scholarship to study theology at the University of Tübingen. He was agonizingly lonely and unpopular among his classmates.

Kepler distinguished himself as a student at Tübingen, and shortly before his graduation, he was offered a post as a teacher of mathematics and astronomy at the Protestant School in Graz. With the post went the title of "Mathematician of the Provence of Styria". (Gratz was the capital of Styria, a province of Austria).

Johannes Kepler was already an ardent follower of Copernicus; and during the summer of his first year in Graz, he began to wonder why the speed of the planets decreased in a regular way according to their distances from the sun, and why the planetary orbits had the particular sizes which Copernicus assigned to them.

On July 9, 1595, in the middle of a lecture which he was giving to his class, Kepler was electrified by an idea which changed the entire course of his life. In fact, the idea was totally wrong, but it struck Kepler with such force that he thought he had solved the riddle of the universe with a single stroke!

Kepler had drawn for his class an equilateral triangle with a circle circumscribed about it, so that the circle passed through all three corners of the triangle. Inside, another circle was inscribed, so that it touched each side of the triangle. It suddenly struck Kepler that the ratio between the sizes of the two circles resembled the ratio between the orbits of Jupiter and Saturn. His mercurial mind immediately leaped from the two-dimensional figure which he had drawn to the five regular solids of Pythagoras and Plato.

In three dimensions, only five different completely symmetrical many-sided figures are possible: the tetrahedron, cube, octahedron, icosahedron and the dodecahedron. There the list stops. As Euclid proved, it is a peculiarity of three-dimensional space that there are only five possible regular polyhedra. These five had been discovered by Pythagoras, and they had been popularized by Plato, the most famous of the Pythagorean philosophers. Because Plato made so much of the five regular solids in his dialogue *Timaeus*, they became known as the "Platonic solids".

In a flash of (completely false) intuition, Kepler saw why there had to be exactly six planets: The six spheres of the planetary orbits were separated by the five Platonic solids! This explained the sizes of the orbits too: Each sphere except the innermost and the outermost was inscribed in one solid and circumscribed about another!

Kepler, who was then twenty-three years old, was carried away with enthusiasm. He immediately wrote a book about his discovery and called it *Mysterium Cosmographicum*, "The Celestial Mystery". The book begins with an introduction strongly supporting the Copernican cosmology. After that comes the revelation of Kepler's marvelous (and false) solution to the cosmic mystery by means of the five Platonic solids. Kepler was unable to make the orbit of Jupiter fit his model, but he explains naively that "nobody will wonder at it, considering the great distance". The figures for the other planets did not quite fit either, but Kepler believed that the distances given by Copernicus were inaccurate.

Finally, after the mistaken ideas of the book, comes another idea, which comes close to the true picture of gravitation. Kepler tries to solve the problem of why the outer planets move more slowly than the inner ones, and he says:

"If we want to get closer to the truth and establish some correspondence in the proportions, then we must choose between these two assumptions: Either the souls of the planets are less active the farther they are from the sun, or there exists only one moving soul in the center of the orbits, that is the sun, which drives the planets the more vigorously the closer the planet is, but whose force is quasi-exhausted when acting on the outer planets, because of the long distance and the weakening of the force which it entails."

In *Mysterium Cosmographicum*, Kepler tried to find an exact mathematical relationship between the speeds of the planets and the sizes of their orbits; but he did not succeed in this first attempt. He finally solved this problem many years later, towards the end of his life.

Kepler sent a copy of his book to Tycho Brahe with a letter in which he called Tycho "the prince of mathematicians, not only of our time, but of all time". Tycho was pleased with this "fan letter"; and he recognized the originality of Kepler's book, although he had reservations about its main thesis.

Meanwhile, religious hatred had been deepening and Kepler, like all other Protestants, was about to be expelled from Catholic Austria. He appealed to Tycho for help, and Tycho, who was in need of a scientific assistant, wrote to Kepler from the castle of Benatek near Prague:

"You have no doubt already been told that I have most graciously been called here by his Imperial Majesty and that I have been received in a most friendly and benevolent manner. I wish that you would come here, not forced by the adversity of fate, but rather of your own will and desire for common study. But whatever your reason, you will find in me your friend, who will not deny you his advice and help in adversity"

To say that Kepler was glad for this opportunity to work with Tycho Brahe is to put the matter very mildly. The figures of Copernicus did not really fit Kepler's model, and his great hope was that Tycho's more accurate observations would give a better fit. In his less manic moments, Kepler also recognized that his model might not be correct after all, but he hoped that Tycho's data would allow him to find the true solution.

Kepler longed to get his hands on Tycho's treasure of accurate data, and concerning these he wrote:

"Tycho possesses the best observations, and thus so-to-speak the material for building the new edifice. He also has collaborators, and everything else he could wish for. He only lacks the architect who would put all this to use according to his own design. For although he has a happy disposition and real architectural skill, he is nevertheless obstructed in his progress by the multitude of the phenomena, and by the fact that the truth is deeply hidden in them. Now old age is creeping upon him, enfeebling his spirit and his forces"

In fact, Tycho had only a short time to live. Kepler arrived in Prague in 1600, and in 1601 he wrote:

"On October 13, Tycho Brahe, in the company of Master Minkowitz, had dinner at the illustrious Rosenborg's table, and held back his water beyond the demands of courtesy. When he drank more, he felt the tension in his bladder increase, but he put politeness before health. When he got home, he was scarcely able to urinate.. After five sleepless nights, he could still only pass water with the greatest pain, and even so the passage was impeded. The insomnia continued, with internal fever gradually leading to delirium; and the food which he ate, from which he could not be kept, exacerbated the evil... On his last night, he repeated over and over again, like someone composing a poem: 'Let me not seem to have lived in vain'."

A few days after Tycho's death, Kepler was appointed to succeed him as Imperial Mathematician of the Holy Roman Empire. Kepler states that the problem of analyzing Tycho's data took such a hold on him that he nearly went out of his mind. With a fanatic diligence rarely equaled in the history of science, he covered thousands of pages with calculations. Finally, after many years of struggle and many false starts, he wrung from Tycho's data three precise laws of planetary motion:

1) The orbits of the planets are ellipses, with the sun at one focal point.

2) A line drawn from the sun to any one of the planets sweeps out equal areas in equal intervals of time.

3) The square of the period of a planet is proportional to the cube of the mean radius of its orbit.

Thanks to Kepler's struggles, Tycho certainly had not lived in vain. Kepler's three laws were to become the basis for Newton's great universal laws of motion and gravitation. Kepler himself imagined a universal gravitational force holding the planets in their orbits around the sun, and he wrote:

"If two stones were placed anywhere in space, near to each other, and outside the reach of force of any other material body, then they would come together after the manner of magnetic bodies, at an intermediate point, each approaching the other in proportion to the other's mass... "

"If the earth ceased to attract the waters of the sea, the seas would rise up and flow to the moon... If the attractive force of the moon reaches down to the earth, it follows that the attractive force of the earth, all the more, extends to the moon, and even farther... "

"Nothing made of earthly substance is absolutely light; but matter which is less dense, either by nature or through heat, is relatively lighter... Out of the definition of lightness follows its motion; for one should not believe that when lifted up it escapes to the periphery of the world, or that it is not attracted to the earth. It is merely less attracted than heavier matter, and is therefore displaced by heavier matter."

Kepler also understood the correct explanation of the tides. He explained them as being produced primarily by the gravitational attraction of the moon, while being influenced to a lesser extent by the gravitational field of the sun.

Unfortunately, when Kepler published these revolutionary ideas, he hid them in a tangled jungle of verbiage and fantasy which repelled the most important of his readers, Galileo Galilei. In fact, the English were the first to appreciate Kepler. King James I (whom Tycho entertained on Hven) invited Kepler to move to England, but he declined the invitation. Although the skies of Europe were darkened by the Thirty Years War, Kepler could not bring himself to leave the German cultural background where he had been brought up and where he felt at home.

4.4 Galileo

Experimental physics

Galileo Galilei was born in Pisa in 1564. He was the son of Vincenzo Galilei, an intellectual Florentine nobleman whose fortune was as small as his culture was great. Vincenzo Galilei was a mathematician, composer and music critic, and from him Galileo must have learned independence of thought, since in one of his books Vincenzo wrote: "It appears to me that those who try to prove a assertion by relying simply on the weight of authority act very absurdly." This was to be Galileo's credo throughout his life. He was destined to demolish the decayed structure of Aristotelian physics with sledgehammer blows of experiment.

Vincenzo Galilei, who knew what it was like to be poor, at first tried to make his son into a wool merchant. However, when Galileo began to show unmistakable signs of genius, Vincenzo decided to send him to the University of Pisa, even though this put a great strain on the family's financial resources.

At the university and at home, Galileo was deliberately kept away from mathematics. Following the wishes of his father, he studied medicine, which was much better paid than mathematics. However, he happened to hear a lecture on Euclid given by Ostilio Ricci, a friend of his father who was Mathematician at the court of the Grand Duke Ferdinand de' Medici.

Galileo was so struck by the logical beauty and soundness of the lecture that he begged Ricci to lend him some of the works of Euclid. These he devoured in one gulp, and they were followed by the works of Archimedes. Galileo greatly admired Archimedes' scientific method, and he modeled his own scientific method after it.

After three years at the University of Pisa, Galileo was forced to return home without having obtained a degree. His father had no more money with which to support him, and Galileo was unable to obtain a scholarship, probably because his irreverent questioning of every kind of dogma had made him unpopular with the authorities. However, by this time he had already made his first scientific discovery.

According to tradition, Galileo is supposed to have made this discovery while attending a service at the Cathedral of Pisa. His attention was attracted to a lamp hung from the vault, which the verger had lighted and left swinging. As the swings became smaller, he noticed that they still seemed to take the same amount of time. He checked this by timing the frequency against his pulse. Going home, he continued to experiment with pendula. He found that the frequency of the oscillations is independent of their amplitude, provided that the amplitude is small; and he found that the frequency depends only on the length of the pendulum.

Having timed the swings of a pendulum against his pulse, Galileo reversed the procedure and invented an instrument which physicians could use for timing the pulse of a patient. This instrument consisted of a pendulum whose length could be adjusted until the swings matched the pulse of the patient. The doctor then read the pulse rate from the calibrated length of the pendulum. Galileo's pulse meter was quickly adopted by physicians throughout Europe. Later, the famous Dutch physicist, Christian Huygens (1629-1695), developed Galileo's discovery into the pendulum clock as we know it today.

While he was living at home after leaving the University of Pisa, Galileo invented a balance for measuring specific gravity, based on Archimedes' Principle in hydrostatics.

Through his writings and inventions, particularly through his treatise on the hydrostatic balance, Galileo was becoming well known, and at the age of 26 he was appointed Professor of Mathematics at the University of Pisa. However, neither age nor the dignity of his new title had mellowed him. As a professor, he challenged authority even more fiercely than he had done as a student. He began systematically checking all the dogmas of Aristotle against the results of experiment.

Aristotle had asserted that the speed of a falling object increased according to its weight: Thus, according to Aristotle, an object ten times as heavy as another would fall ten times as fast. This idea was based on the common experience of a stone falling faster than a feather.

Galileo realized that the issue was being complicated by air resistance. There were really two questions to be answered: 1) How would a body fall in the absence of air? and 2) What is the effect of air resistance? Galileo considered the first question to be the more fundamental of the two, and in order to answer it, he experimented with falling weights made of dense materials, such as iron and lead, for which the effect of air resistance was reduced to a minimum.

According to Galileo's student and biographer, Viviani, Galileo, wishing to refute Aristotle, climbed the Leaning Tower of Pisa in the presence of all the other teachers and philosophers and of all the students, and "by repeated experiments proved that the velocity of falling bodies of the same composition, unequal in weight, does not attain the proportion of their weight as Aristotle assigned it to them, but rather that they move with equal velocity." (Some historians doubt Viviani's account of this event, since no mention of it appears in other contemporary sources.)

Galileo maintained that, in a vacuum, a feather would fall to the ground like a stone. This experiment was not possible in Galileo's time, but later it was tried, and Galileo's prediction was found to be true.

Galileo realized that falling bodies gain in speed as they fall, and he wished to find a quantitative law describing this acceleration. However, he had no good method for measuring very small intervals of time. Therefore he decided to study a similar process which was slow enough to measure: He began to study the way in which a ball, rolling down an inclined plane, increases in speed.

Describing these experiments, Galileo wrote:

"..Having placed the board in a sloping position... we rolled the ball along the channel, noting , in a manner presently to be described, the time required to make the descent. We repeated the experiment more than once, in order to measure the time with an accuracy such that the deviation between two observations never exceeded one-tenth of a pulse beat"

"Having performed this operation, and having assured ourselves of its reliability, we now rolled the ball only one quarter of the length of the channel, and having measured the time of its descent, we found it precisely one-half the former. Next we tried other distances, comparing the time for the whole length with that for the half, or with that for two-thirds or three-fourths, or indeed any fraction. In such experiments, repeated a full hundred times, we always found that the spaces traversed were to each other as the squares of the times..."

"For the measurement of time, we employed a large vessel of water placed in an elevated position. To the bottom of this vessel was soldered a pipe of small diameter giving a thin jet of water, which we collected in a small glass during the time of each descent... The water thus collected was weighed after each descent on a very accurate balance. The differences and ratios of these weights gave us the differences and ratios of the times, and with such an accuracy that although the operation was repeated many, many times, there was no appreciable discrepancy in the results"

These experiments pointed to a law of motion for falling bodies which Galileo had already guessed: The acceleration of a falling body is constant; the velocity increases in linear proportion to the time of fall; and the distance traveled increases in proportion to the square of the time.

Extending these ideas and experiments, Galileo found that a projectile has two types of motion superimposed: the uniformly accelerated falling motion just discussed, and, at the same time, a horizontal motion with uniform velocity. He showed that, neglecting air resistance, these two types of motion combine to give the projectile a parabolic trajectory.

Galileo also formulated the principle of inertia, a law of mechanics which states that in the absence of any applied force, a body will continue at rest, or if in motion, it will continue indefinitely in uniform motion. Closely related to this principle of inertia is the principle of relativity formulated by Galileo and later extended by Einstein: Inside a closed room, it is impossible to perform any experiment to determine whether the room is at rest, or whether it is in a state of uniform motion.

For example, an observer inside a railway train can tell whether the train is in motion by looking out of the window, or by the vibrations of the car; but if the windows were covered and the tracks perfectly smooth, there would be no way to tell. An object dropped in a uniformly-moving railway car strikes the floor directly below the point from which it was dropped, just as it would do if the car were standing still.

The Galilean principle of relativity removed one of the objections which had been raised against the Copernican system. The opponents of Copernicus argued that if the earth really were in motion, then a cannon ball, shot straight up in the air, would not fall

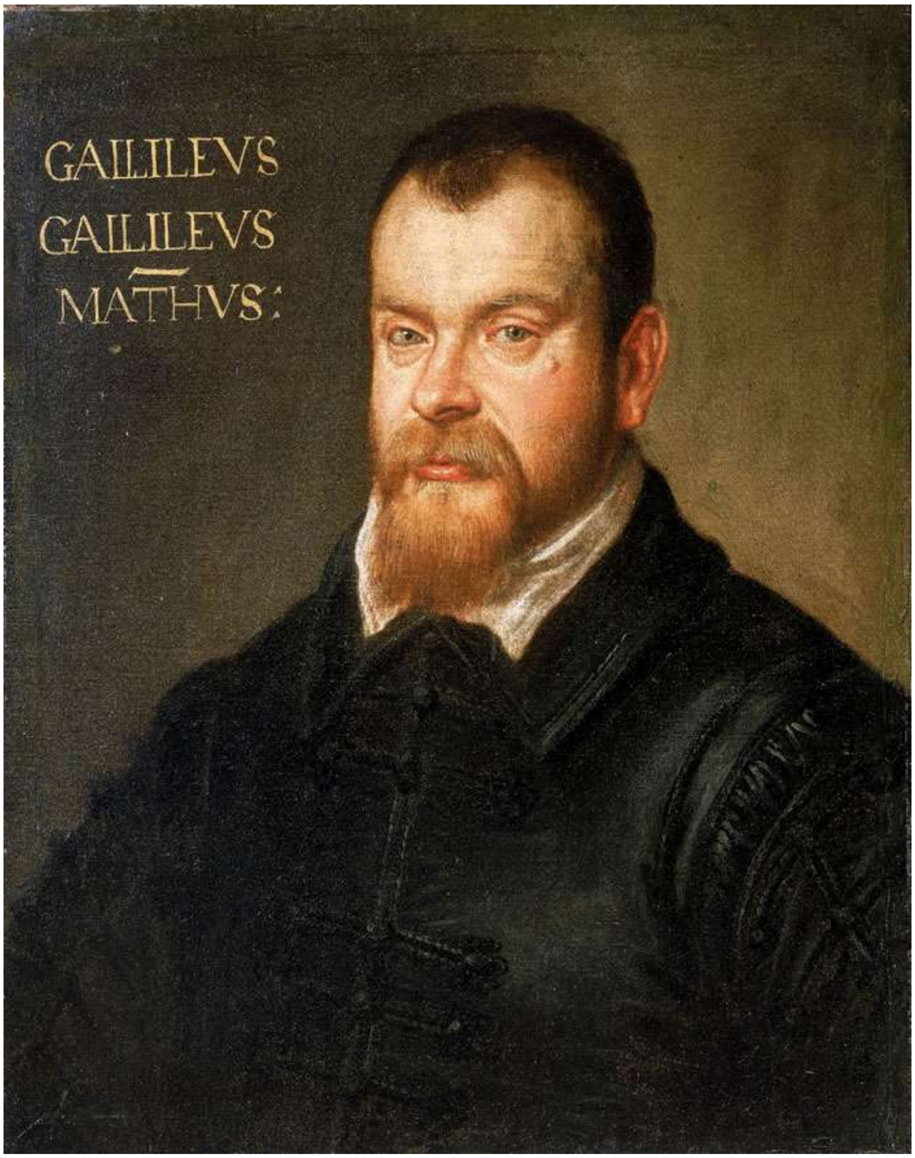

Figure 4.5: **Galileo Galilei in a portrait by Domenico Tintoretto.**

back on the cannon but would land somewhere else. They also said that the birds and the clouds would be left behind by the motion of the earth.

In 1597, Kepler sent Galileo a copy of his *Mysterium Cosmographicum*. Galileo read the introduction to the book, which was the first printed support of Copernicus from a professional astronomer, and he replied in a letter to Kepler:

"...I shall read your book to the end, sure of finding much that is excellent in it. I shall do so with the more pleasure because I have for many years been an adherent of the Copernican system, and it explains to me the causes of many of the phenomena of nature which are quite unintelligible on the commonly accepted hypothesis."

"I have collected many arguments in support of the Copernican system and refuting the opposite view, which I have so far not ventured to make public for fear of sharing the fate of Copernicus himself, who, though he acquired immortal fame with some, is yet to an infinite multitude of others (for such is the number of fools) an object of ridicule and derision. I would certainly publish my reflections at once if more people like you existed; as they don't, I shall refrain from publishing."

Kepler replied urging Galileo to publish his arguments in favor of the Copernican system:

"...Have faith, Galileo, and come forward! If my guess is right, there are but few among the prominent mathematicians of Europe who would wish to secede from us, for such is the force of truth." However, Galileo left Kepler's letter unanswered, and he remained silent concerning the Copernican system.

By this time, Galileo was 33 years old, and he had become Professor of Mathematics at the University of Padua. His Aristotelian enemies at the University of Pisa had succeeded in driving him out, but by the time they did so, his fame had become so great that he was immediately offered a position at three times the salary at Padua.

The move was a very fortunate one for Galileo. Padua was part of the free Venetian Republic, outside the power of the Inquisition, and Galileo spent fifteen happy and productive years there. He kept a large house with a master mechanic and skilled craftsmen to produce his inventions (among which was the thermometer). His lectures were attended by enthusiastic audiences, sometimes as large as two thousand; and he had two daughters and a son with a Venetian girl.

The telescope

In 1609, news reached Galileo that a Dutch optician had combined two spectacle lenses in such a way as to make distant objects seem near. Concerning this event, Galileo wrote:

"A report reached my ears that a certain Fleming had constructed a spyglass by means of which visible objects, though very distant from the eye of the observer, were distinctly seen as if nearby. Of this truly remarkable effect, several experiences were related, to which some persons gave credence while others denied them."

"A few days later the report was confirmed to me in a letter from (a former pupil) at Paris; which caused me to apply myself wholeheartedly to inquire into the means by which I might arrive at the invention of a similar instrument. This I did shortly afterward through deep study of the theory of refraction."

"First I prepared a tube of lead at the ends of which I fitted two glass lenses, both plane on one side, while on the other side one was spherically convex and the other concave. Then, placing my eye near the concave lens, I perceived objects satisfactorally large and near, for they appeared three times closer and nine times larger than when seen with the naked eye alone."

"Next I constructed another more accurate instrument, which represented objects as enlarged more than sixty times. Finally, sparing neither labor nor expense, I succeeded in constructing for myself an instrument so excellent that objects seen through it appeared nearly one thousand times larger and over thirty times closer than when regarded with our natural vision."

Galileo showed one of his early telescopes to his patrons, the Signoria of Venice. Writing of this, Galileo says:

"Many noblemen and senators, though of advanced age, mounted to the top of one of the highest towers to watch the ships, which were visible through my glass two hours before they were seen entering the harbor; for it makes a thing fifty miles off as near and clear as if it were only five."

The senate asked Galileo whether he would give the city a similar instrument to aid in its defense against attack by sea. When he did this, they immediately doubled his salary, and they confirmed him in his position for life.

After perfecting the telescope as much as he could, Galileo turned it towards the moon, the planets and the stars. He made a series of revolutionary discoveries which he announced in a short booklet called *Siderius Nuncius*, (The Siderial Messenger). The impact of this booklet was enormous, as can be judged by the report of Sir Henry Wotton, the British Ambassador to Venice:

"Now touching the occurents of the present", Sir Henry wrote, "I send herewith to His Majesty the strangest piece of news (as I may justly call it) that he has ever yet received from any part of the world; which is the annexed book (come abroad this very day) of the Mathematical Professor at Padua, who by the help of an optical instrument (which both enlargeth and approximateth the object) invented first in Flanders and bettered by himself, hath discovered four new planets rolling around the sphere of Jupiter, besides many other unknown fixed stars; likewise the true cause of the *Via Lactae* (Milky Way), so long searched; and lastly that the moon is not spherical but endued with many prominences, and, which is strangest of all, illuminated with the solar light by reflection from the body of the earth, as he seemeth to say. So as upon the whole subject, he hath overthrown all former astronomy.."

"These things I have been so bold to discourse unto your Lordship, whereof here all corners are full. And the author runneth a fortune to be either exceeding famous or exceeding ridiculous. By the next ship your Lordship shall receive from me one of the above instruments, as it is bettered by this man."

Wherever Galileo turned his powerful telescope, he saw myriads of new stars, so utterly outnumbering the previously known stars that mankind's presumption to know anything at all about the universe suddenly seemed pitiful. The Milky Way now appeared as a sea of stars so numerous that Galileo despaired of describing them in detail. The vastness of the universe as postulated by Nicolas Copernicus and Gordiano Bruno (one ridiculed and the other burned alive) was now brought directly to Galileo's senses. In fact, everywhere he looked he saw evidence supporting the Copernican system and refuting Aristotle and Ptolemy.

The four moons of Jupiter, which Galileo had discovered, followed the planet in its motion, thus refuting the argument that if the earth revolved around the sun, the moon would not be able to revolve around the earth. Also, Jupiter with its moons formed a sort of Copernican system in miniature, with the massive planet in the center and the four small moons circling it, the speed of the moons decreasing according to their distance from Jupiter.

Galileo discovered that the planet Venus has phase changes like the moon, and that these phase changes are accompanied by changes in the apparent size of the planet. Copernicus had predicted that if the power of human vision could be improved, exactly these changes in the appearance of Venus would be observed. Galileo's observations proved that Venus moves in an orbit around the sun: When it is on the opposite side of the sun from the earth, it appears small and full; when it lies between the earth and the sun, it is large and crescent.

Galileo also observed mountains on the moon. He measured their height by observing the way in which sunlight touches their peaks just before the lunar dawn, and he found some of the peaks to be several miles high. This disproved the Aristotelian doctrine that the moon is a perfect sphere, and it established a point of similarity between the moon and the earth.

Galileo observed that the dark portion of the moon is faintly illuminated, and he asserted that this is due to light reflected from the earth, another point of similarity between the two bodies. Generally speaking, the impression which Galileo gained from his study of the moon is that it is a body more or less like the earth, and that probably the same laws of physics apply on the moon as on the earth.

All these observations strongly supported the Copernican system, although the final rivet in the argument, the observation of stellar parallax, remained missing until the 19th century. Although he did not possess this absolutely decisive piece of evidence, Galileo thought that he had a strong enough basis to begin to be more open in teaching the Copernican system. His booklet, *Siderius Nuncius* had lifted him to an entirely new order of fame. He had seen what no man had ever seen before, and had discovered new worlds. His name was on everyone's lips, and he was often compared to Columbus.

Still it moves

In 1610, Galileo left Padua to take up a new post as Mathematician to the court of the Medicis in Florence; and in the spring of 1611, he made a triumphal visit to Rome. Describing this visit, Cardinal del Monte wrote: "If we were living under the ancient

Republic of Rome, I really believe that there would have been a column on the Capital erected in Galileo's honor!" The Pope received Galileo in a friendly audience, and Prince Cesi made him a member of the Academia dei Lincei.

The Jesuit astronomers were particularly friendly to Galileo. They verified his observations and also improved some of them. However, Galileo made many enemies, especially among the entrenched Aristotelian professors in the universities. He enjoyed controversy (and publicity), and he could not resist making fools of his opponents in such a way that they often became bitter personal enemies.

Not only did Galileo's law describing the acceleration of falling bodies contradict Aristotle, but his principle of inertia contradicted the Aristotelian dogma, *omne quod movetur ab alio movetur* - whatever moves must be moved by something else. (The Aristotelians believed that each planet is moved by an angel.) Galileo also denied Aristotle's teaching that generation and decay are confined to the sphere beneath the orbit of the moon.

Although Galileo was at first befriended and honored by the Jesuit astronomers, he soon made enemies of the members of that order through a controversy over priority in the discovery of sunspots. In spite of this controversy, Galileo's pamphlet on sunspots won great acclaim; and Cardinal Maffeo Barberini (who later became Pope Urban VIII) wrote to Galileo warmly praising the booklet.

In 1613, the Medicis gave a dinner party and invited Professor Castelli, one of Galileo's students who had become Professor of Mathematics at Pisa. After dinner, the conversation turned to Galileo's discoveries, and the Grand Duchess Christina, mother of Duke Cosimo de' Medici, asked Castelli his opinion about whether the motion of the earth contradicted the Bible.

When this conversation was reported to Galileo, his response was to publish a pamphlet entitled *Letter to Castelli*, which was later expanded into a larger pamphlet called *Letter to the Grand Duchess Christina*. These pamphlets, which were very widely circulated, contain the following passage:

"...Let us grant, then, that Theology is conversant with the loftiest divine contemplation, and occupies the regal throne among the sciences by this dignity. By acquiring the highest authority in this way, if she does not descend to the lower and humbler speculations of the subordinate sciences, and has no regard for them because they are not concerned with blessedness, then her professors should not arrogate to themselves the authority to decide on controversies in professions which they have neither studied nor practiced. Why this would be as if an absolute despot, being neither a physician nor an architect, but knowing himself free to command, should undertake to administer medicines and erect buildings according to his whim, at the grave peril of his poor patients' lives, and the speedy collapse of his edifices..."

Galileo's purpose in publishing these pamphlets was to overcome the theological objections to the Copernican system. The effect was exactly the opposite. The *Letter to Castelli* was brought to the attention of the Inquisition, and in 1616 the Inquisition prohibited everyone, especially Galileo, from holding or defending the view that the earth turns on its axis and moves in an orbit around the sun.

Galileo was silenced, at least for the moment. For the next eighteen years he lived unmolested, pursuing his scientific research. For example, continuing his work in optics, he constructed a compound microscope.

In 1623, marvelous news arrived: Cardinal Maffio Barberini had been elected Pope. He was a great intellectual, and also Galileo's close friend. Galileo went to Rome to pay his respects to the new Pope, and he was received with much warmth. He had six long audiences with the Pope, who showered him with praise and gifts. The new Pope refused to revoke the Inquisition's decree of 1616, but Galileo left Rome with the impression that he was free to discuss the Copernican system, provided he stayed away from theological arguments.

Galileo judged that the time was right to bring forward his evidence for the Copernican cosmology; and he began working on a book which was to be written in the form of a Platonic dialogue. The characters in the conversation are Salivati, a Copernican philosopher, Sagredo, a neutral but intelligent layman, and Simplicio, a slightly stupid Aristotelian, who always ends by losing the arguments.

The book, which Galileo called *Dialogue on the Two Chief World Systems*, is a strong and only very thinly veiled argument in favor of the Copernican system. When it was published in 1632, the reaction was dramatic. Galileo's book was banned almost immediately, and the censor who had allowed it to be printed was banished in disgrace. When the agents of the Inquisition arrived at the bookstores to confiscate copies of the *Dialogue*, they found that the edition had been completely sold out.

The Pope was furious. He felt that he had been betrayed. Galileo's enemies had apparently convinced the Pope that the character called Simplicio in the book was a caricature of the Pope himself! Galileo, who was seventy years old and seriously ill, was dragged to Rome and threatened with torture. His daughter, Maria Celeste, imposed severe penances and fasting on herself, thinking that these would help her prayers for her father. However, her health was weak, and she became ill.

Meanwhile, Galileo, under threat of torture, had renounced his advocacy of the motion of the earth. According to tradition, as he rose from his knees after the recantation he muttered *"Eppur si muove!"*, ("Still it moves!") It is unlikely that he muttered anything of the kind, since it would have been fatally dangerous to do so, and since at that moment, Galileo was a broken man. Nevertheless, the retort which posterity has imagined him to make remains unanswerable. As Galileo said, before his spirit was broken by the Inquisition, "...It is not in the power of any creature to make (these ideas) true or false or otherwise than of their own nature and in fact they are."

Galileo was allowed to visit the bedside of his daughter, Marie Celeste, but in her weak condition, the anxiety of Galileo's ordeal had been too much for her. Soon afterward, she died. Galileo was now a prisoner of the Inquisition. He used his time to write a book on his lifelong work on dynamics and on the strength of material structures. The manuscript of this book, entitled *Two New Sciences*, was smuggled out of Italy and published in Holland.

When Galileo became blind, the Inquisition relaxed the rules of his imprisonment, and he was allowed to have visitors. Many people came to see him, including John Milton, who was then 29 years old. One wonders whether Milton, meeting Galileo, had any premonition of his own fate. Galileo was already blind, while Milton was destined to become so. The two men had another point in common: their eloquent use of language. Galileo was a many-sided person, an accomplished musician and artist as well as a great scientist. The impact of his ideas was enhanced by his eloquence as a speaker and a writer. This can be seen from the following passage, taken from Galileo's *Dialogue*, where Sagredo comments on the Platonic dualism between heavenly perfection and earthly corruption:

"...I cannot without great wonder, nay more, disbelief, hear it being attributed to natural bodies as a great honor and perfection that they are impassable, immutable, inalterable, etc.; as, conversely, I hear it esteemed a great imperfection to be alterable, generable and mutable. It is my opinion that the earth is very noble and admirable by reason of the many different alterations, mutations and generations which incessantly occur in it. And if, without being subject to any alteration, it had been one vast heap of sand, or a mass of jade, or if, since the time of the deluge, the waters freezing that covered it, it had continued an immense globe of crystal, whereon nothing had ever grown, altered or changed, I should have esteemed it a wretched lump of no benefit to the Universe, a mass of idleness, and in a word, superfluous, exactly as if it had never been in Nature. The difference for me would be the same as between a living and a dead creature."

"I say the same concerning the moon, Jupiter and all the other globes of the Universe. The more I delve into the consideration of the vanity of popular discourses, the more empty and simple I find them. What greater folly can be imagined than to call gems, silver and gold noble, and earth and dirt base? For do not these persons consider that if there were as great a scarcity of earth as there is of jewels and precious metals, there would be no king who would not gladly give a heap of diamonds and rubies and many ingots of gold to purchase only so much earth as would suffice to plant a jasmine in a little pot or to set a tangerine in it, that he might see it sprout, grow up, and bring forth such goodly leaves, fragrant flowers and delicate fruit?"

The trial of Galileo cast a chill over the intellectual atmosphere of southern Europe, and it marked the end of the Italian Renaissance. However, the Renaissance had been moving northward, and had produced such figures as Dürer and Gutenberg in Germany, Erasmus and Rembrandt in Holland, and Shakespeare in England. In 1642, the same year during which Galileo died in Italy, Isaac Newton was born in England.

Suggestions for further reading

1. Joseph C. Pitt, *Galileo, Human Knowledge and the Book of Nature; Method Replaces Metaphysics*, Kluwer, Dordrecht, (1992).
2. Michael Segre, *In the Wake of Galileo*, Rutgers University Press, New Brunswick, N.J., (1991).
3. Stillman Drake, *Galileo, Pioneer Scientist*, Toronnto University Press, (1990).
4. Silvio A. Bedini, *The Pulse of Time; Galileo Galilei, the Determination of Longitude and the Pendulum Clock*, Olschki, Fierenze, (1991).

5. Stillman Drake et al., *Nature, Experiment and the Sciences; Essays on Galileo and the History of Science*, Kluwer, Dordrecht, (1990).
6. Pietro Redondi, *Galileo Heretic*, Princeton University Press, (1987).
7. William A. Wallace, *Galileo and his Sources; The Heritage of the Collegio Romani in Galileo's Science*, Princeton University Press, (1984).
8. William A. Wallace, *Prelude to Galileo*, Reidel, Dordrecht, (1981).
9. Stillman Drake, *Telescopes, Tides nad Tactics; a Galilean Dialogue about the Starry Messinger and Systems of the World*, University of Chicago Press, (1980).
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11. K.J.J. Hintikka et al. editors, *Conference on the History and Philosophy of Science*, Reidel, Dordrecht, (1981).

Chapter 5

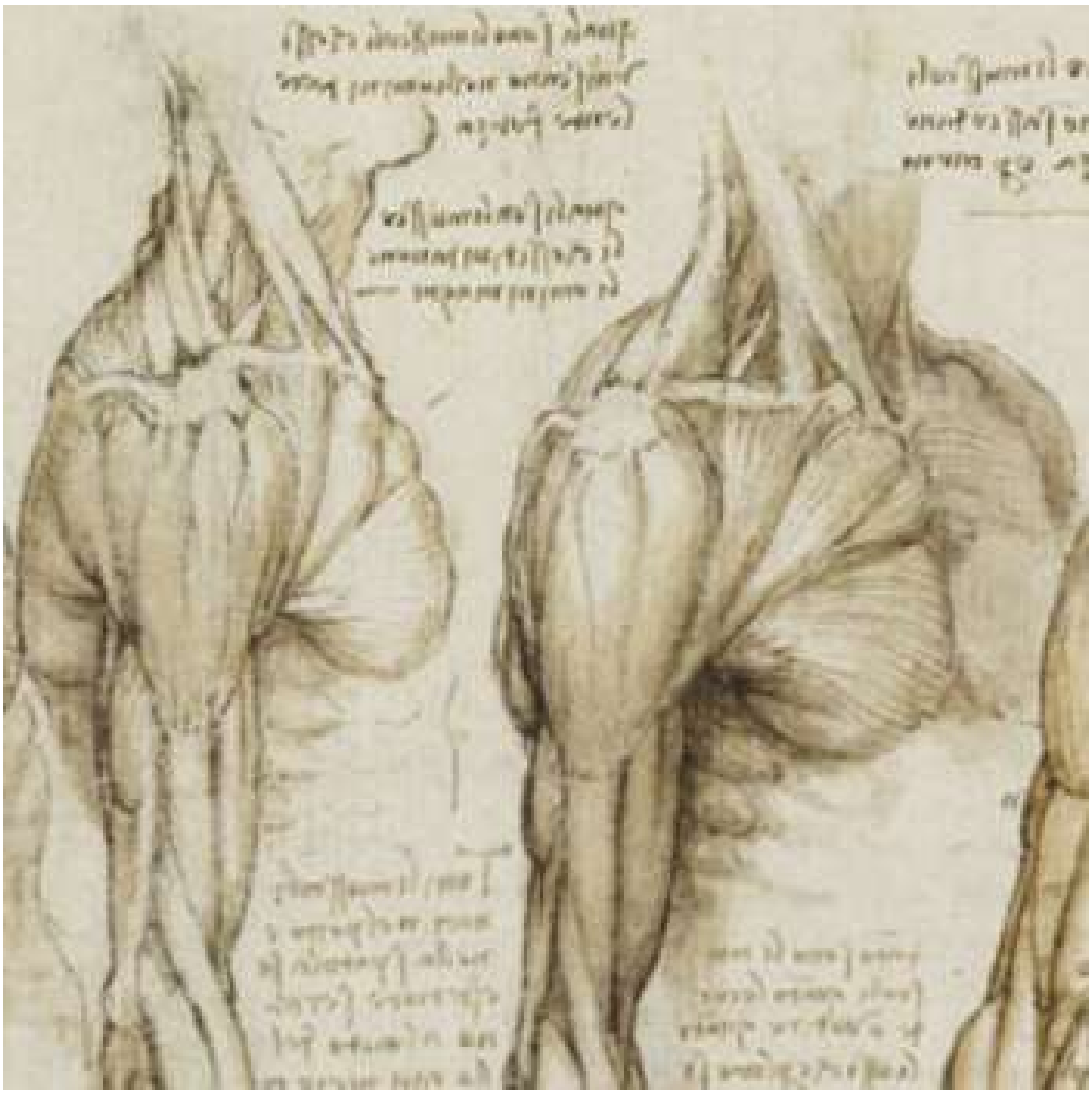
PIONEERS OF MEDICINE

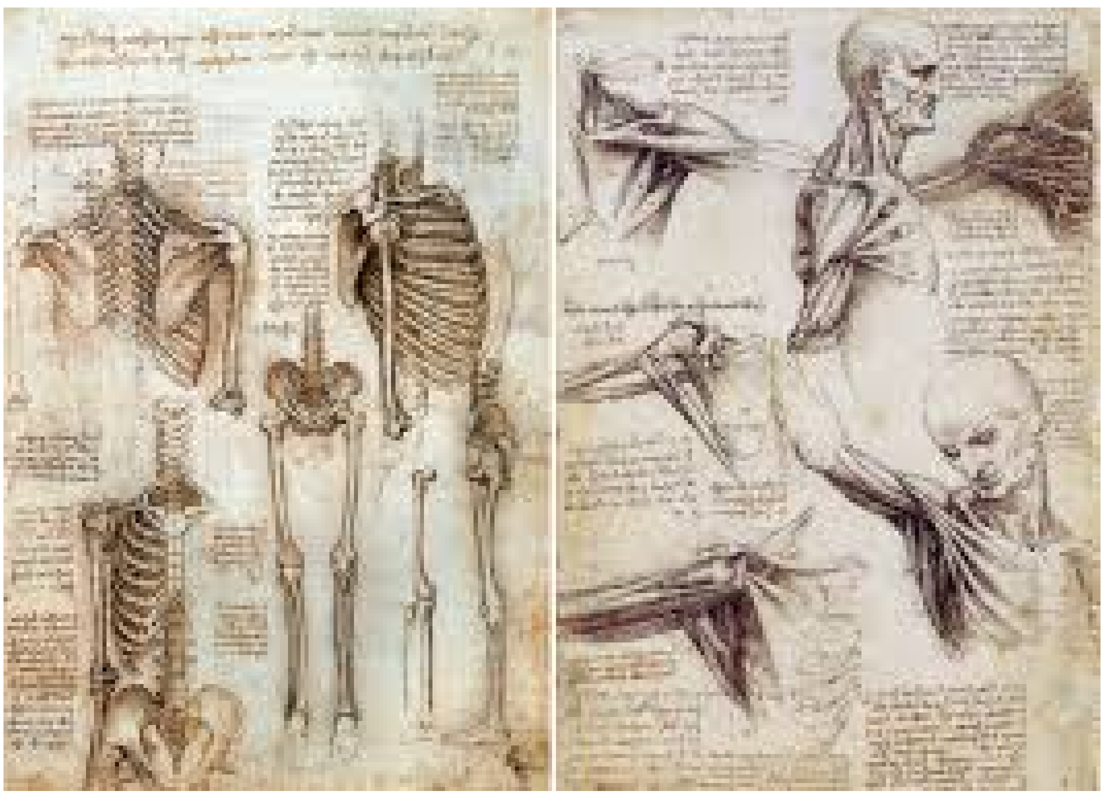
5.1 Leonardo's anatomical drawings

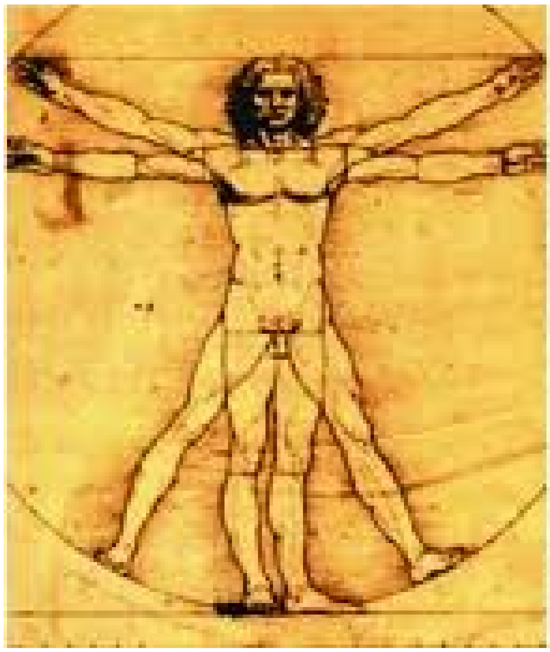
Leonardo's interest in anatomy began when he was a student in Verrocio's workshop. It is not known exactly when he began dissecting the human body, but a likely guess is that it was shortly after his move to Milan. He began this research in order to aid his artistic representation of the human body, but as the work progressed, his main interest shifted to determining the mechanisms by which the human body performed its functions.

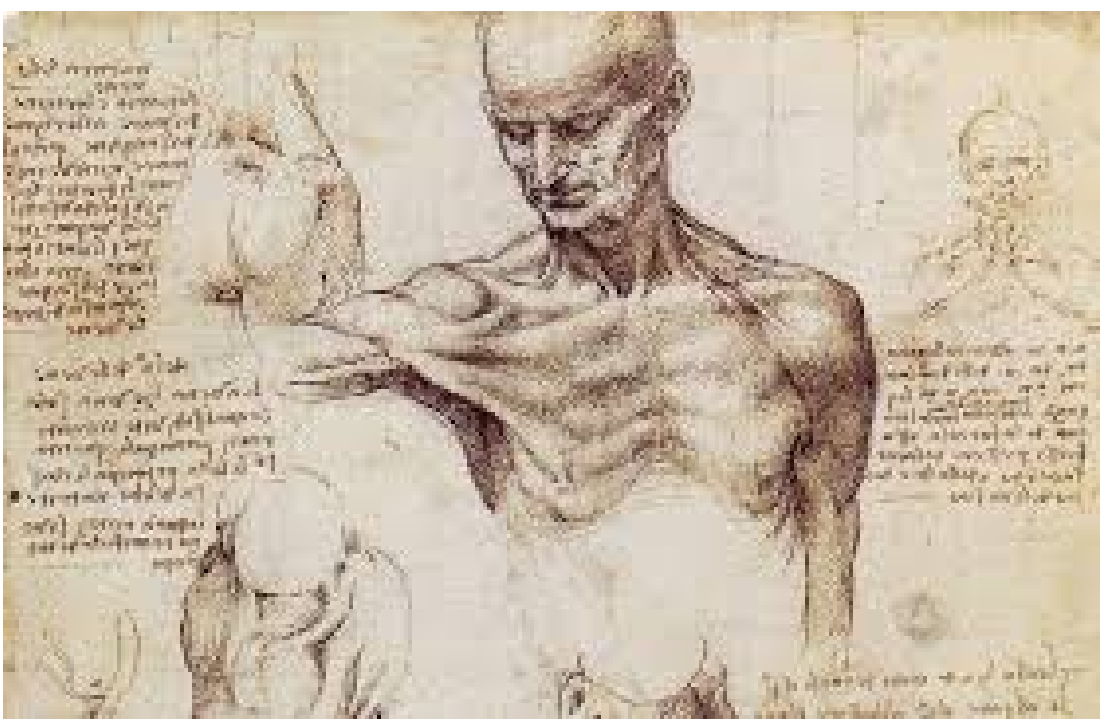
During the next twenty years, he did practical work in anatomy on the dissection table in Milan, then at hospitals in Florence and Rome, and in Pavia, where he collaborated with the physician-anatomist Marcantonio della Torre. By his own count Leonardo dissected 30 corpses in his lifetime.

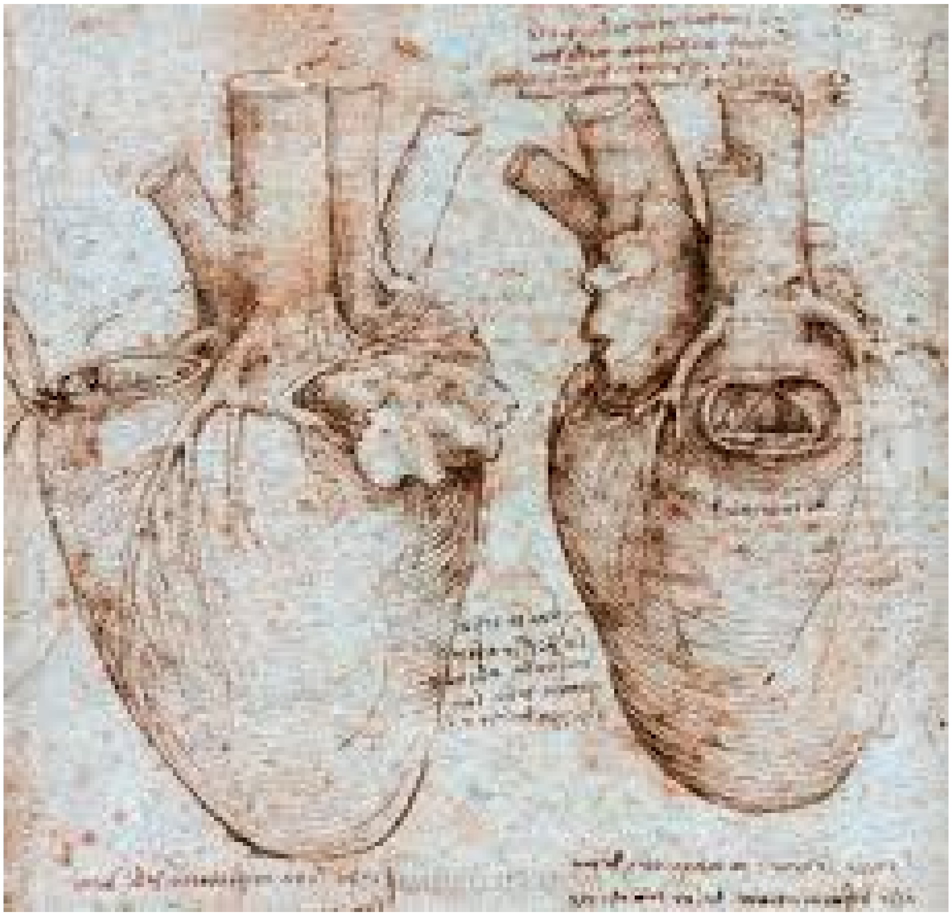
Leonardo intended to publish his drawings in a treatise on anatomy- If he had done so his discoveries would have transformed European knowledge of the subject. But when he died in 1519, the drawings remained a mass of undigested material among his private papers and their significance was lost to the world for almost 400 years.

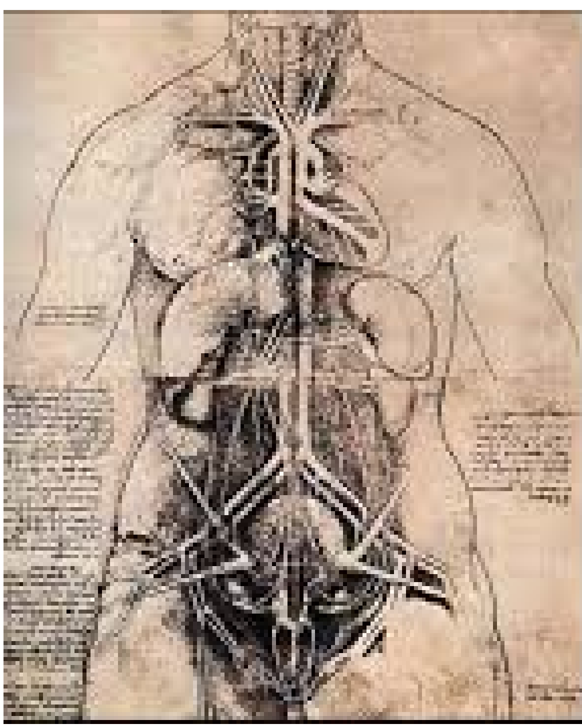












5.2 Andraas Vesalius

"The father of modern anatomy"

Andreas Versalius (1514-1564) was a pioneering anatomist, famous for his influential book *De Humani Corporis Fabrica Libri Septem* (On the fabric of the human body in seven books). He was born in Brussels, which was then a part of the Hapsburg Netherlands, and his name was originally Andrias van Wessel. He later adopted a Latinized version of his name, as was a common practice among European scholars at that time. His 7-volume book was so influential that he is often called "the father of modern anatomy".

A long family tradition in medicine

Versalius was born into a family that had a long tradition in medicine. Wikipedia states that **"His great grandfather, Jan van Wesel, probably born in Wesel, received a medical degree from the University of Pavia and taught medicine at the University of Leuven. His grandfather, Everard van Wesel, was the Royal Physician of Emperor Maximilian, whilst his father, Anders van Wesel, served as apothecary to Maximilian..."**

A professor at the University of Padua

When Versalius completed his medical studies at the University of Leuven, he was immediately offered the chair of surgery and anatomy at the University of Padua. Previously, students had been taught from the classical texts of Galen (129-216 AD), whose authority was never questioned. By contrast. Versalius insisted that dissection was the only way of finding the truth. After years of anatomical dissection and observation, and in collaboration with such artists as Jan Stephen van Calcar (a former student of Titian), he produced his great book.

Figure 5.1: **Portrait of Andreas Vesalius by Jan van Calcar.**

Figure 5.2: **The Holy Roman Emperor, Charles V, who was an important patron of Vesalius.**

Figure 5.3: **Vesalius's Fabrica contained many intricately detailed drawings of human dissections, often in allegorical poses..**

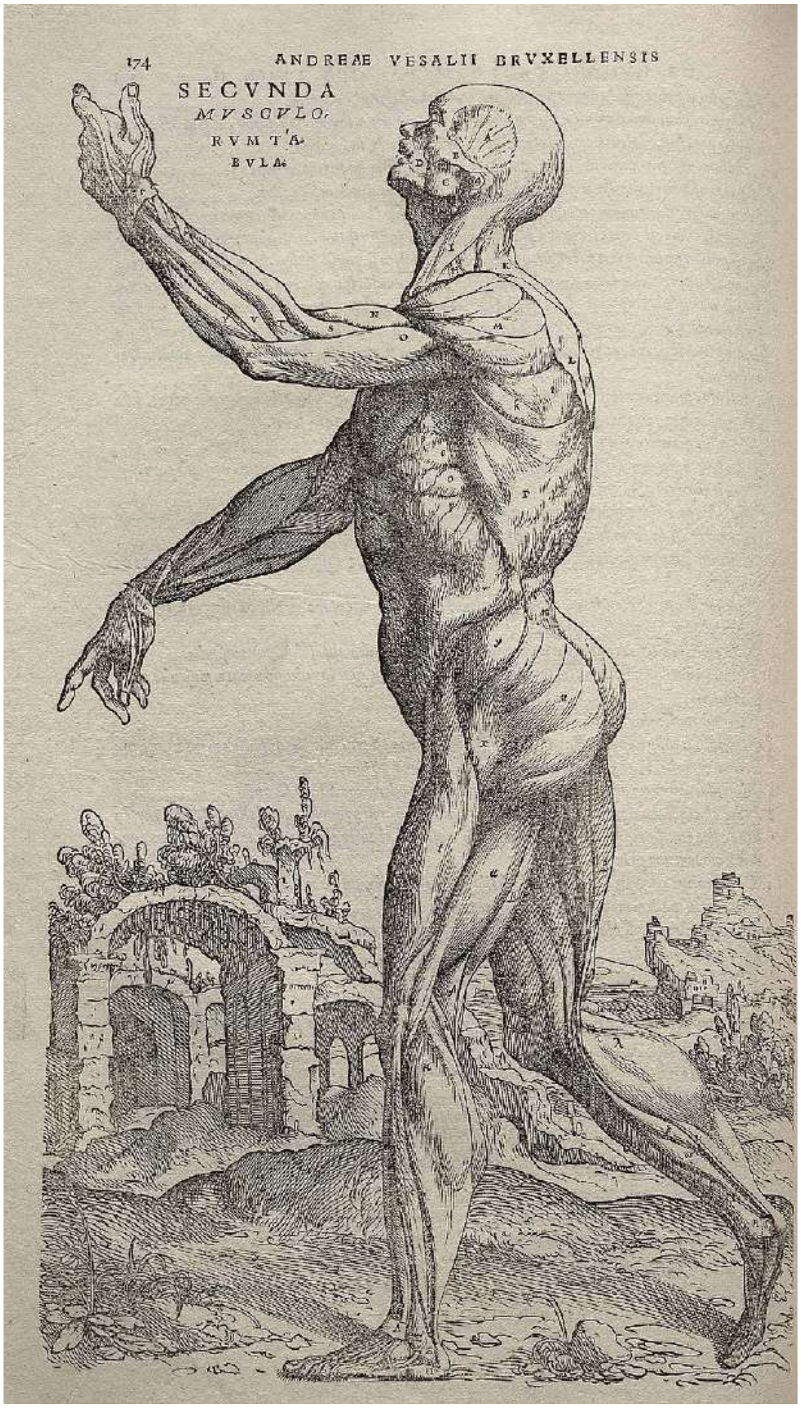


Figure 5.4: **Vesalius's Fabrica p. 174 .**

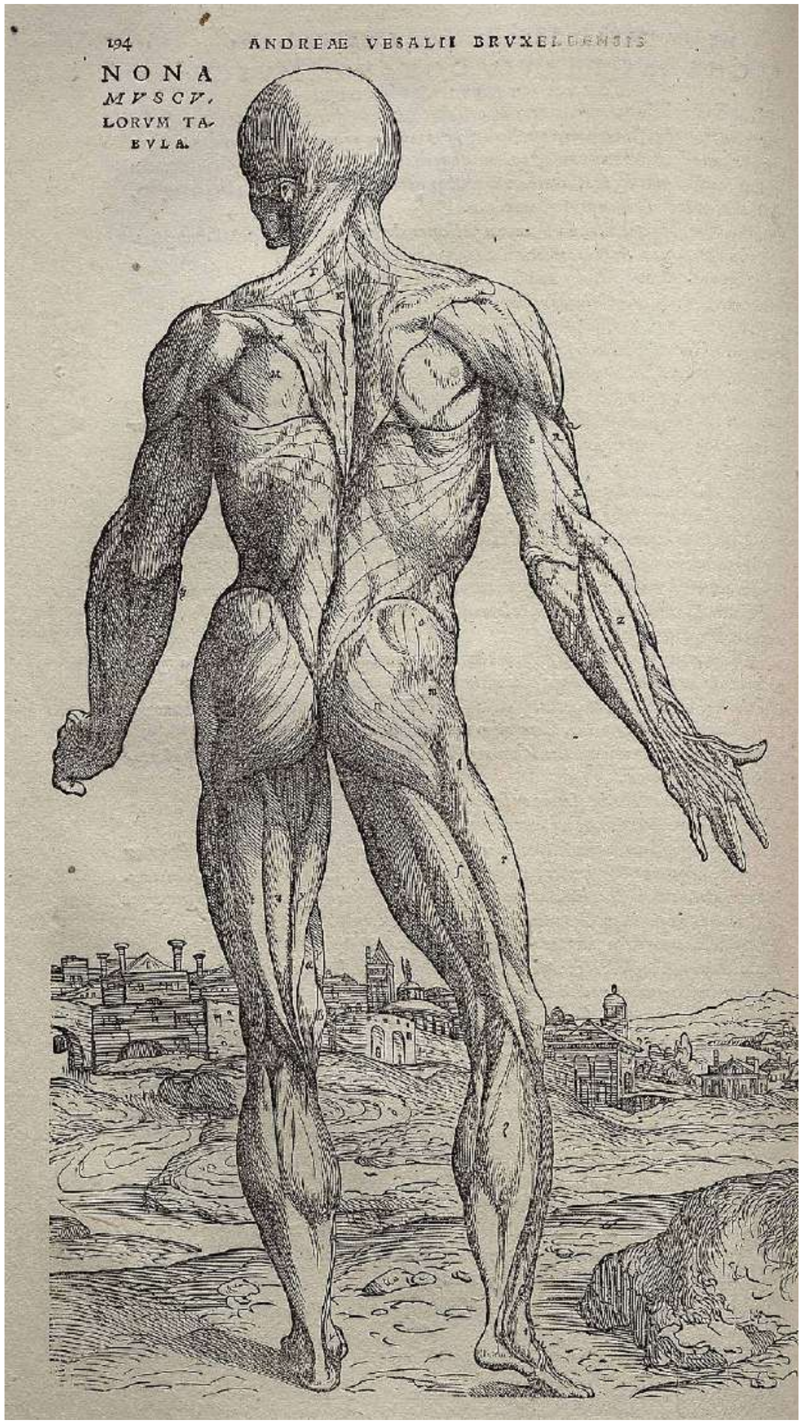


Figure 5.5: **Vesalius's Fabrica p. 194 .**

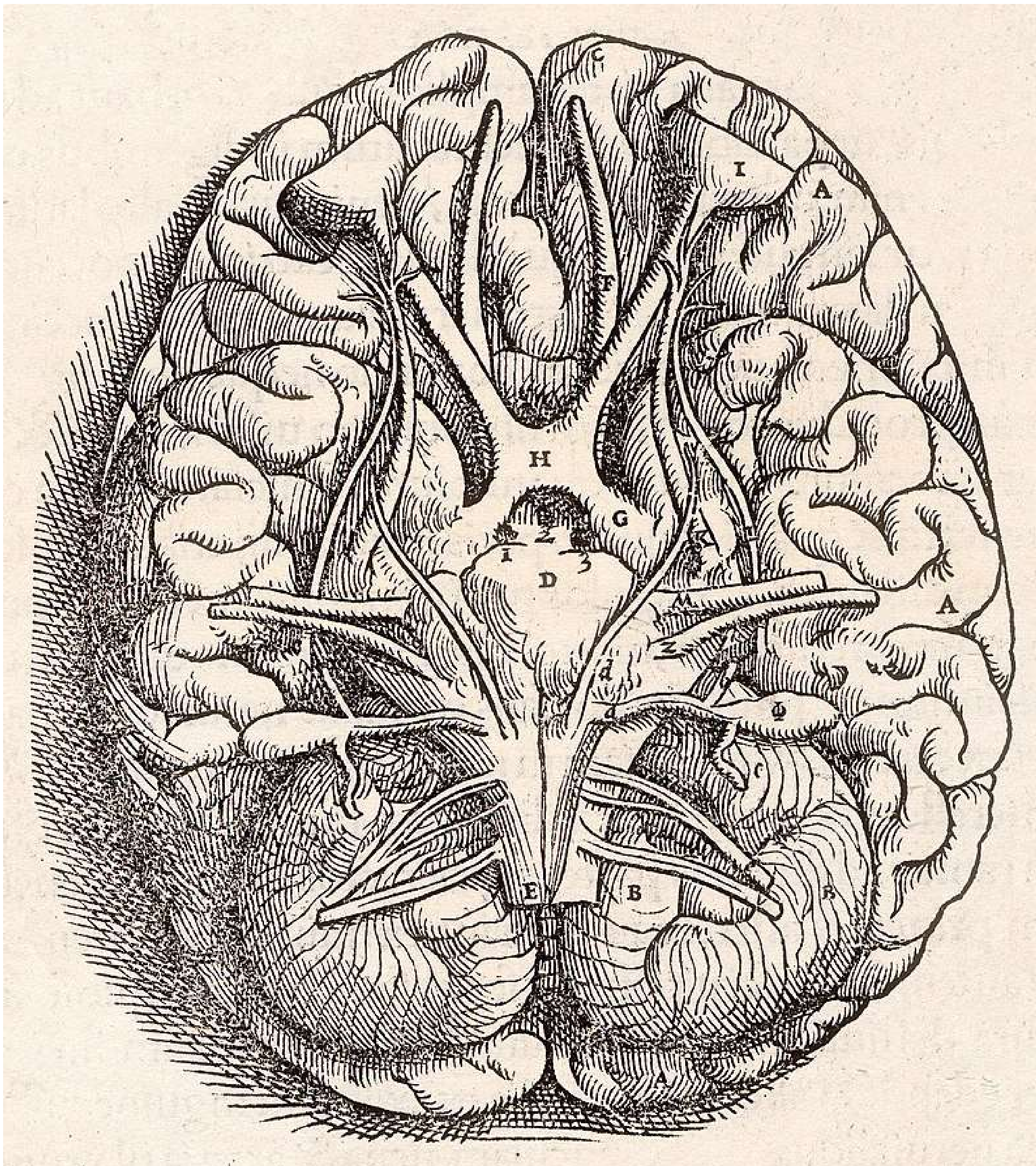


Figure 5.6: **Base of the brain, showing the optic chiasma, cerebellum, olfactory bulbs, etc..**

5.3 William Harvey

William Harvey (1578-1657) was the first person to describe accurately, and in detail, the action of the heart in circulating the blood through the bodies of animals and humans.

He came from a well-placed family. His father was a jurist at Folkstone, England, and later served as Folkstone's mayor. The family had considerable wealth.

William Harvey attended Cambridge University, where he received a Bachelor of Arts degree in 1597. He then studied at the University of Padua in Italy, where he graduated at the age of 25 as a Doctor of Medicine. He had "conducted himself so wonderfully well in the examination and had shown such skill, memory and learning that he had far surpassed even the great hopes which his examiners had formed of him." Harvey at the University of Padua

After obtainining a medical degree at the University of Padua, Harvey returned to England, where he also obtained another medical degree from Cambridge University. He was admitted to the Royal College of Physicians in 1604. Harvey was then elected to be the physician in charge of St. Bartholomew's Hospital, a position that he held for almost all the remainder of his life. He was also appointed Physician Extraordinary to King James I, and later Physician Ordinary to King Charles I.

De Motu Cordis

William Harvey made many contributions to medical science, but he is especially remembered for his book, *De Moru Cordis* (Anatomical Account of the Motion of the Heart and Blood). The 72-page book was published in 1628 in Frankfurt, where as Harvey knew, it would be immediately dispersed through Europe.

Harvey believed that an understanding of the action of the heart and circulatory system required observation of living hearts in action, and this presented extremely severe difficulties. Harvey wrote: "...I found the task so truly arduous... that I was almost tempted to think... that the movement of the heart was only to be comprehended by God. For I could neither rightly perceive at first when the systole and when the diastole took place by reason of the rapidity of the movement..."

Nevertheless he persisted, and after years of experimentation and observation of beating hearts in a great variety of animals, including cold-blooded snakes and reptiles, he formed a correct picture of the action of the heart, the arteries and the veins. Having no microscope, he was unable to observe directly the motion of blood in the capillaries, but his theories regarding this flow were correct.

Harvey's book was at first met with skepticism, but within 20 years or so, it was accepted as being correct. Today William Harvey is honored as one of the great pioneers of medical science.

Figure 5.7: **Portrait of William Harvey.**

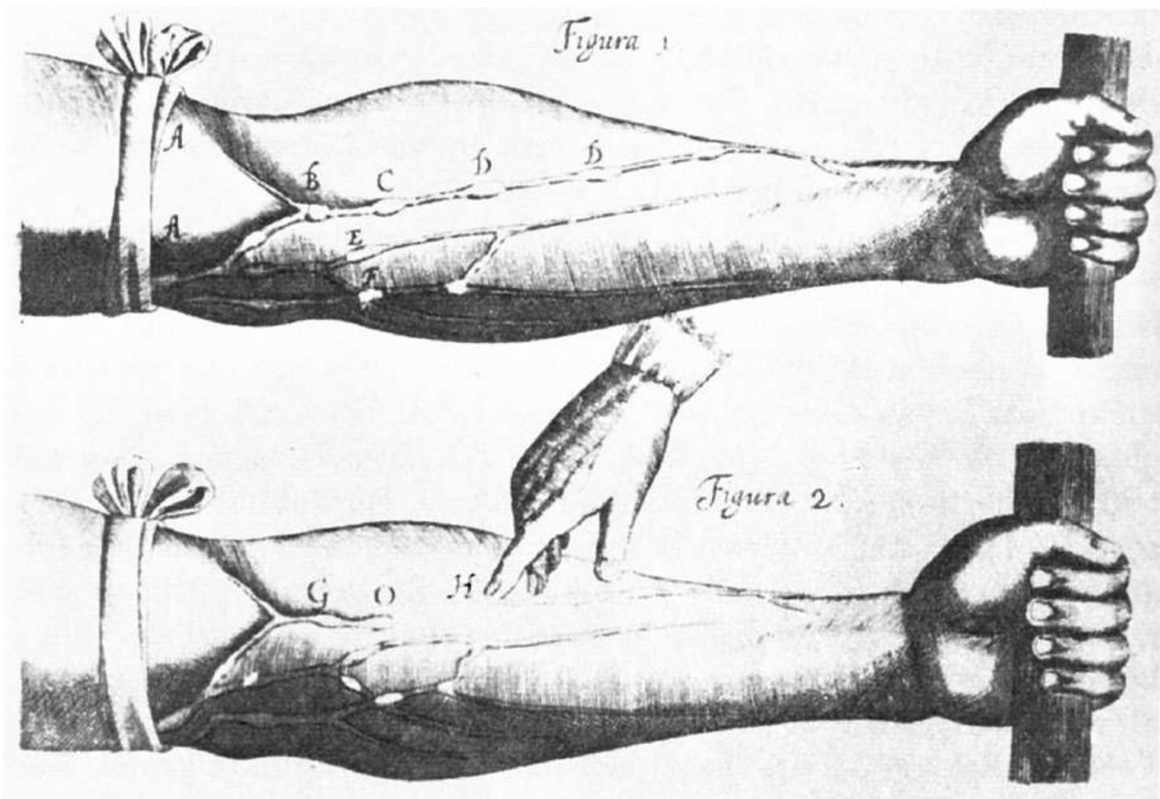


Figure 5.8: **An experiment from Harvey's de Motu Cordis.**

Figure 5.9: **William Harvey on a 1957 Soviet postage stamp.**

Suggestions for further reading

1. Irma A. Richter (editor), *Selections from the Notebooks of Leonardo da Vinci*, Oxford University Press (1977).
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Chapter 6

ROBERT BOYLE AND ROBERT HOOKE

6.1 Searching for the Philosopher's Stone

Alchemy originated in Hellenistic Egypt during the first few centuries AD, and later spread to many parts of the world, including both Asia and Europe. Just as astrology preceded true astronomy and astrophysics, so alchemy preceded true chemistry. It combined mysticism, secrecy and superstition with a number of genuine chemical discoveries and methods.

One of the aims of alchemists was the transmutation of base metals into silver or gold. Like the ancient Greeks, they believed earth, water, air and fire to be elements, and they thought that transmutation of one metal into another could be achieved by combining these four elements in the proper way.

Other aims of the alchemists were to find an elixir that could confer immortality, to find a medicine that could cure all diseases, and to discover a universal solvent. In Europe, the alchemists of the Middle Ages thought that these aims could be achieved if they could only find the Philosopher's Stone.

Besides isolating substances that are now known to be true elements, such as sulfur and mercury, alchemists produced medicines that were of value to patients. Alchemy developed differently depending on the region. In both India and China, alchemy lead to the discovery of gunpowder. In England, Roger Bacon (1219-1292) was the first to record the composition of gunpowder. Bacon worked as an an alchemist as well as in other fields. Bacon's greatest work, the *Opus Magnum* was intended to reform the curricula of universities. Besides alchemy, it also discusses mathematics, optics and astronomy, and advocates the use of the experimental method.

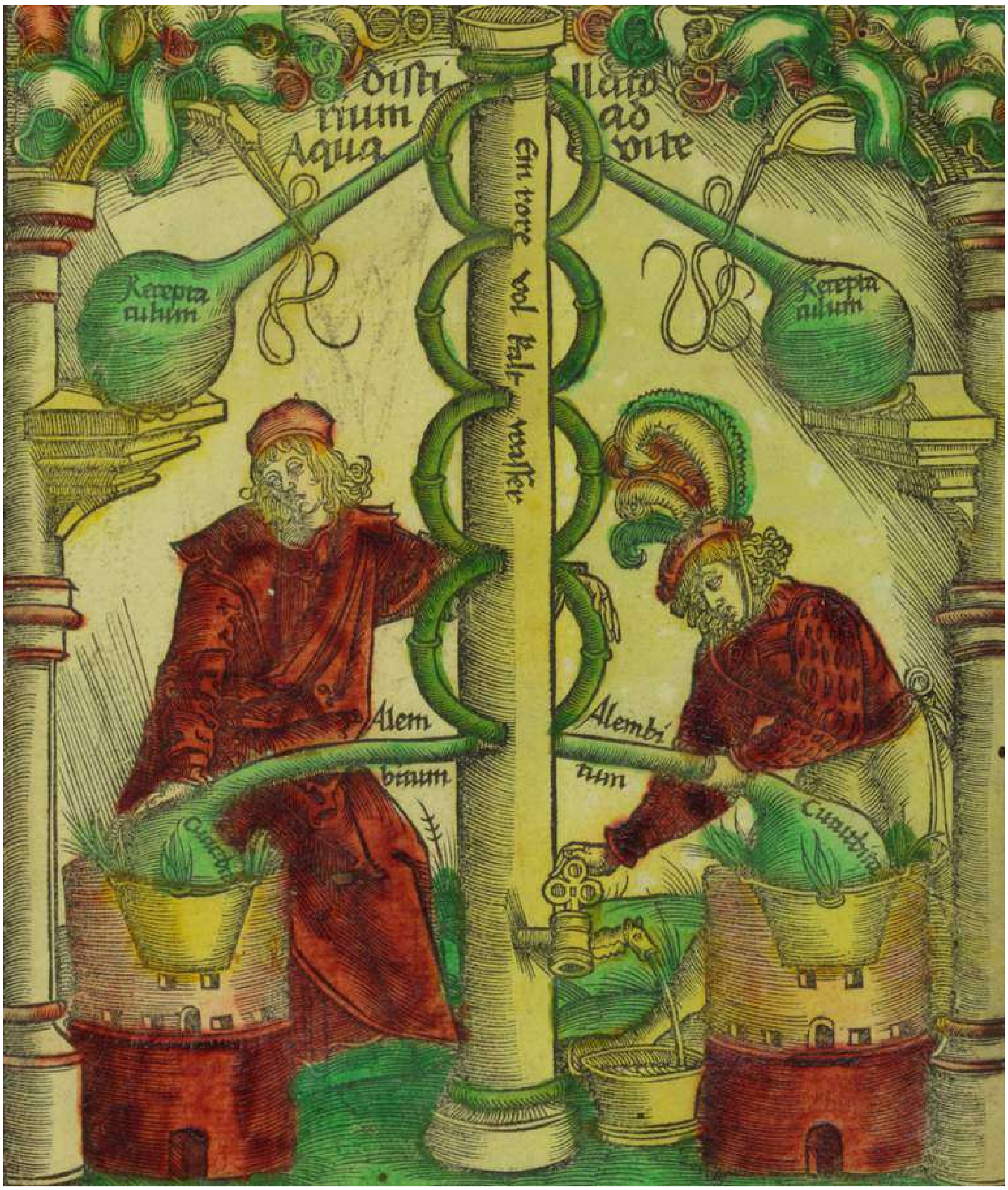


Figure 6.1: **The alchemy of the Middle Ages in Europe contained strong elements of secrecy and mysticism.**

Figure 6.2: **Kimiya-yi sa'adal (The Alchemy of Happiness), a text on Islamic philosophy and alchemy by the Persian philosopher and mystic Al-Ghazali (11th century).**

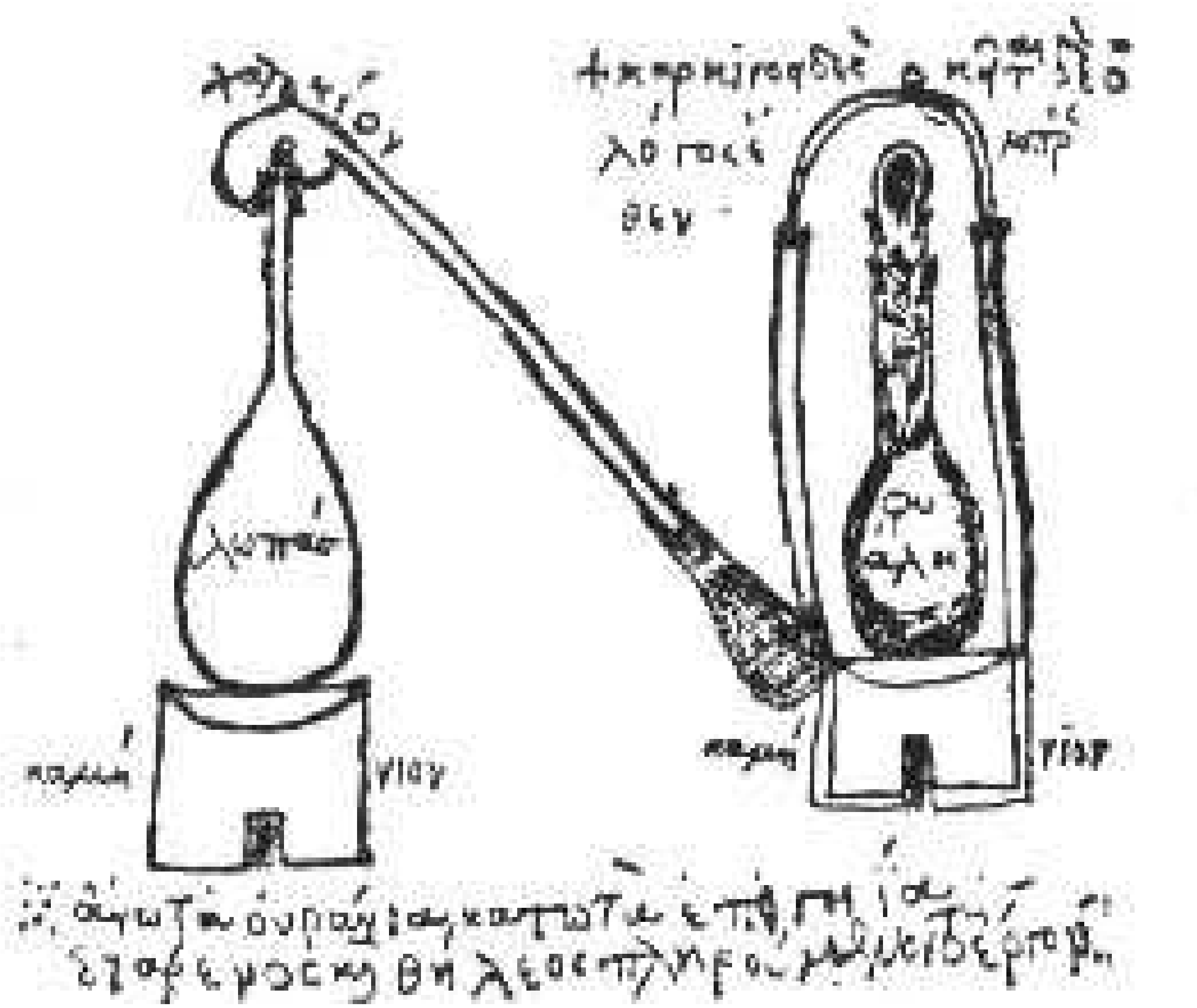


Figure 6.3: **Ambix, cucurbit and retort of Zosimos, from Marcelin Berthelot, Collection des anciens alchimistes grecs (3 vol., Paris, 1887-1888).**

Figure 6.4: **A medieval alchemist.**

6.2 Robert Boyle: The last alchemist or the first modern chemist?

"Son of the Earl of Cork and father of chemistry"

Robert Boyle (1627-1691) was born in Ireland, the seventh son and fourteenth child of the immensely rich 1st Earl of Cork. As a very young boy, Boyle was privately tutored in Latin, Greek and French. When he was eight years old, following the death of his mother, he was sent to England to be educated at Eton College.

After three years at Eton, Boyle traveled to continental Europe with a French tutor. Galileo Galilei was still alive at that time, and they visited him in Florence. Undoubtedly, Galileo's insistence on adherence to strictly experimental methods made a strong impression on the youthful Boyle.

In 1644, Robert Boyle, then 17 years old, returned to England with a strong interest in scientific research. With the death of his father, he had inherited substantial estates in Ireland, as well as a mansion in Stalbridge, Dorset, England. He lived at Stalbridge between 1644 and 1652, and performed many of his experiments there. He also became a very active member of the "invisible college", which later developed into the Royal Society of London. He visited his Irish estates between 1652 and 1654, but found it difficult to do experimental work in Ireland because of the lack of proper equipment.

In 1654 Robert Boyle moved to Oxford, where he was better able to perform his experiments. He rented a large apartment there, and hired Robert Hooke as his scientific assistant. Together they built an air pump, with which Boyle established the fact that at a constant temperature, the volume of any gas is inversely proportional to the pressure, a relationship that has come to be known as Boyle's Law.

Robert Boyle's last 20 years were spent in the London home of his sister Katherine, with whom he shared all his scientific discussions and ideas. He and his sister worked together on many problems and experiments. Katherine's salon brought Boyle into contact with many important intellectuals of the time, and thus widened his influence.

Although Robert Boyle was an experimentalist, and thus a pioneer of modern chemistry, he was also an alchemist, He believed the transmutation of base metals into silver and gold to be possible. Boyle even helped to achieve the 1689 repeal of a statute forbidding the "multiplication of gold".

Important scientific publications of Robert Boyle

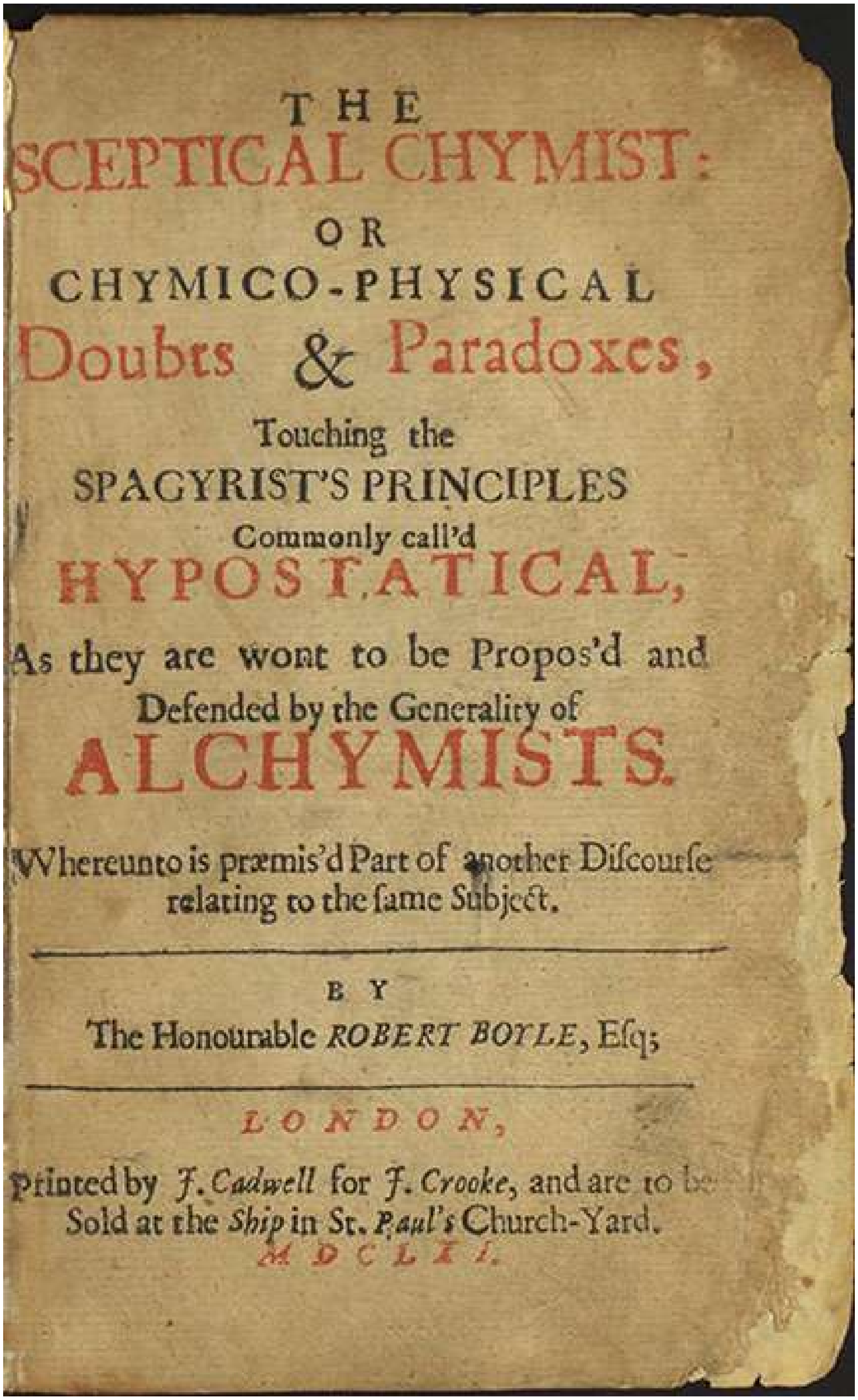
- 1660 - New Experiments Physico-Mechanical: Touching the Spring of the Air and their Effects
- 1661 - The Sceptical Chymist
- 1662 - Whereunto is Added a Defence of the Authors Explication of the Experiments, Against the Obiections of Franciscus Linus and Thomas Hobbes (a book-length addendum to the second edition of New Experiments Physico-Mech anical)
- 1663 - Considerations touching the Usefulness of Experimental Natural Philosophy (followed by a second part in 1671)
- 1664 - Experiments and Considerations Touching Colours, with Observations on a Diamond that Shines in the Dark
- 1665 - New Experiments and Observations upon Cold
- 1666 - Hydrostatical Paradoxes
- 1666 - Origin of Forms and Qualities according to the Corpuscular Philosophy. (A continuation of his work on the spring of air demonstrated that a reduction in ambient pressure could lead to bubble formation in living tissue. This description of a viper in a vacuum was the first recorded description of decompression sickness.)
- 1669 - A Continuation of New Experiments Physico-mechanical, Touching the Spring and Weight of the Air, and Their Effects
- 1670 - Tracts about the Cosmical Qualities of Things, the Temperature of the Subterraneal and Submarine Regions, the Bottom of the Sea, etc. with an Introduction to the History of Particular Qualities
- 1672 - Origin and Virtues of Gems
- 1673 - Essays of the Strange Subtilty, Great Efficacy, Determinate Nature of Effluviums
- 1674 - Two volumes of tracts on the Saltiness of the Sea, Suspicions about the Hidden Realities of the Air, Cold, Celestial Magnets
- 1674 - Animadversions upon Mr. Hobbes's Problemata de Vacuo
- 1676 - Experiments and Notes about the Mechanical Origin or Production of Particular Qualities, including some notes on electricity and magnetism

- 1678 - Observations upon an artificial Substance that Shines without any Preceding Illustration

  1680 - The Aerial Noctiluca
- 1682 - New Experiments and Observations upon the Icy Noctiluca (a further continuation of his work on the air)
- 1684 - Memoirs for the Natural History of the Human Blood
- 1685 - Short Memoirs for the Natural Experimental History of Mineral Waters
- 1686 - A Free Enquiry into the Vulgarly Received Notion of Nature
- 1690 - Medicina Hydrostatica
- 1691 - Experimenta et Observationes Physicae

Figure 6.5: **Robert Boyle (1627-1691).**

Figure 6.6: **Robert Hooke (1635-1703). As a young man, he worked as Robert Boyle's assistant during Boyle's stay at Oxford University, helping Boyle to construct his improved air pump. Hooke later made many important contributions to microscopy, physics and astronomy.**



THE
SCEPTICAL CHYMIST:
OR
CHYMICO-PHYSICAL
Doubts & Paradoxes,
Touching the
SPAGYRIST'S PRINCIPLES
Commonly call'd
HYPOSTATICAL;
As they are wont to be Propos'd and
Defended by the Generality of
ALCHYMISTS.
Whereunto is præmis'd Part of another Discourse
relating to the same Subject.

BY
The Honourable *ROBERT BOYLE*, Esq;

LONDON,
Printed by *J. Cadwell* for *J. Crooke*, and are to be
Sold at the *Ship* in St. *Paul's* Church-Yard.
MDCLXI.

Figure 6.7: **Frontpeice of Boyle's book *The Sceptical Chymist.* Like some of Galileo's books, it is written in the form of a dialogue.**

Suggestions for further reading

1. Alexander Roob, *Alchemy and Mysticism*, Bibliotheca Universalis, 2019.
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Chapter 7

LIVES OF RENAISSANCE EXPLORERS

7.1 Prince Henry the Navigator, (1394-1460)

Infante Dom Henrique of Portugal, Duke of Viseu is better known as Prince Henry the Navigator. He used his position as the son of King John I of Portugal, and his financial resources Grand Master of the Military Order of Christ (the successor to the Knights Templar) to encourage an era of Portuguese shipbuilding and exploration.

When John I died, Prince Henry's elder brother Edward became king. Edward granted Henry all the profits from trading within the areas that his expeditions discovered. Henry also was given a monopoly on tuna fishing within the Algarve, thus further increasing his financial resources.

Prince Henry was fascinated with Africa, not only because it was a source of gold, but also because of the legend of Prester John, who was said to have ruled a Christian country in Africa. Henry encouraged Portugal to conquer the Moorish port of Ceuta in Northern Morocco, the terminus of a trade route.

Henry also encouraged the design of new types of ships, notable the caravel, which was very seaworthy and maneuverable, and able to sail close to the wind. The "trade winds" had been discovered by Prince Henry's expeditions. These were later used by Columbus on his voyages but the caravel's ability to sail close to the wind made it to some extent independent of the trade winds.

Expeditions sponsored by Prince Henry searched for the "Western Nile" and discovered the Senegal River in about 1444. This was south of the Moslem trade routes. Both gold and slaves began to pour into Portugal, enriching the country at the expense of the Moslem traders in Algiers and Tunis, who were ruined. It can be seen that Portuguese explorations were motivated by greed as much as by curiosity, and that cruelty to indigenous peoples also played a role. Sadly, the same can be said about much of European exploration.

Figure 7.1: **Prince Henry the Navigator, (1394-1460).**

7.2 Christopher Columbus, (1451-1506)

Christopher Columbus. or in Italian, Cristoforo Colombo, was born in Genoa. Italy. He was largely self-educated, but very widely read on many subjects, including geography, astronomy, and history. He possessed a copy of Marco Polo's book, and made enthusiastic comments in the margins.

As a young man, Columbus participated in a number of voyages, which took him to the British Isles, possibly to Iceland, and possibly as far south as what is now Ghana. He married a Portuguese noblewoman named Filipa Moniz Perestrelo, with whom he had a son.

Inspired by Marco Polo's book, Columbus dreamed of reaching China and India by sailing westward. He was encouraged in this plan by his correspondence with the astronomer and geographer Paolo Toscanelli. In a letter to Columbus, Toscanelli wrote:

"The said voyage is not only possible, but it is true, and certain to be honourable and to yield incalculable profit, and very great fame among all Christians. But you cannot know this perfectly save through experience and practice, as I have had in the form of the most copious and good and true information from distinguished men of great learning who have come from the said parts, here in the court of Rome, and from others being merchants who have had business for a long time in those parts, men of high authority."

After failing to receive support for his proposed westward voyages in Portugal, Columbus moved to Spain, and there he was more successful. After much campaigning by Columbus, Queen Isabella and King Ferdinand agreed to sponsor a voyage. In the end, Columbus made four voyages in the name of the crown of Castile,

In August, 1492, Columbus sailed westward with three ships under his command. After a stopover in the Canary Islands, the ships continued westward, carried by westerly trade winds. They made landfall on an island somewhere in the Caribbean. The exact identity of this island is uncertain. Believing that he had reached India, Columbus called the natives of the island "Indians".

Wikipedia says of him:

"Columbus made three further voyages to the New World, exploring the Lesser Antilles in 1493, Trinidad and the northern coast of South America in 1498, and the eastern coast of Central America in 1502. Many of the names he gave to geographical features - particularly islands - are still in use. He continued to seek a passage to the East Indies, and the extent to which he was aware that the Americas were a wholly separate landmass is uncertain. He never clearly renounced his belief that he had reached the Far East and gave the name indios ("Indians") to the indigenous peoples he encountered. Columbus's strained relationship with the Spanish crown and its appointed colonial administrators in America led to his arrest and removal from Hispaniola in 1500, and later to protracted litigation over the benefits that he and his heirs claimed were owed to them by the crown. Columbus's expeditions inaugurated a period of exploration, conquest, and colonization that lasted for

Figure 7.2: **Christopher Columbus, (1451-1506).**

centuries, helping create the modern Western world. The transfers between the Old World and New World that followed his first voyage are known as the Columbian exchange, and the period of human habitation in the Americas prior to his arrival is referred to as the Pre-Columbian era.

"Columbus's legacy continues to be debated. He was widely venerated in the centuries after his death, but public perceptions have changed as recent scholars have given greater attention to negative aspects of his life, such as his enslavement of the indigenous population in his quest for gold and his brutal subjugation of the Taíno people, leading to their near-extinction, as well as allegations of tyranny towards Spanish colonists. Many landmarks and institutions in the Western Hemisphere bear his name, including the country of Colombia and the name Columbia, which is used as a personification for the United States, and appears in many place names there."

7.3 John Cabot, (c.1450-c.1500)

John Cabot (Giovanni Caboto) was born in Genoa, Italy. He later moved to Venice, where he married and had three sons, Ludovico, Sebastian and Sancto. However, in about 1480 he appears to have got into financial trouble, and he was forced to flee with his family to Spain. Even in Spain, his creditors attempted (unsuccessfully) to have him arrested.

After attempting to find Spanish sponsorship for an Atlantic expedition of discovery, Cabot moved to England, where he was more successful. English friends put him into contact with King Henry VII, the first Tudor monarch.

Luckily the king was interested in exploration, and he granted Cabot and his three sons letters of patent giving them **"... free authority, faculty and power to sail to all parts, regions and coasts of the eastern, western and northern sea, under our banners, flags and ensigns, with five ships or vessels of whatsoever burden and quality they may be, and with so many and with such mariners and men as they may wish to take with them in the said ships, at their own proper costs and charges, to find, discover and investigate whatsoever islands, countries, regions or provinces of heathens and infidels, in whatsoever part of the world placed, which before this time were unknown to all Christians."**

The expeditions were to sail from the English port of Bristol, and Bristol was to have a monopoly on trade to any regions discovered. Cabot's first voyage was unsuccessful, However, his second voyage, in a single small ship called the Mathew, reached the shores of Canada.

The chronicle of the city of Bristol states that **"This year, on St. John the Baptist's Day [24 June 1497], the land of America was found by the Merchants of Bristol in a shippe of Bristowe, called the Mathew; the which said the ship departed from the port of Bristowe, the second day of May, and came home again the 6th of August next following."**

On his return from the voyage, John Cabot rode to London to report to King Henry VII. Besides considerable financial rewards from the king, Cabot received much adulation. A contemporary named Soncino wrote that Cabot **"is called the Great Admiral, and vast honour is paid to him and he goes dressed in silk, and these English run after him like mad".**

In May, 1498, John Cabot led a large expedition of five ships, which sailed westward from Bristol. The carried with them "cloth, caps, lace points and other trifles". Seemingly the intention was to use these in trade. One of the ships was forced to seek shelter from a storm, and remained in an Irish port. John Cabot died, either on this expedition, or else shortly afterward.

Wikipedia states that **"The historian Alwyn Ruddock worked on Cabot and his era for 35 years. She suggested that Cabot and his expedition successfully returned to England in the spring of 1500. She claimed their return followed an epic two-year exploration of the east coast of North America, south into the Chesapeake Bay area and perhaps as far as the Spanish territories in the Caribbean. Her evidence included the well-known world map of the Spanish**

Figure 7.3: **John Cabot, (c.1450-c.1500).**

cartographer Juan de la Cosa. His chart included the North American coast and seas ‘discovered by the English’ between 1497 and 1500...”

“The Cabot Project at the University of Bristol was organized in 2009 to search for the evidence on which Ruddock’s claims rest, as well as to undertake related studies of Cabot and his expeditions. The lead researchers on the project, Evan Jones and Margaret Condon, claim to have found further evidence to support aspects of Ruddock’s case, including some of the information she intended to use to argue for a successful return of the 1498 expedition to Bristol. These appear to place John Cabot in London by May 1500, albeit Jones and Condon have yet to publish their documentation.”

Figure 7.4: **A replica of Cabot's ship, the Matthew, in Bristol.**

7.4 Amerigo Vespucci, (1454-1512)

Amerigo Vespucci, after whom the continents of North and South America are named, was born in Florence t into a family with political connections to Lorenzo di Medici, the de facto ruler of the city-state. He was educated by his uncle, a famous humanist scholar who gave Amerigo a broad education including not only literature, philosophy, rhetoric, and Latin, but also geography and astronomy, subjects that were to be important to his future career.

In 1488, Lorenzo di Pierfrancesco de' Medici, a younger member of the powerful Medici family, sent Amerigo Vespucci to Seville in Spain to investigate some business relationships with which he was dissatisfied. Lorenzo asked Amerigo to investigate the Florentine merchant Gianotto Berardi, whom Lorenzo was thinking of hiring. In this way, Amerigo Vespucci became involved in the voyages of discovery that were then taking place, since Berardi had invested heavily in the voyages of Columbus.

Vespucci personally sailed on several voyages, both for Spain and for Portugal. He wrote colorful accounts of these voyages which were very widely printed and read throughout Europe. Whether or not everything in Vespucci's writings is true is questionable, but the fact that his writings made Europeans highly aware of the voyages of exploration and discovery is beyond dispute.

In 1502 0r 1503, Amerigo wrote in a letter to Lorenzo di Pierfrancesco de' Medici:

"A few days ago I wrote you at some length about my return from those new regions we searched for and found with the fleet, at the expense and by the command of the most serene King of Portugal, and which can properly be called a *New World*, since our forebears had absolutely no knowledge of it, nor do any of those who are hearing about it today...On 7 August 1501, we dropped our anchor off the shores of that new land, thanking God with solemn prayers and the celebration of the Mass. Once there, we determined that the new land was not an island but a continent..."

Amerigo Vespucci's accounts of his voyages came to the attention of a group of humanist scholars in France, who included Matthias Ringmann and Martin WaldseemÃ¼ller. In 1507, they published their *Introduction to Cosmography.* In a preface to this very popular publication. Ringman wrote:

"I see no reason why anyone could properly disapprove of a name derived from that of Amerigo, the discoverer, a man of sagacious genius. A suitable form would be Amerige, meaning Land of Amerigo, or America, since Europe and Asia have received women's names."

In February, 1505, Amerigo Vespucci was back in Spain, where he was summoned to an audience by King Ferdinand, who wished to know more about matters of navigation and a possible route to India. Over the next months, he received large payments from the crown, and he was made a citizen of Castile and Leon by royal proclamation. He continued to work as a chandler, supplying ships bound for the newly discovered lands. In 1508, Amerigo Vespucci was named Chief Pilot of the House of Commerce, a body which regulated Spain's trade with its overseas possessions. After Vespucci's death in 1512. his

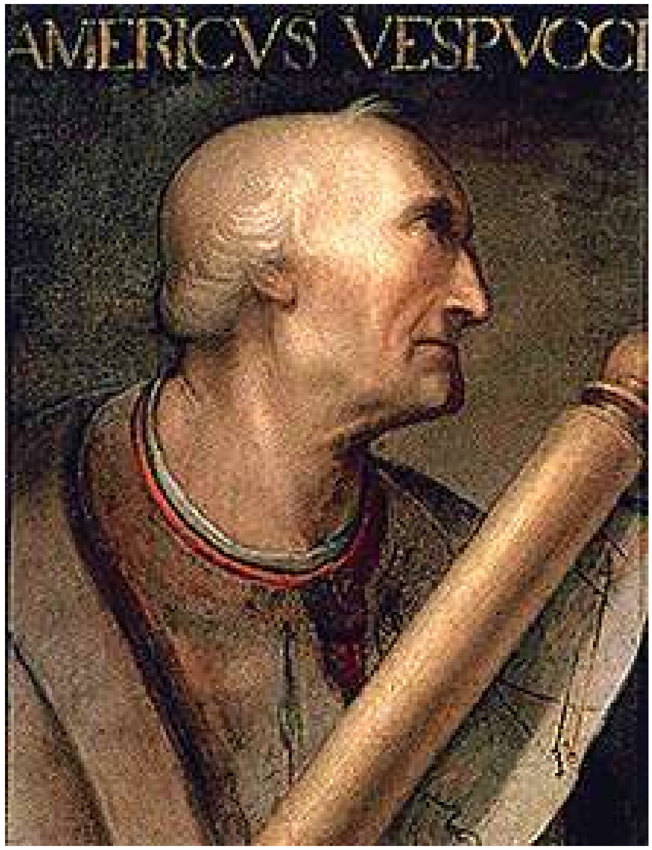

Figure 7.5: **Amerigo Vespucci, (1454-1512), in a posthumous portrait in the Giovio Series at the Uffizi in Florence, attributed to Cristofano dell'Altissimo.**

wife was awarded a yearly pension of 10,000 "maravedis", to be deducted from the pay of the new Chief Pilot.

7.5 Vasco da Gama, (c.1460-1524)

Wikipedia says of him: **"His initial voyage to India (1497-1499) was the first to link Europe and Asia by an ocean route, connecting the Atlantic and the Indian oceans and therefore, the West and the Orient. This is widely considered a milestone in world history, as it marked the beginning of a sea-based phase of global multiculturalism. Da Gama's discovery of the sea route to India opened the way for an age of global imperialism and enabled the Portuguese to establish a long-lasting colonial empire in Asia. Traveling the ocean route allowed the Portuguese to avoid sailing across the highly disputed Mediterranean and traversing the dangerous Arabian Peninsula. The sum of the distances covered in the outward and return voyages made this expedition the longest ocean voyage ever made until then, far longer than a full voyage around the world..."**

Figure 7.6: **Vasco da Gama, (c.1460-1524), Viceroy of Portuguese India.**

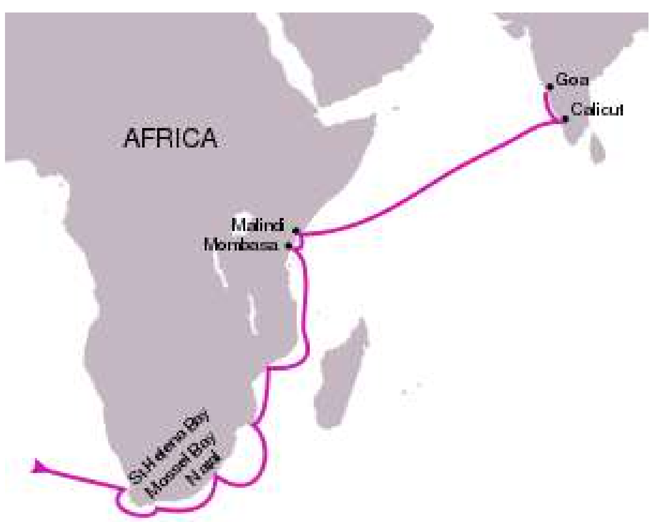

Figure 7.7: **The route followed in Vasco da Gama's first voyage (1497-1499).**

7.6 Ferdinand Magellan, (1480-1521)

Ferdinando Magellan, born into a family of minor Portuguese nobility, became a skilled officer in the navy of King Manuel I of Portugal. However, when Manuel I rejected Magellan's proposal for a voyage to reach India by sailing around the southern tip of South America, Fernando Magellan went to Spain with the plan and appealed to Spain's ruler, Charles I (who later became Holy Roman Emperor and Archduke of Austria).

This time, Magellan was successful, and Charles I sponsored an expedition of five ships and 250 men. On the 20th of December, 1519, the fleet sailed westward, making landfall at Rio de Janeiro. They then sailed southward, searching for a passage through to the (not yet named) Pacific Ocean. Deteriorating weather conditions forced the explorers to spend the winter in a natural harbor which they had discovered.

During the winter, there was a mutiny. Despite losing control of three of his five ships at one point, Magellan managed to quell the mutiny, beheading one of its leaders and marooning another.

The next spring, the expedition succeeded in finding a route around the southern tip of South America. After the stormy conditions that they had experienced on what is now known as the Strait of Magellan, the ocean on the other side seemed peaceful. Magellan named it the *Pacific Ocean*.

They thought that the remaining voyage across the Pacific to the Spice Islands could be accomplished in a few days, but in fact the voyage took three months and twenty days. When the ships finally made landfall on the island of Guam, supplies of food and water were exhausted and many of the crew members had died of scurvy.

During conflicts with the natives of Guam, Magellan was killed. His body was retained by the natives, who wished to keep it as a trophy. Magellan had previously reached this region on another expedition, and so he can be thought of as having completed a personal circumnavigation of the globe.

Out of the five ships that started the expedition, only one, the *Victoria*, eventually limped back to England; and of the 250 men who started the journey, only 18 or 19 survivors returned.

Wikipedia says of him:

"In the immediate aftermath of the circumnavigation, few celebrated Magellan for his accomplishments, and he was widely discredited and reviled in Spain and his native Portugal. The Portuguese regarded Magellan as a traitor for having sailed for Spain. In Spain, Magellan's reputation suffered due to the largely unflattering accounts of his actions given by the survivors of the expedition..."

"Magellan has come to be renowned for his navigational skill and tenacity. The first circumnavigation has been called 'the greatest sea voyage in the Age of Discovery', and even 'the most important maritime voyage ever undertaken'. Appreciation of Magellan's accomplishments may have been enhanced over time by the failure of subsequent expeditions which attempted to retrace his route..."

Figure 7.8: **Ferdinand Magellan, (1480-1521) in an anonymous portrait.**

Figure 7.9: **A 1561 map of America showing Magellan's name for the pacific, Mare pacificum, and the Strait of Magellan, labelled Frenum Magaliani.**

Figure 7.10: **Victoria, the sole ship of Magellan's fleet to complete the circumnavigation.**

7.7 Sir Francis Drake, (c.1540-1596)

Sir Francis Drake was a British naval officer and privateer, commissioned and later knighted by Queen Elizabeth I. He was second in command with the rank of Vice Admiral at the sea battle in which the English fleet defeated the Spanish Armada. In England, Drake was regarded as a hero, while in Spain he was seen as a dangerous and bloodthirsty pirate. King Phillip II of Spain is said to have offered a reward of 20,000 ducats (about $10,000,000 in today's currency) to anyone who could kill or capture him.

In 1577, Queen Elizabeth sent Drake on a mission to challenge the Spanish claim to the west coast of North America. The expedition suffered great attrition: Of the six ships under Drake's command that started the voyage, only one remained to sail north along the west coast of South America. This lone ship, renamed *The Golden Hind*, reached the western coast of and North America. and stopped for repairs before continuing its voyage of circumnavigation. Drake claimed part of present-day California for Queen Elizabeth and her successors before continuing his voyage of circumnavigation.

According to Wikipedia,

"On 26 September, Golden Hind sailed into Plymouth with Drake and 59 remaining crew aboard, along with a rich cargo of spices and captured Spanish treasures. The Queen's half-share of the cargo surpassed the rest of the crown's income for that entire year. Drake was hailed as the first Englishman to circumnavigate the Earth (and the second such voyage arriving with at least one ship intact)..."

"Drake presented the Queen with a jewel token commemorating the circumnavigation. Taken as a prize off the Pacific coast of Mexico, it was made of enamelled gold and bore an African diamond and a ship with an ebony hull."

Figure 7.11: **Sir Francis Drake, (c.1540-1596), in an oil painting by Marcus Gheeraerts the Younger.**

Figure 7.12: **A map of Drake's route around the world. The northern limit of Drake's exploration of the Pacific coast of North America is still in dispute.**

7.8 Abel Tasman, (1603-1659)

Abel Tasman was born in the province of Groningen, Netherlands. He became a navigator and sea captain employed by the Dutch East India Company to explore the southern part of the Indian Ocean. He lead two major voyages of discovery.

Tasman's first voyage, 1642-1643

In August, 1642, the Dutch East India Company chose Abel Tasman and Franchoijs Jacobszoon Visscher to lead an expedition to explore the uncharted region east of the Cape of Good Hope, west of the southern tip of South America, and south of the Solomon Islands. Because of a mistake in copying Marco Polo's maps, it was believed that an undiscovered land, rich in gold and named "Provinces of Beach", lay somewhere in this region.

The expedition, consisting of two small sailing ships, stopped at the island of Mauritius in the Indian Ocean for several months to repair the ships and to allow the crew to enjoy the plentiful food of the island.

On 24 November, 1642, the expedition sighted the west coast of the large island now known as Tasmania. Tasman and his two ships spent some time exploring the newly discovered land, but the weather suddenly worsened, and he turned southward, continuing his main mission.

On 13 December, 1642, after enduring some extremely rough weather, Tasman and his expedition sighted what is now known as the South Island of New Zealand. They were the first Europeans to reach the island.

Tasman's second voyage, 1644

On 30 January, 1644, Tasman left Batavia in the Dutch East Indies, in command of three ships. for his second major voyage of exploration. He mapped the northern coast of Australia ("New Holland"), making observations on its nature and people.

Tasman's achievements

Wikipedia says of him:

"From the point of view of the Dutch East India Company, Tasman's explorations were a disappointment: he had neither found a promising area for trade nor a useful new shipping route. Although received modestly, the company was upset to a degree that Tasman did not fully explore the lands he found, and decided that a more 'persistent explorer' should be chosen for any future expeditions. For over a century, until the era of James Cook, Tasmania and New Zealand were not visited by Europeans - mainland Australia was visited, but usually only by accident."

Figure 7.13: **Abel Tasman, (1603-1659), detail from portrait by Jacob Gerritsz.**

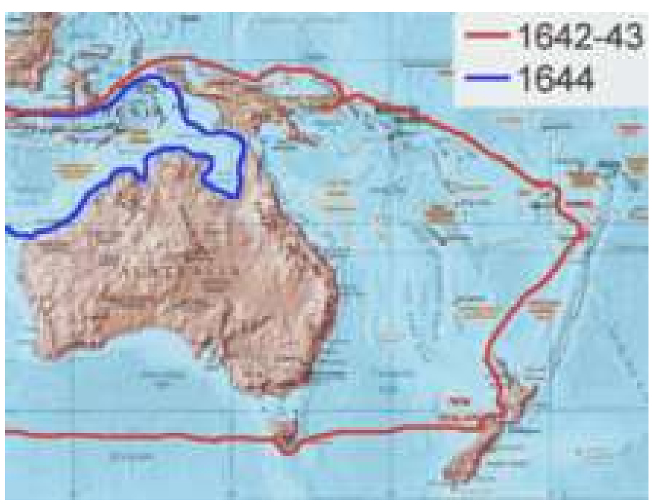

Figure 7.14: **Routes taken by Tasman in the Australasian region, on his first and second voyages.**

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Chapter 8

POETS OF THE RENAISSANCE

8.1 Dante Alighieri, (1265-1321)

Inferno, Canto I

Midway upon the journey of our life
I found myself within a forest dark,
For the straightforward pathway had been lost.

Ah me! how hard a thing it is to say
What was this forest savage, rough, and stern,
Which in the very thought renews the fear.

So bitter is it, death is little more;
But of the good to treat, which there I found,
Speak will I of the other things I saw there.

I cannot well repeat how there I entered,
So full was I of slumber at the moment
In which I had abandoned the true way.

But after I had reached a mountain's foot,
At that point where the valley terminated,
Which had with consternation pierced my heart,

Upward I looked, and I beheld its shoulders,
Vested already with that planet's rays
Which leadeth others right by every road.

Then was the fear a little quieted

Figure 8.1: **Dante Alighieri in a posthumous portrait by Sandro Botticelli. Dante wrote in the Italian vernacular language rather than Latin, establishing a precedent that was later followed by Petrarch and Boccaccio. Dante's *Divina Comedia* has been described as the greatest poem in the Italian language.**

That in my heart's lake had endured throughout
The night, which I had passed so piteously.

And even as he, who, with distressful breath,
Forth issued from the sea upon the shore,
Turns to the water perilous and gazes;

So did my soul, that still was fleeing onward,
Turn itself back to re-behold the pass
Which never yet a living person left.

After my weary body I had rested,
The way resumed I on the desert slope,
So that the firm foot ever was the lower.

And lo! almost where the ascent began,
A panther light and swift exceedingly,
Which with a spotted skin was covered o'er!

And never moved she from before my face,
Nay, rather did impede so much my way,
That many times I to return had turned.

The time was the beginning of the morning,
And up the sun was mounting with those stars
That with him were, what time the Love Divine

At first in motion set those beauteous things;
So were to me occasion of good hope,
The variegated skin of that wild beast,

The hour of time, and the delicious season;
But not so much, that did not give me fear
A lion's aspect which appeared to me.

He seemed as if against me he were coming
With head uplifted, and with ravenous hunger,
So that it seemed the air was afraid of him;

And a she-wolf, that with all hungerings
Seemed to be laden in her meagreness,
And many folk has caused to live forlorn!

She brought upon me so much heaviness,
With the affright that from her aspect came,
That I the hope relinquished of the height.

And as he is who willingly acquires,
And the time comes that causes him to lose,
Who weeps in all his thoughts and is despondent,

E'en such made me that beast withouten peace,
Which, coming on against me by degrees
Thrust me back thither where the sun is silent.

While I was rushing downward to the lowland,
Before mine eyes did one present himself,
Who seemed from long-continued silence hoarse.

When I beheld him in the desert vast,
"Have pity on me," unto him I cried,
"Whiche'er thou art, or shade or real man!"

He answered me: "Not man; man once I was,
And both my parents were of Lombardy,
And Mantuans by country both of them.

'Sub Julio' was I born, though it was late,
And lived at Rome under the good Augustus,
During the time of false and lying gods.

A poet was I, and I sang that just
Son of Anchises, who came forth from Troy,
After that Ilion the superb was burned.

But thou, why goest thou back to such annoyance?
Why climb'st thou not the Mount Delectable,
Which is the source and cause of every joy?

"Now, art thou that Virgilius and that fountain
Which spreads abroad so wide a river of speech?"
I made response to him with bashful forehead.

"O, of the other poets honour and light,
Avail me the long study and great love
That have impelled me to explore thy volume!

Thou art my master, and my author thou,
Thou art alone the one from whom I took
The beautiful style that has done honour to me.

Behold the beast, for which I have turned back;
Do thou protect me from her, famous Sage,
For she doth make my veins and pulses tremble."

"Thee it behoves to take another road,"
Responded he, when he beheld me weeping,
"If from this savage place thou wouldst escape;

Because this beast, at which thou criest out,
Suffers not any one to pass her way,
But so doth harass him, that she destroys him;

And has a nature so malign and ruthless,
That never doth she glut her greedy will,
And after food is hungrier than before.

Many the animals with whom she weds,
And more they shall be still, until the Greyhound
Comes, who shall make her perish in her pain.

He shall not feed on either earth or pelf,
But upon wisdom, and on love and virtue;
'Twixt Feltro and Feltro shall his nation be;

Of that low Italy shall he be the saviour,
On whose account the maid Camilla died,
Euryalus, Turnus, Nisus, of their wounds;

Through every city shall he hunt her down,
Until he shall have driven her back to Hell,
There from whence envy first did let her loose.

Therefore I think and judge it for thy best
Thou follow me, and I will be thy guide,
And lead thee hence through the eternal place,

Where thou shalt hear the desperate lamentations,
Shalt see the ancient spirits disconsolate,

Who cry out each one for the second death;

And thou shalt see those who contented are
Within the fire, because they hope to come,
Whene'er it may be, to the blessed people;

To whom, then, if thou wishest to ascend,
A soul shall be for that than I more worthy;
With her at my departure I will leave thee;

Because that Emperor, who reigns above,
In that I was rebellious to his law,
Wills that through me none come into his city.

He governs everywhere, and there he reigns;
There is his city and his lofty throne;
O happy he whom thereto he elects!"

And I to him: "Poet, I thee entreat,
By that same God whom thou didst never know,
So that I may escape this woe and worse,

Thou wouldst conduct me there where thou hast said,
That I may see the portal of Saint Peter,
And those thou makest so disconsolate."

Then he moved on, and I behind him followed.

8.2 Petrarch, (1304-1374)

If no love is, O God, what fele I so?
(translated by Geoffrey Chaucer)

If no love is, O God, what fele I so?
And if love is, what thing and which is he?
If love be good, from whennes cometh my woo?
If it be wikke, a wonder thynketh me,
When every torment and adversite
That cometh of hym, may to me savory thinke,
For ay thurst I, the more that ich it drynke.
And if that at myn owen lust I brenne,

From whennes cometh my waillynge and my pleynte?
If harm agree me, whereto pleyne I thenne?
I noot, ne whi unwery that I feynte.
O quike deth, O swete harm so queynte,
How may of the in me swich quantite,
But if that I consente that it be?
And if that I consente, I wrongfully
Compleyne, iwis. Thus possed to and fro,
Al sterelees withinne a boot am I
Amydde the see, betwixen wyndes two,
That in contrarie stonden evere mo.
Allas! what is this wondre maladie?
For hete of cold, for cold of hete, I dye.

Figure 8.2: **Petrarch was an Italian poet and humanist of the early Renaissance. His sonnets were widely admired throughout Europe. His work, together with that of Boccaccio, had a strong influence of the development of the modern Italian language.**

8.3 Geoffrey Chaucer, (c.1340's-1400)

Troilus And Criseyde: Book 03
(the first few verses)

Incipit prohemium tercii libri.

O blisful light of whiche the bemes clere
Adorneth al the thridde hevene faire!
O sonnes lief, O Ioves doughter dere,
Plesaunce of love, O goodly debonaire,
In gentil hertes ay redy to repaire!
O verray cause of hele and of gladnesse,
Y-heried be thy might and thy goodnesse!

In hevene and helle, in erthe and salte see
Is felt thy might, if that I wel descerne;
As man, brid, best, fish, herbe and grene tree
Thee fele in tymes with vapour eterne.
God loveth, and to love wol nought werne;
And in this world no lyves creature,
With-outen love, is worth, or may endure.

Ye Ioves first to thilke effectes glade,
Thorugh which that thinges liven alle and be,
Comeveden, and amorous him made
On mortal thing, and as yow list, ay ye
Yeve him in love ese or adversitee;
And in a thousand formes doun him sente
For love in erthe, and whom yow liste, he hente.

Ye fierse Mars apeysen of his ire,
And, as yow list, ye maken hertes digne;
Algates, hem that ye wol sette a-fyre,
They dreden shame, and vices they resigne;
Ye do hem corteys be, fresshe and benigne,
And hye or lowe, after a wight entendeth;
The Ioyes that he hath, your might him sendeth.

Ye holden regne and hous in unitee;
Ye soothfast cause of frendship been also;
Ye knowe al thilke covered qualitee
Of thinges which that folk on wondren so,

Whan they can not construe how it may io,
She loveth him, or why he loveth here;
As why this fish, and nought that, comth to were
.
Ye folk a lawe han set in universe,
And this knowe I by hem that loveres be,
That who-so stryveth with yow hath the werse:
Now, lady bright, for thy benignitee,
At reverence of hem that serven thee,
Whos clerk I am, so techeth me devyse
Som Ioye of that is felt in thy servyse.

Ye in my naked herte sentement
Inhelde, and do me shewe of thy swetnesse. –
Caliope, thy vois be now present,
For now is nede; sestow not my destresse,
How I mot telle anon-right the gladnesse
Of Troilus, to Venus heryinge?
To which gladnes, who nede hath, god him bringe!

Prologue to the Canterbury Tales
the first 100 lines

Whan that Aprille with his shoures soote
The droghte of Marche hath perced to the roote,
And bathed every veyne in swich licour,
Of which vertu engendred is the flour;
Whan Zephirus eek with his swete breeth
Inspired hath in every holt and heeth
The tendre croppes, and the yonge sonne
Hath in the Ram his halfe cours y-ronne,
And smale fowles maken melodye,
That slepen al the night with open ye,
(So priketh hem nature in hir corages:
Than longen folk to goon on pilgrimages,
And palmers for to seken straunge strondes,
To ferne halwes, couthe in sondry londes;
And specially, from every shires ende
Of Engelond, to Caunterbury they wende,
The holy blisful martir for to seke,
That hem hath holpen, whan that they were seke.
Bifel that, in that sesoun on a day,

Figure 8.3: **A 19th century portrait of Geoffrey Chaucer. Besides being a poet, Chaucer was a diplomat, civil servant, Member of Parliament, astronomer and philosopher. He is best known for his *Canterbury Tales*, written in Middle English, at a time when most literary works were in French or Latin. Chaucer has been called "the father of English literature".**

In Southwerk at the Tabard as I lay
Redy to wenden on my pilgrimage
To Caunterbury with ful devout corage,
At night was come in-to that hostelrye
Wel nyne and twenty in a compaignye,
Of sondry folk, by aventure y-falle
In felawshipe, and pilgrims were they alle,
That toward Caunterbury wolden ryde;
The chambres and the stables weren wyde,
And wel we weren esed atte beste.
And shortly, whan the sonne was to reste,
So hadde I spoken with hem everichon,
That I was of hir felawshipe anon,
And made forward 18 erly for to ryse,
To take our wey, ther as I yow devyse.
But natheles, whyl I have tyme and space,
Er that I ferther in this tale pace,
Me thinketh it acordaunt to resoun,
To telle yew al the condicioun
Of ech of hem, so as it semed me,
And whiche they weren, and of what degree;
And eek in what array that they were inne:
And at a knight than wol I first biginne.
A KNIGHT ther was, and that a worthy man,
That fro the tyme that he first bigan
To ryden out, he loved chivalrye,
Trouthe and honour, fredom and curteisye.
Ful worthy was he in his lordes werre,
And thereto hadde he riden (no man ferre)
As wel in cristendom as hethenesse,
And evere honoured for his worthinesse.
At Alisaundre he was, whan it was wonne;
Ful ofte tyme he hadde the bord bigonne
Aboven alle naciouns in Pruce.
In Lettow hadde he reysed and in Ruce,
No cristen man so ofte of his degree.
In Gernade at the sege eek hadde he be
Of Algezir, and riden in Belmarye.
At Lyeys was he, and at Satalye,
Whan they were wonne; and in the Grete See
At many a noble aryve hadde he be,
At mortal batailles hadde he been fiftene,
And foughten for our feith at Tramissene

In listes thryes, and ay slayn his foo.
This ilke worthy knight hadde been also
Somtyme with the lord of Palatye,
Ageyn another hethen in Turkye:
And everemore he hadde a sovereyn prys.
And though that he were worthy, he was wys,
And of his port as meek as is a mayde.
He nevere yet no vileinye ne sayde
In al his lyf, un-to no maner wight.
He was a verray parfit gentil knight.
But for to tellen yow of his array,
His hors were goode, but he was nat gay.
Of fustian he wered a gipoun
Al bismotered with his habergeoun.
For he was late y-come from his viage,
And wente for to doon his pilgrimage.
With him ther was his sone, a yong SQUYER,
A lovyer, and a lusty bacheler,
With lokkes crulle, as they were leyd in presse.
Of twenty yeer of age he was, I gesse.
Of his stature he was of evene lengthe,
And wonderly delivere, and greet of strengthe.
And he hadde been somtyme in chivachye,
In Flaundres, in Artoys, and Picardye,
And born him wel, as of so litel space,
In hope to stonden in his lady grace.
Embrouded was he, as it were a mede
Al ful of fresshe floures, whyte and rede,
Singinge he was, or floytinge, 57 al the day;
He was as fresh as is the month of May.
Short was his goune, with sleves longe and wyde.
Wel coude he sitte on hors, and faire ryde.
He coude songes make and wel endyte,
Iuste and eek daunce, and wel purtreye and wryte.
So hote he lovede, that by nightertale
He sleep namore than doth a nightingale.
Curteys he was, lowly, and servisable,
And carf biforn his fader at the table.

8.4 William Shakespeare, (1564-1616)

William Shakespeare is widely regarded as the greatest writer in the English language, and the greatest dramatist in the history of world literature. Shakespeare's works hold second place after the Bible for the number of languages into which they have been translated. He wrote many sonnets, two of which are given below, but his plays themselves are poetry. Most of them are written in unrhymed iambic pentameter, with rhymed cupplets often used to end a scene. Today, Shakespeare's plays are more frequently and widely performed than those of any other playwright.

Aubade

Hark! hark! the lark at heaven's gate sings,
And Phoebus 'gins arise,
His steeds to water at those springs
On chaliced flowers that lies;
And winking Mary-buds begin
To ope their golden eyes:
With everything that pretty bin,
My lady sweet, arise!
Arise, arise!

Blow, Blow, Thou Winter Wind

Blow, blow, thou winter wind
Thou art not so unkind
As man's ingratitude;
Thy tooth is not so keen,
Because thou art not seen,
Although thy breath be rude.

Heigh-ho! sing, heigh-ho! unto the green holly:
Most freindship if feigning, most loving mere folly:
Then heigh-ho, the holly!
This life is most jolly.

Freeze, freeze thou bitter sky,
That does not bite so nigh
As benefits forgot:
Though thou the waters warp,
Thy sting is not so sharp
As a friend remembered not.
Heigh-ho! sing, heigh-ho! unto the green holly:

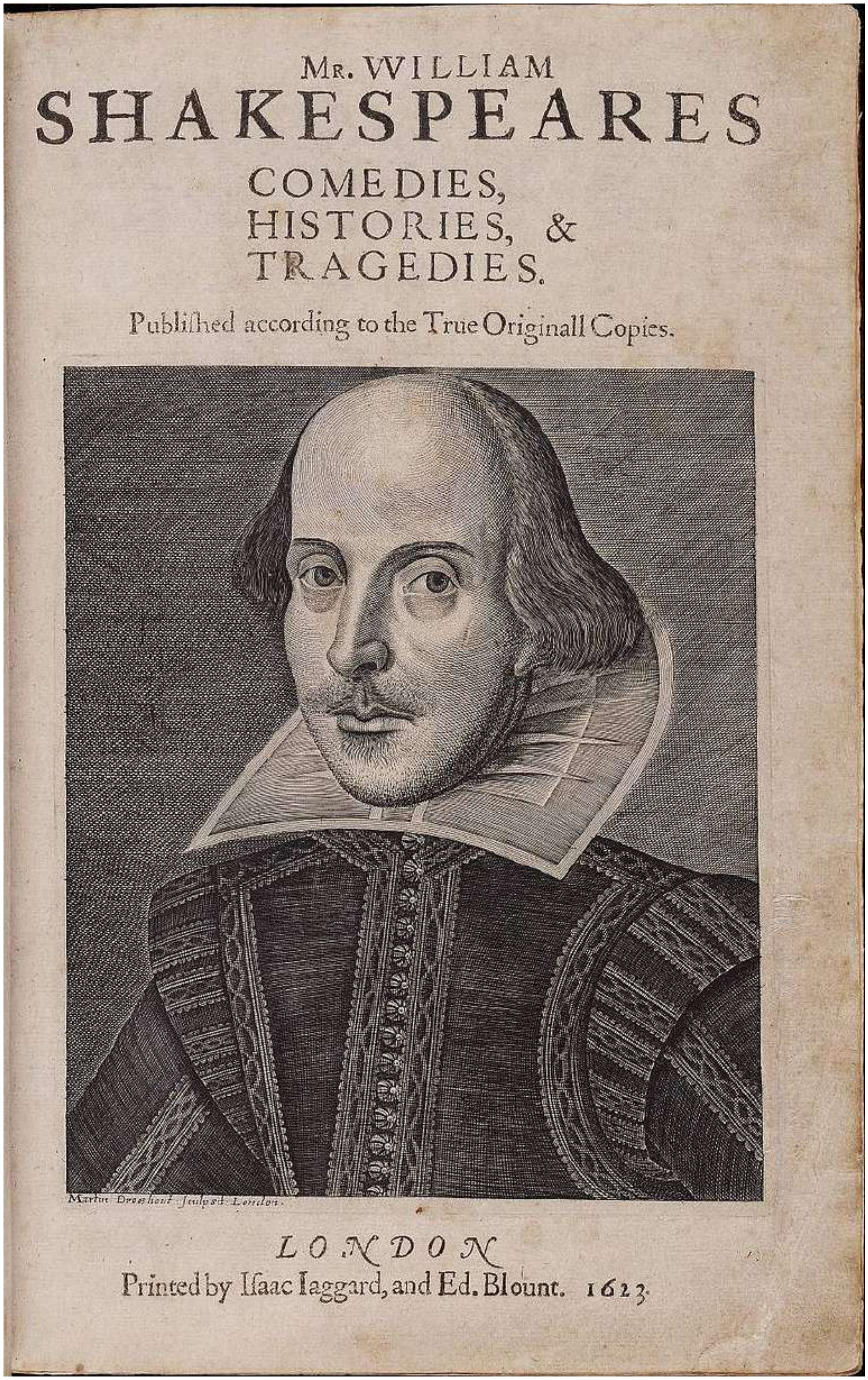

Figure 8.4: **Title page of the First Folio, 1623. Copper engraving of Shakespeare by Martin Droeshout.**

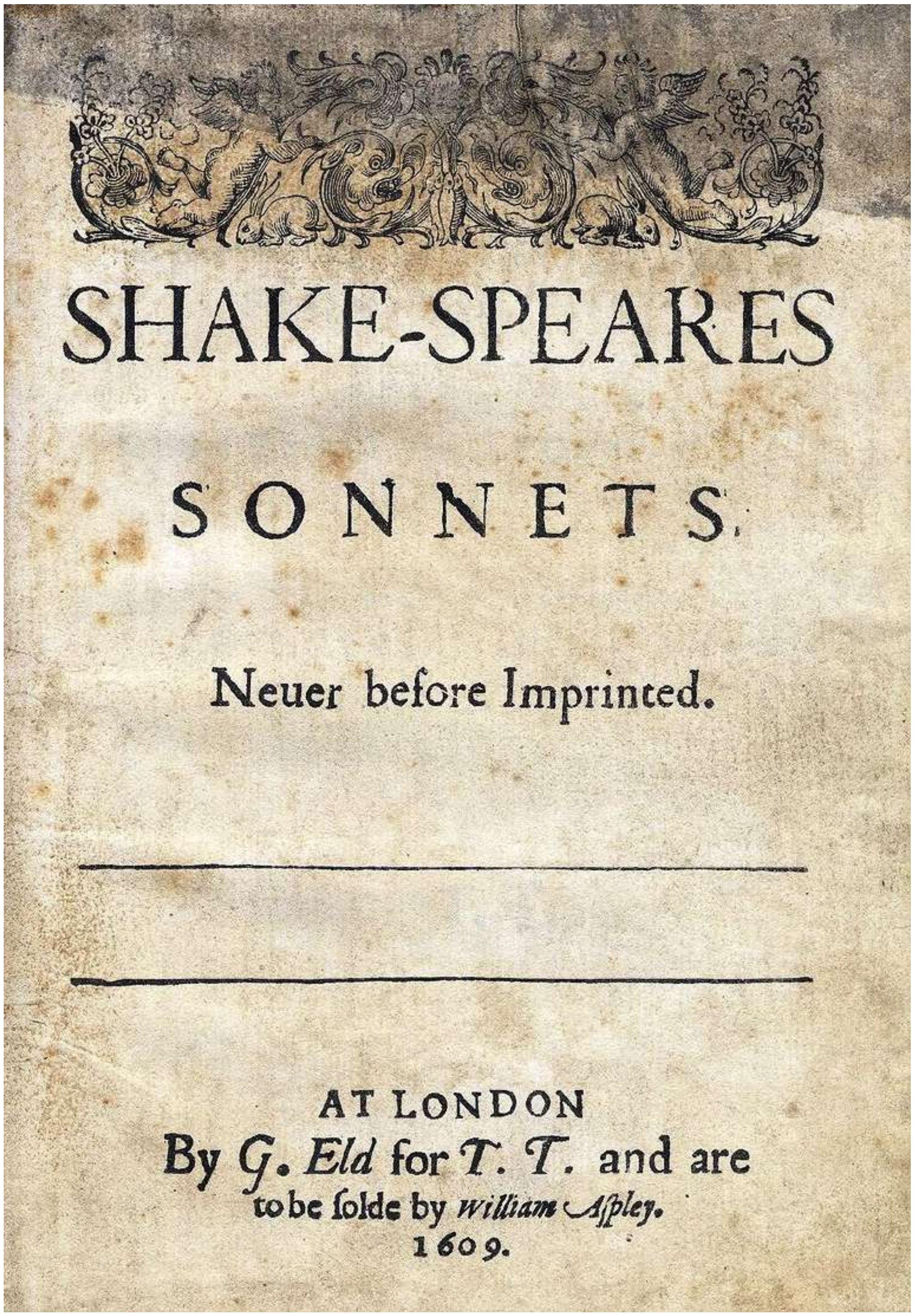

Figure 8.5: **Title page from 1609 edition of Shake-Speares Sonnets.**

Most freindship if feigning, most loving mere folly:
Then heigh-ho, the holly!
This life is most jolly.

All the World's a Stage

All the world's a stage,
And all the men and women merely players;
They have their exits and their entrances,
And one man in his time plays many parts,
His acts being seven ages. At first, the infant,
Mewling and puking in the nurse's arms.
Then the whining schoolboy, with his satchel
And shining morning face, creeping like snail
Unwillingly to school. And then the lover,
Sighing like furnace, with a woeful ballad
Made to his mistress' eyebrow. Then a soldier,
Full of strange oaths and bearded like the pard,
Jealous in honor, sudden and quick in quarrel,
Seeking the bubble reputation
Even in the cannon's mouth. And then the justice,
In fair round belly with good capon lined,
With eyes severe and beard of formal cut,
Full of wise saws and modern instances;
And so he plays his part. The sixth age shifts
Into the lean and slippered pantaloon,
With spectacles on nose and pouch on side;
His youthful hose, well saved, a world too wide
For his shrunk shank, and his big manly voice,
Turning again toward childish treble, pipes
And whistles in his sound. Last scene of all,
That ends this strange eventful history,
Is second childishness and mere oblivion,
Sans teeth, sans eyes, sans taste, sans everything.

Silvia

Who is Silvia? What is she?
That all our swains commend her?
Holy, fair, and wise is she;
The heaven such grace did lend her,
That she might admired be.

Is she kind as she is fair?
For beauty lives with kindness:
Love doth to her eyes repair,
To help him of his blindness;
And, being help'd, inhabits there.

Then to Silvia let us sing,
That Silvia is excelling;
She excels each mortal thing
Upon the dull earth dwelling:
To her let us garlands bring.

Sonnet 73: That time of year thou mayst in me behold

That time of year thou mayst in me behold
When yellow leaves, or none, or few, do hang
Upon those boughs which shake against the cold,
Bare ruin'd choirs, where late the sweet birds sang.
In me thou see'st the twilight of such day
As after sunset fadeth in the west,
Which by and by black night doth take away,
Death's second self, that seals up all in rest.
In me thou see'st the glowing of such fire
That on the ashes of his youth doth lie,
As the death-bed whereon it must expire,
Consum'd with that which it was nourish'd by.
This thou perceiv'st, which makes thy love more strong,
To love that well which thou must leave ere long.

Sonnet 116: Let me not to the marriage of true minds

Let me not to the marriage of true minds
Admit impediments. Love is not love
Which alters when it alteration finds,
Or bends with the remover to remove.
O no! it is an ever-fixed mark
That looks on tempests and is never shaken;
It is the star to every wand'ring bark,
Whose worth's unknown, although his height be taken.
Love's not Time's fool, though rosy lips and cheeks
Within his bending sickle's compass come;
Love alters not with his brief hours and weeks,

But bears it out even to the edge of doom.
If this be error and upon me prov'd,
I never writ, nor no man ever lov'd.

8.5 John Donne, (1572-1631)

No Man is an Island

No man is an island,
Entire of itself;
Every man is a piece of the continent,
A part of the main.

If a clod be washed away by the sea,
Europe is the less,
As well as if a promontory were:
As well as if a manor of thy friend's
Or of thine own were.

Any man's death diminishes me,
Because I am involved in mankind.
And therefore never send to know for whom the bell tolls;
It tolls for thee.

Death Be Not Proud

Death, be not proud, though some have called thee
Mighty and dreadful, for thou art not so;
For those whom thou think'st thou dost overthrow
Die not, poor Death, nor yet canst thou kill me.
From rest and sleep, which but thy pictures be,
Much pleasure; then from thee much more must flow,
And soonest our best men with thee do go,
Rest of their bones, and soul's delivery.
Thou art slave to fate, chance, kings, and desperate men,
And dost with poison, war, and sickness dwell,
And poppy or charms can make us sleep as well
And better than thy stroke; why swell'st thou then?
One short sleep past, we wake eternally
And death shall be no more; Death, thou shalt die.

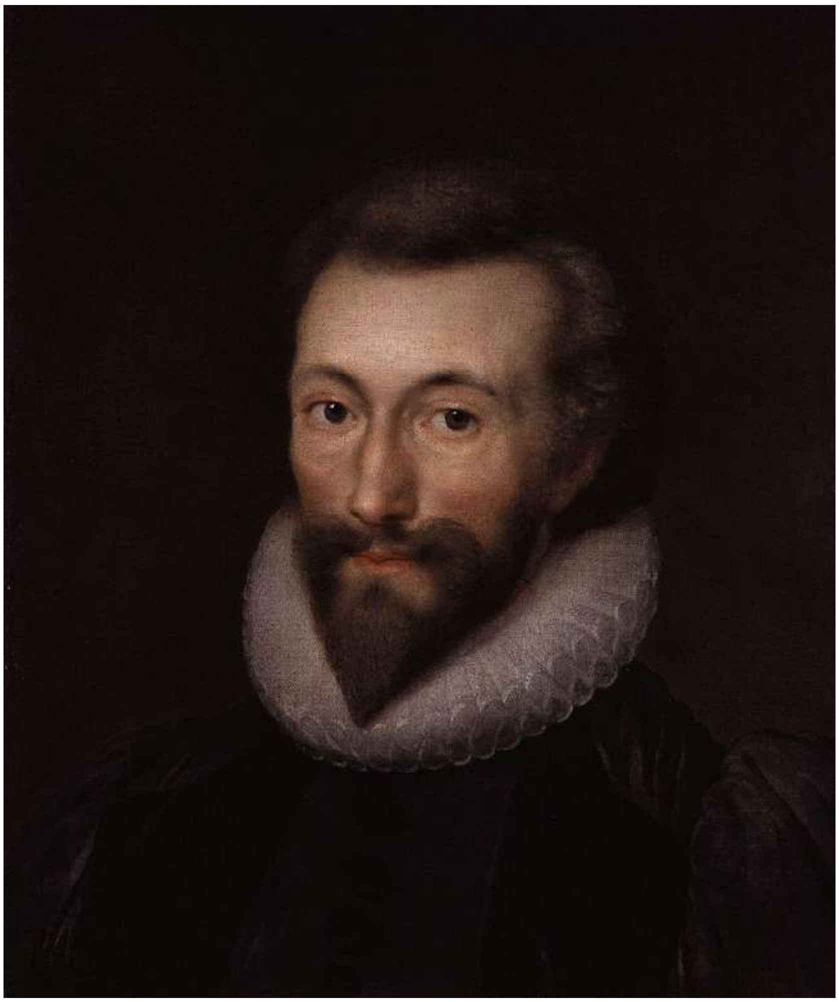

Figure 8.6: **Donne, painted by Isaac Oliver**

The Sun Rising

Busy old fool, unruly sun,
Why dost thou thus,
Through windows, and through curtains call on us?
Must to thy motions lovers' seasons run?
Saucy pedantic wretch, go chide
Late school boys and sour prentices,
Go tell court huntsmen that the king will ride,
Call country ants to harvest offices,
Love, all alike, no season knows nor clime,
Nor hours, days, months, which are the rags of time.

Thy beams, so reverend and strong
Why shouldst thou think?
I could eclipse and cloud them with a wink,
But that I would not lose her sight so long;
If her eyes have not blinded thine,
Look, and tomorrow late, tell me,
Whether both th' Indias of spice and mine
Be where thou leftst them, or lie here with me.
Ask for those kings whom thou saw'st yesterday,
And thou shalt hear, All here in one bed lay.

She's all states, and all princes, I,
Nothing else is.
Princes do but play us; compared to this,
All honor's mimic, all wealth alchemy.
Thou, sun, art half as happy as we,
In that the world's contracted thus.
Thine age asks ease, and since thy duties be
To warm the world, that's done in warming us.
Shine here to us, and thou art everywhere;
This bed thy center is, these walls, thy sphere.

8.6 John Milton, (1608-1674)

How Soon Hath Time

How soon hath Time, the subtle thief of youth,
Stoln on his wing my three and twentieth year!
My hasting days fly on wtih full career,
But my late spring no bud or blossom shew'th.
Perhaps my semblance might deceive the truth,
That I to manhood am arrived so near,
And inward ripeness doth much less appear,
That some more timely-happy spirits endu'th.
Yet be it less or more, or soon or slow,
It shall be still in strictest measure even
To that same lot, however mean or high,
Toward which Time leads me, and the will of Heaven;
All is, if I have grace to use it so,
As ever in my great Taskmaster's eye.

On His Blindness

When I consider how my light is spent
Ere half my days in this dark world and wide,
And that one talent which is death to hide
Lodg'd with me useless, though my soul more bent
To serve therewith my Maker, and present
My true account, lest he returning chide,
"Doth God exact day-labour, light denied?"
I fondly ask. But Patience, to prevent
That murmur, soon replies: "God doth not need
Either man's work or his own gifts: who best
Bear his mild yoke, they serve him best. His state
Is kingly; thousands at his bidding speed
And post o'er land and ocean without rest:
They also serve who only stand and wait."

Eve speaks to Adam, from Paradise Lost

With thee conversing I forget all time;
All seasons, and their change, all please alike.
Sweet is the breath of Morn, her rising sweet,
With charm of earliest birds: pleasant the sun,
When first on this delightful land he spreads
His orient beams, on herb, tree, fruit, and flower,
Glistering with dew; fragrant the fertile earth
After soft showers; and sweet the coming on

Figure 8.7: **John Milton is best known for his epic poem, *Paradise Lost*, which is considered to be one of the finest compositions in the English language. He lived at a time of civil war in England and was on the side of the victorious Parliamentarians. As a result, he held governmental offices until the restoration of the monarchy in 1660. By that time, Milton was completely blind, but he continued to write.**

Of grateful Evening mild; then silent Night
With this her solemn bird and this fair moon,
And these the gems of Heaven, her starry train:
But neither breath of Morn when she ascends
With charm of earliest birds; nor rising sun
On this delightful land, nor herb, fruit, flower,
Glistering with dew; nor fragrance after showers;
Nor grateful Evening mild; nor silent Night
With this her solemn bird; nor walk by moon,
Or glittering star-light without thee is sweet

Chapter 9

RENAISSANCE COMPOSERS

9.1 John Dunstable (1390-1453)

John Dunstable (often spelled Dunstaple) was probably born in Dunstable, Bedfordshire, England. He was undoubted a highly educated man, and an author of astronomical and astrological and mathematical texts, although there is no record of him at either Oxford or Cambridge. As a musical composer, his fame was very widespread, and although manuscripts of his music were lost because of the dissolution of the monasteries, his music has been reconstructed from manuscripts in Germany and Italy, where his influence was also felt. He introduced a polyphonic style of composition, with rich harmonies based of thirds and sixths, This came to be called the *contenance angloise* style, and it was continued by other composers. Of Dunstable's musical compoisitions that have survived, most are religious. He is also thought to have composed many secular works, but none can be attributed to him with certainty.

9.2 Josquin des Pres (1450-1521)

Josquin des Pres was born in France, but he spent much of his life in Italy, in Milan, in the service of the Svorza family and in Rome as a singer in the choir of Pope Innocent VII and later the choir of the Borgia Pope Alexander VI. He composed 18 masses, 62 motets, 3 motets.chansons, and 63 chansons.

Wikipedia states that **"Josquin lived during a transitional stage in music history. Musical styles were changing rapidly, in part owing to the movement of musicians between different regions of Europe.[37] Many northern musicians moved to Italy, the heart of the Renaissance, attracted by the Italian nobility's patronage of the arts; while in Italy, these composers were influenced by the native Italian styles, and often brought those ideas with them back to their homelands. The sinuous musical lines of the Ockeghem generation, the contrapuntal complexity of the Netherlanders, and the homophonic textures of the Italian lauda and secular music began to merge into a unified style; indeed**

Figure 9.1: **A woodcut depicting Josquin des Pres.**

Josquin was to be the leading figure in this musical process, which eventually resulted in the formation of an international musical language, of which the most famous composers included Palestrina and Lassus."

9.3 Orlando de Lassus (1532-1594)

Orlando de Lassus was born in Hapsburg Netherlands (modern-day Belgium). He is said to have been kidnapped three times because of his remarkably beautiful singing voice. He became one of the most influential composers of the late Renaissance. He travelled to Italy at an early age, and worked there for Cosimo di Medici.

At the age of only 21, Orlando de Lassus became maestro di cappella of the Basilica of Saint John Lateran, the ecumenical mother church of Rome, a spectacularly important post for someone so young.

Later in his life, Orlando moved to Munich, joining the court of Albrecht V, Duke of Bavaria where, who was trying to build up a musical establishment to match the courts of Italy. Orlando de Lassus settled in Munich with his wife and children, refusing to leave despite being offered important posts elsewhere.

Wikipedia says of him, **"One of the most prolific, versatile, and universal composers of the late Renaissance, Lassus wrote over 2,000 works in all Latin, French, Italian and German vocal genres known in his time. These include 530 motets, 175 Italian madrigals and villanellas, 150 French chansons, and 90 German lieder.**

Figure 9.2: **Portrait of Orlando de Lassus.**

9.4 William Byrd (1539-1623)

One of the greatest English composers

William Byrd studied music under the famous English composer Thomas Tallis (1505-1585). According to Wikipedia he was **"Widely considered to be one of the greatest composers of the Renaissance and one of the greatest British composers, he had a huge influence on composers both from his native England and those on the continent. He wrote in many of the forms current in England at the time, including various types of sacred and secular polyphony, keyboard (the so-called Virginalist school), and consort music."**

Lincoln Cathedral and the Chapel Royal

William Byrd's first employment was as organist and master of the choristers at Lincoln Cathedral, a post that he obtained in 1563 at the age of 24. He composed a number of his important works while at this post.

In 1572, Byrd obtained the prestigious post of Gentleman of the Chapel Royal. This post brought him into contact with Queen Elizabeth I, who was a music lover and an accomplished keyboard player.

Persecuted as a Catholic during the reign of Elizabeth I

The time in which William Byrd lived was one in which many Catholics were persecuted for their beliefs. Byrd was originally an Anglican, but sometime during the 1570's he became a Roman Catholic. This was dangerous at the time, although Queen Elizabeth I was somewhat more tolerant than her father Henry VIII had been. This was the era in which King Phillip II of Spain sent an armada to invade England and to bring England back within the authority of the Pope in Rome.

Because of Byrd's conversion to Catholicism, his membership of the Chapel Royal was suspended, his movements were restricted, and his house was placed on the search list.

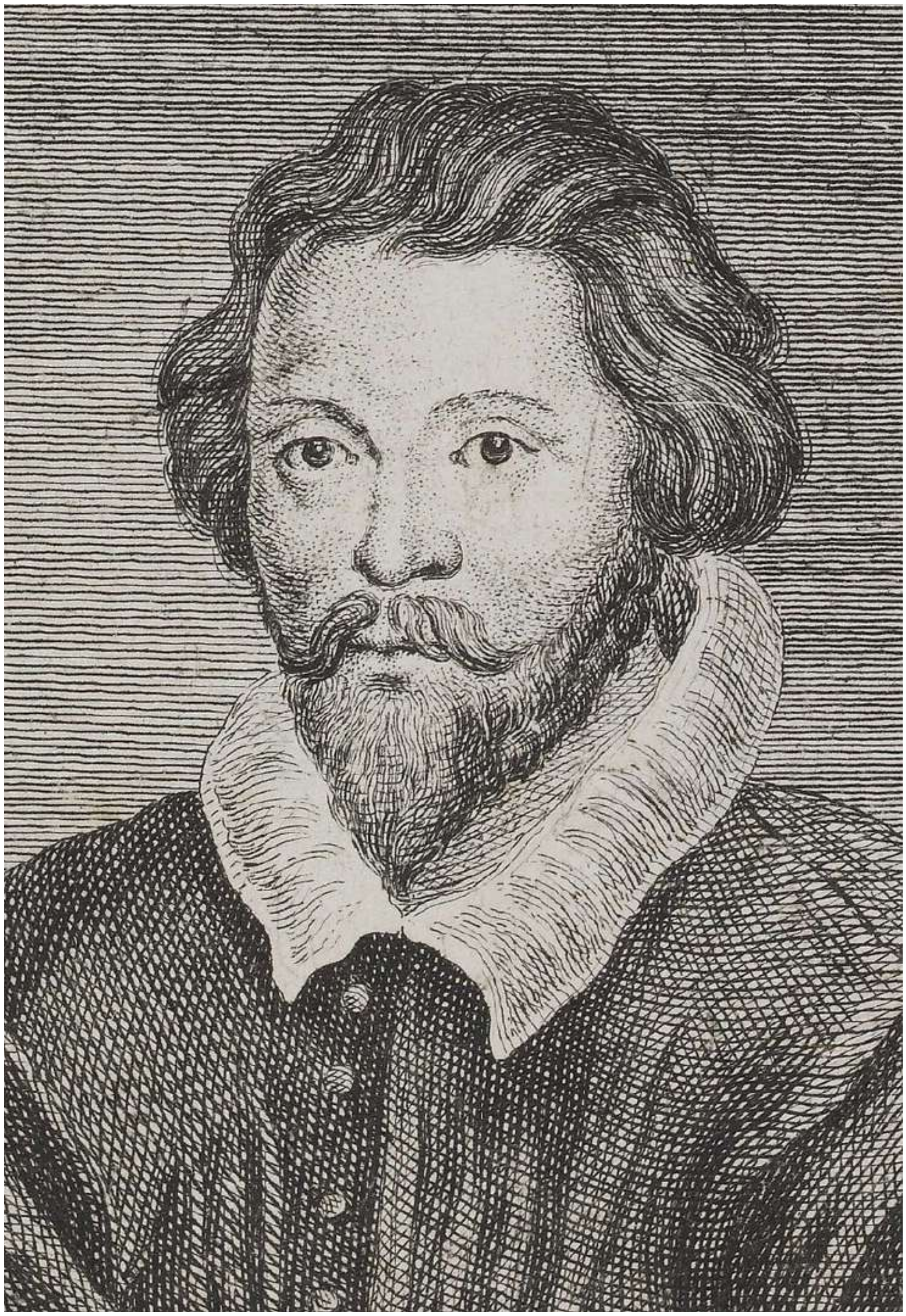

Figure 9.3: **William Byrd**

9.5 Giovanni Gabrielli (1554-1612)

Gabrielli studied music with his uncle and with Orlando de Lassus

Although little is known with certainty about Gabrielli's early life, he is thought to have studied music with his uncle, the composer Andreas Gabrielli (1543-1585), who was employed at the Saint Mark's Basilica in Venice. He later traveled to Munich to the court of Duke Albert V, to study with the renowned composer Orlando de Lassus. He probably stayed there until about 1579, and de Lassus was an important influence on Giovanni Gabrielli's musical style.

At Saint Mark's Basilica in Venice

In 1584, Giovanni Gabrielli became the principal organist of Saint Mark's Basilica in Venice. A year later, following the death of his uncle, he became the principal composer at Saint Mark's as well. In this double position, Gabrielli introduced antiphonal compositions, in which members of the choir were spatially separated from from each other in two or three groups, and splendid effects were produced through call and response.

Today Giovanni Gabrielli is considered to be one of the most important and influential composers of the late Renaissance,

9.6 Carlo Gesualdo (1566-1613)

Famous for his music and for a double murder

Carlo Gesualdo, Prince of Venosa, Italy, is famous not only for his daring musical compositions, but also for a double murder: Gesualdo was married to his first cousin, Donna Maria d'Avalos, the daughter of Carlo d'Avalos, prince of Montesarchio and Sveva Gesualdo, princess of Venosa. On the night of October 16, 1590, Gesualdo caught his wife in bed with Fabrizio Carafa, third Duke of Andrea and seventh Count of Ruovo, and he killed them both on the spot. A court later ruled that Gesualdo had not committed a crime but had only done his duty as a husband. Nevertheless, this double murder haunted Gesualdo and caused him to become depressed in his old age. He kept a special servant whose duty it was to beat him every day, and he tried to obtain a relic of a saint in the hope that he could, in this way, obtain absolution.

Meanwhile, Gesualdo had composed music so highly original and chromatic that its like was not seen until the late 19th century. He lived in his castle, where he hired a group of resident virtuoso musicians to perform his works.

Figure 9.4: **Carlo Gesualdo, Prince of Venosa.**

9.7 Claudio Monteverdi (1567-1643)

Italy during Monteverdi's lifetime

We speak of Claudio Monteverdi as an Italian composer, but it would perhaps be more correct to call him Venetian. During the time when he lived, Italy has no political unity. It was instead a collection of small states which were frequently at war with each other. Among these small states, Venice was the most prosperous and progressive, artistically developed and with freedom of expression for its citizens.

Composer of madrigals

During the course of his life, Claudio Monteverdi composed nine books of madrigals. What are madrigals? They are a form of secular choral music, usually for soprano, alto, tenor and bass, and almost always relating to love, passion, jealousy and so on. During the Renaissance and Baroque periods, singing madrigals was a frequent after-dinner pass-time among well-educated people.

Musical director of St. Mark's Cathedral in Venice

In 1613, Monteverdi became the musical director of the famous St. Mark's Cathedral in Venice (Basilico San Marco). He remained in this position for many years, and was given a generous salary. His duties included not only recruiting and instructing choir members and instrumentalists, but also composing works to celebrate special occasions, such as Holy Cross Day, Christmas Eve. and celebrations of the Doge. Monteverdi introduced works written in a more modern style into the repertoire of San Marco. His duties left him with some free time, and he used this to contribute compositions to other churches in Venice.

Pioneer of opera

Wikipedia states that **"The Italian composer Claudio Monteverdi (1567-1643), in addition to a large output of church music and madrigals, wrote prolifically for the stage. His theatrical works were written between 1604 and 1643 and included operas, of which three - *L'Orfeo* (1607), *Il ritorno d'Ulisse in patria* (1640) and *L'incoronazione di Poppea* (1643) - have survived with their music and librettos intact. In the case of the other seven operas, the music has disappeared almost entirely, although some of the librettos exist. The loss of these works, written during a critical period of early opera history, has been much regretted by commentators and musicologists."**

Figure 9.5: **Claudio Monteverdi by Bernardo Strozzi.**

Chapter 10

DESCARTES, NEWTON, LEIBNIZ AND PASCAL

10.1 Uniting geometry and algebra

Until the night of November 10, 1619, algebra and geometry were separate disciplines. On that autumn evening, the troops of the Elector of Bavaria were celebrating the Feast of Saint Martin at the village of Neuberg in Bohemia. With them was a young Frenchman named René Descartes (1596-1659), who had enlisted in the army of the Elector in order to escape from Parisian society. During that night, Descartes had a series of dreams which, as he said later, filled him with enthusiasm, converted him to a life of philosophy, and put him in possession of a wonderful key with which to unlock the secrets of nature.

The program of natural philosophy on which Descartes embarked as a result of his dreams led him to the discovery of analytic geometry, the combination of algebra and geometry. Essentially, Descartes' method amounted to labeling each point in a plane with two numbers, x and y. These numbers represented the distance between the point and two perpendicular fixed lines, (the coordinate axes). Then every algebraic equation relating x and y generated a curve in the plane.

Descartes realized the power of using algebra to generate and study geometrical figures; and he developed his method in an important book, which was among the books that Newton studied at Cambridge. Descartes' pioneering work in analytic geometry paved the way for the invention of differential and integral calculus by Fermat, Newton and Leibniz. (Besides taking some steps towards the invention of calculus, the great French mathematician, Pierre de Fermat (1601-1665), also discovered analytic geometry independently, but he did not publish this work.)

Analytic geometry made it possible to treat with ease the elliptical orbits which Kepler had introduced into astronomy, as well as the parabolic trajectories which Galileo had calculated for projectiles.

Descartes also worked on a theory which explained planetary motion by means of "vortices"; but this theory was by no means so successful as his analytic geometry.

7

Figure 10.1: **Portrait of René Descartes, after Frans Hals.**

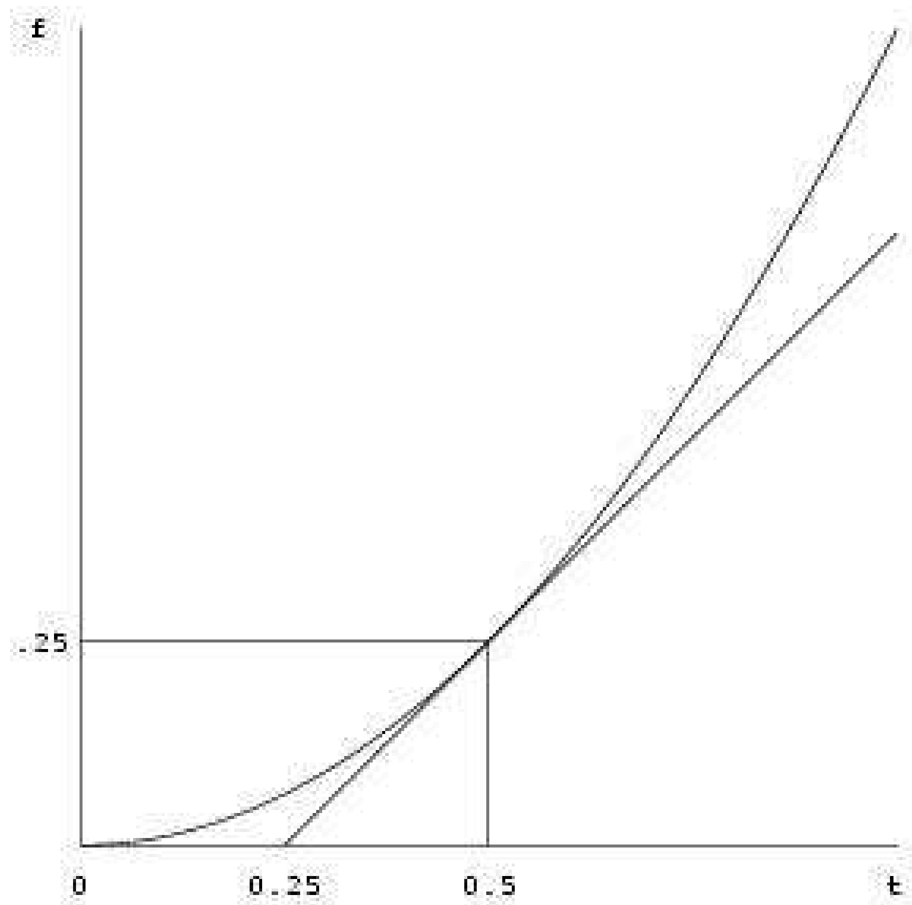

Figure 10.2: **This figure shows the parabola $f = t^2$ plotted using the method of Descartes. Values of f are measured on the vertical axis, while values of t are measured along the horizontal axis. The curve tells us the value of f corresponding to every value of t. For example, when t = 1, f = 1, while when t = 2, f = 4. If we want to know the value of $f = t^2$ corresponding to a particular value of t, we go vertically up to the curve from the horizontal axis, and then horizontally left from the curve to the vertical axis.**

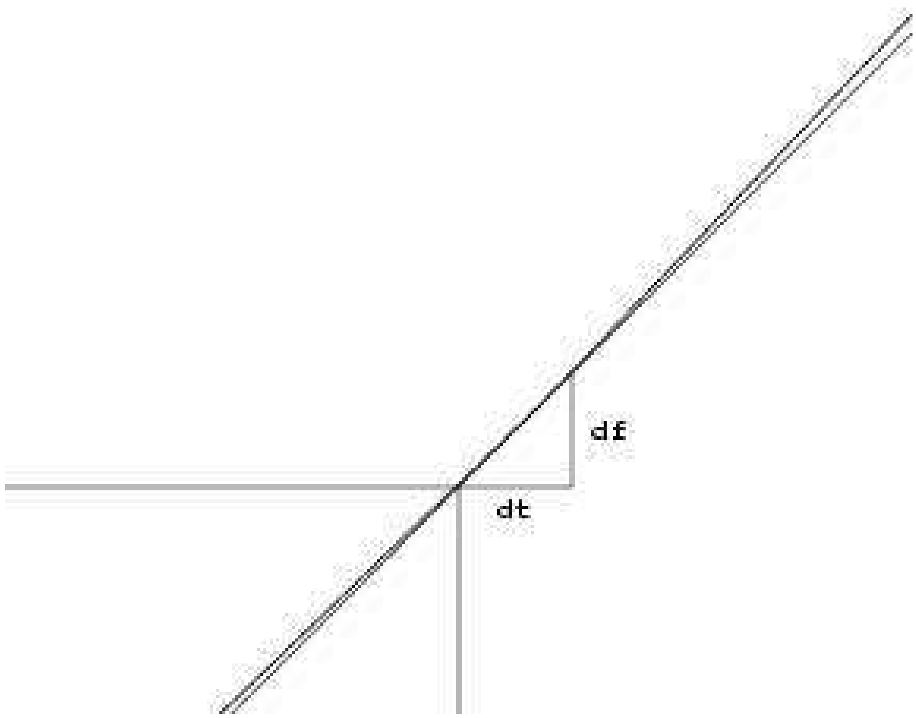

Figure 10.3: **The slope of a curve at a given point t is defined as the limit of the ratio df/dt, when dt becomes infinitesimally small.**

10.2 Descartes' work on Optics, physiology and philosophy

Descartes did important work in optics, physiology and philosophy. In philosophy, he is the author of the famous phrase *"Cogito, ergo sum"*, "I think; therefore I exist", which is the starting point for his theory of knowledge. He resolved to doubt everything which it was possible to doubt; and finally he was reduced to knowledge of his own existence as the only real certainty.

René Descartes died tragically through the combination of two evils which he had always tried to avoid: cold weather and early rising. Even as a student, he spent a large portion of his time in bed. He was able to indulge in this taste for a womblike existence because his father had left him some estates in Brittany. Descartes sold these estates and invested the money, from which he obtained an ample income. He never married, and he succeeded in avoiding responsibilities of every kind.

10.3 Descartes' tragic death

Descartes might have been able to live happily in this way to a ripe old age if only he had been able to resist a flattering invitation sent to him by Queen Christina of Sweden. Christina, the intellectual and strong-willed daughter of King Gustav Adolf, was determined to bring culture to Sweden, much to the disgust of the Swedish noblemen, who considered that money from the royal treasury ought to be spent exclusively on guns and fortifications. Unfortunately for Descartes, he had become so famous that Queen Christina wished to take lessons in philosophy from him; and she sent a warship to fetch him from Holland, where he was staying. Descartes, unable to resist this flattering attention from a royal patron, left his sanctuary in Holland and sailed to the frozen north.

The only time Christina could spare for her lessons was at five o'clock in the morning, three times a week. Poor Descartes was forced to get up in the utter darkness of the bitterly cold Swedish winter nights to give Christina her lessons in a draughty castle library; but his strength was by no means equal to that of the queen, and before the winter was over he had died of pneumonia.

10.4 Newton's early life

On Christmas day in 1642 (the year in which Galileo died), a recently widowed woman named Hannah Newton gave birth to a premature baby at the manor house of Woolsthorpe, a small village in Lincolnshire, England. Her baby was so small that, as she said later, "he could have been put into a quart mug", and he was not expected to live. He did live, however, and lived to achieve a great scientific synthesis, uniting the work of Copernicus, Brahe, Kepler, Galileo and Descartes.

When Isaac Newton was four years old, his mother married again and went to live with her new husband, leaving the boy to be cared for by his grandmother. This may have caused Newton to become more solemn and introverted than he might otherwise have been. One of his childhood friends remembered him as "a sober, silent, thinking lad, scarce known to play with the other boys at their silly amusements".

10.5 Newton becomes a student at Cambridge

As a boy, Newton was fond of making mechanical models, but at first he showed no special brilliance as a scholar. He showed even less interest in running the family farm, however; and a relative (who was a fellow of Trinity College) recommended that he be sent to grammar school to prepare for Cambridge University.

When Newton arrived at Cambridge, he found a substitute father in the famous mathematician Isaac Barrow, who was his tutor. Under Barrow's guidance, and while still a student, Newton showed his mathematical genius by inventing the binomial theorem.

To understand Newton's work on the binomial theorem, we can begin by thinking of what happens when we multiply the quantity a + b by itself. The result is $a^2 + 2ab + b^2$. Now suppose that we continue the process and multiply $a^2 + 2ab + b^2$ by $a + b$. The result of this second multiplication is $a^3 + 3a^2b + 3ab^2 + b^3$, which can also be written as $(a + b)^3$. Continuing in this way we can obtain higher powers of a + b:

$$
\begin{aligned}
(a+b)^1 &= a+b \\
(a+b)^2 &= a^2+2ab+b^2 \\
(a+b)^3 &= a^3+3a^b+3b^2a+b^3 \\
(a+b)^4 &= a^4+4a^3b+6a^2b^2+4ab^3+b^4
\end{aligned} \tag{10.1}
$$

and so on. Newton realized that in general, an integral power of a + b can be expressed in the form:

$$
(a+b)^n = a^n + \frac{n}{1!}a^{n-1}b + \frac{n(n-1)}{2!}a^{n-2}b^2 + \frac{n(n-1)(n-2)}{3!}a^{n-3}b^3 + \cdots \tag{10.2}
$$

where

$$
\begin{aligned}
0! &\equiv 1 \\
1! &\equiv 1 \\
2! &\equiv 2 \times 1 = 2 \\
3! &\equiv 3 \times 2 \times 1 = 6 \\
4! &\equiv 4 \times 3 \times 2 \times 1 = 24 \\
\vdots \; &\vdots \qquad\qquad \vdots
\end{aligned} \tag{10.3}
$$

From the definition of n!, it follows that

$$\begin{aligned} n &= \frac{n!}{(n-1)!} \\ n(n-1) &= \frac{n!}{(n-2)!} \\ n(n-1)(n-3) &= \frac{n!}{(n-3)!} \end{aligned} \tag{10.4}$$

so that we can rewrite the equation for $(a+b)^n$ can be rewritten in the form

$$(a+b)^n = \sum_{j=0}^{n} \frac{n!}{j!(n-j)!)} a^{n-j} b^j \tag{10.5}$$

The large Greek letter $\sum$ indicates a sum. In this case, it is taken over all integral values from 0 up to and including to n.

10.6 Differential calculus

In 1665, Cambridge University was closed because of an outbreak of the plague, and Newton returned for two years to the family farm at Woolsthorpe. He was then twenty-three years old. During the two years of isolation, Newton developed his binomial theorem into the beginnings of differential calculus. He imagined Δt to be an extremely small increase in the value of a variable t. For example, t might represent time, in which case Δt would represent an infinitesimal increase in time - a tiny fraction of a split-second. Newton realized that the series

$$(t+\Delta t)^p = t^p + pt^{p-1}\Delta t + + \frac{p(p-1)}{2!} t^{p-2}(\Delta t)^2 + \cdots \tag{10.6}$$

could then be represented to a very good approximation by its first two terms, and in the limit $\Delta t \to 0$, he obtained the result:

$$\begin{matrix} \text{limit} \\ \Delta t \to 0 \end{matrix} \left[\frac{f(t+\Delta t) - f(t)}{\Delta t} \right] = pt^{p-1} \tag{10.7}$$

Thus, in the particular case where $f(t) = t^p$ he found that

$$\frac{df}{dt} \equiv \begin{matrix} \text{limit} \\ \Delta t \to 0 \end{matrix} \left[\frac{f(t+\Delta t) - f(t)}{\Delta t} \right] = pt^{p-1} \tag{10.8}$$

$\dfrac{d}{dt}$ can be thought of as an operator which one can apply to a function f (t). Today we call this operation "differentiation", and df/dt is called the function's "first derivative".

The derivative of a function can be interpreted as the slope (at a particular point t) of a curve representing the function. Differential calculus is the branch of mathematics that deals with differentiation, with slopes, with tangents, and with rates of change.

We have used modern notation to go through the reasoning that Newton used to develop his binomial theorem into differential calculus. The quantities that we today call "derivatives", he called "fluxions", i.e. flowing quantities, perhaps because he associated them with a water clock that he had made as a boy - a water-filled jar with a hole in the bottom. If $f(t)$ represents the volume of water in the jar as a function of time, then df/dt represents the rate at which water is flowing out through the hole.

Newton also applied his "method of fluxions" to mechanics. From the three laws of planetary motion discovered by the German astronomer Kepler, Newton had deduced that the force with which the sun attracts a planet must fall off as the square of the distance between the planet and the sun. With great boldness, he guessed that this force is *universal*, and that every object in the universe attracts every other object with a gravitational force that is directly proportional to the product of the two masses, and inversely proportional to the square of the distance between them.

Newton also guessed correctly that in attracting an object outside its surface, the earth acts as though its mass were concentrated at its center. However, he could not construct the proof of this theorem, since it depended on integral calculus, which did not exist in 1666. (Newton himself perfected integral calculus later in his life.)

Referring to the year 1666, Newton wrote later: "I began to think of gravity extending to the orb of the moon; and having found out how to estimate the force with which a globe revolving within a sphere presses the surface of the sphere, from Kepler's rule of the periodical times of the planets being in a sesquialternate proportion of their distances from the centres of their orbs, I deduced that the forces which keep the planets in their orbs must be reciprocally as the squares of the distances from the centres about which they revolve; and thereby compared the force requisite to keep the moon in her orb with the force of gravity at the surface of the earth, and found them to answer pretty nearly."

"All this was in the plague years of 1665 and 1666, for in those days I was in the prime of my age for invention, and minded mathematics and philosophy more than at any time since."

Newton was not satisfied with this incomplete triumph, and he did not show his calculations to anyone. He not only kept his ideas on gravitation to himself, (probably because of the missing proof), but he also refrained for many years from publishing his work on the calculus. By the time Newton published, the calculus had been invented independently by the great German mathematician and philosopher, Gottfried Wilhelm Leibniz (1646-1716); and the result was a bitter quarrel over priority. However, Newton did publish his experiments in optics, and these alone were enough to make him famous.

10.7 Optics

Newton's famous experiments in optics also date from these years. The sensational experiments of Galileo were very much discussed at the time, and Newton began to think about ways to improve the telescope. Writing about his experiments in optics, Newton says:

"In the year 1666 (at which time I applied myself to the grinding of optic glasses of other figures than spherical), I procured me a triangular prism, to try therewith the celebrated phenomena of colours. And in order thereto having darkened my chamber, and made a small hole in the window shuts to let in a convenient quantity of the sun's light, I placed my prism at its entrance, that it might thereby be refracted to the opposite wall."

"It was at first a very pleasing divertisment to view the vivid and intense colours produced thereby; but after a while, applying myself to consider them more circumspectly, I became surprised to see them in an oblong form, which, according to the received laws of refraction I expected should have been circular."

Newton then describes his crucial experiment. In this experiment, the beam of sunlight from the hole in the window shutters was refracted by two prisms in succession. The first prism spread the light into a rainbow-like band of colors. From this spectrum, he selected a beam of a single color, and allowed the beam to pass through a second prism; but when light of a single color passed through the second prism, the color did not change, nor was the image spread out into a band. No matter what Newton did to it, red light always remained red, once it had been completely separated from the other colors; yellow light remained yellow, green remained green, and blue remained blue.

Newton then measured the amounts by which the beams of various colors were bent by the second prism; and he discovered that red light was bent the least. Next in sequence came orange, yellow, green, blue and finally violet, which was deflected the most. Newton recombined the separated colors, and he found that together, they once again produced white light.

Concluding the description of his experiments, Newton wrote:

"...and so the true cause of the length of the image (formed by the first prism) was detected to be no other than that light is not similar or homogenial, but consists of *deform rays, some of which are more refrangible than others*."

"As rays of light differ in their degrees of refrangibility, so they also differ in their disposition to exhibit this or that particular colour... To the same degree of refrangibility ever belongs the same colour, and to the same colour ever belongs the same degree of refrangibility."

"...The species of colour and the degree of refrangibility belonging to any particular sort of rays is not mutable by refraction, nor by reflection from natural bodies, nor by any other cause that I could yet observe. When any one sort of rays hath been well parted from those of other kinds, it hath afterwards obstinately retained its colour, notwithstanding my utmost endeavours to change it."

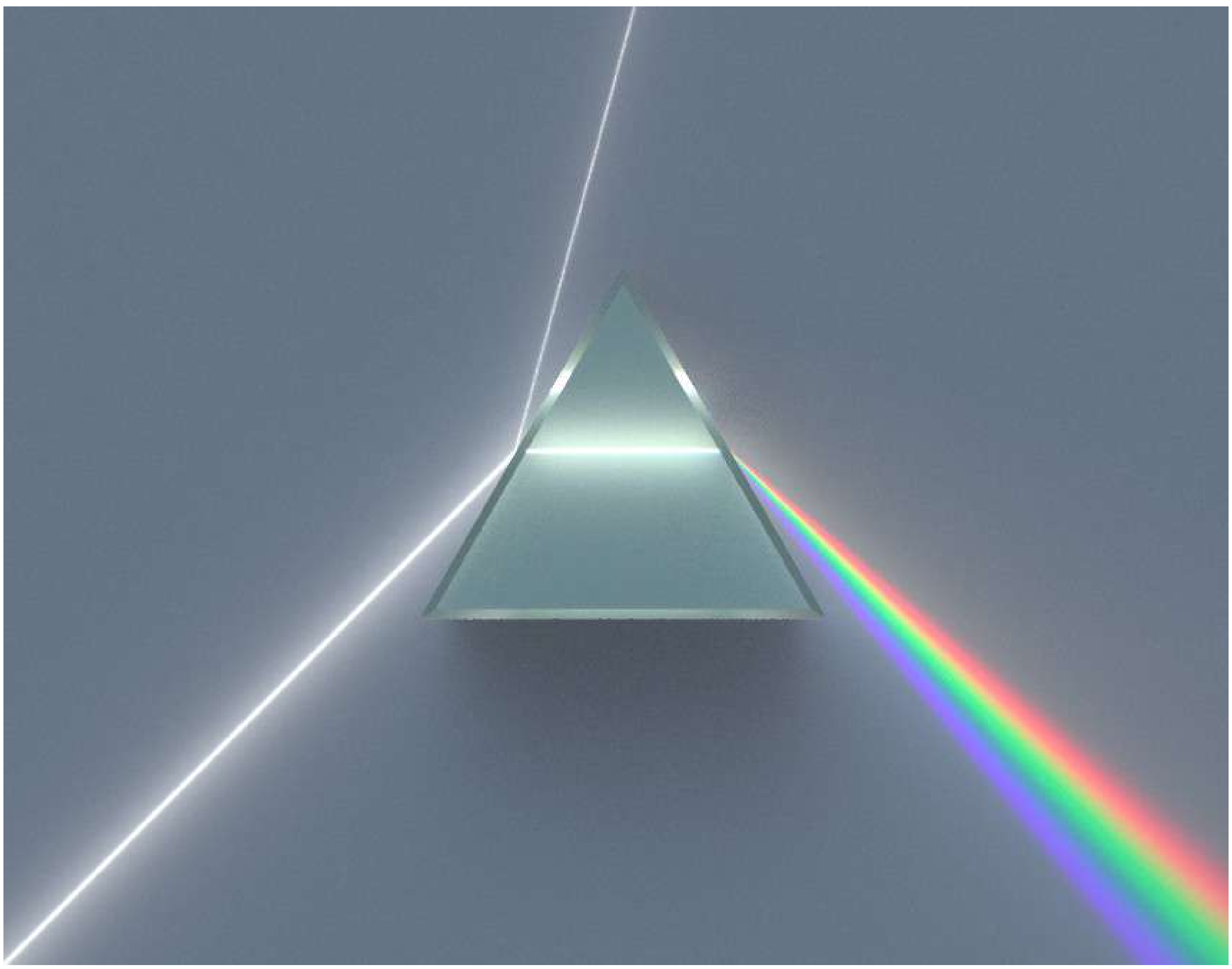

Figure 10.4: **Illustration of a dispersive prism separating white light into the colours of the spectrum, as discovered by Newton.**

Figure 10.5: **Replica of Newton's second reflecting telescope, which he presented to the Royal Society in 1672.**

10.8 Integral calculus

In 1669, Newton's teacher, Isaac Barrow, generously resigned his post as Lucasian Professor of Mathematics so that Newton could have it. Thus, at the age of 27, Newton became the head of the mathematics department at Cambridge. He was required to give eight lectures a year, but the rest of his time was free for research.

Newton worked at this time on developing what he called "the method of inverse fluxions". Today we call his method "integral calculus". What did Newton mean by "inverse fluxions"? By "fluxions" he meant differentials, so we must think of an operation that is the reverse of differentiation.

Suppose that we know from our experience with differentiation that (for example)

$$\text{if and only if } f = t^p + C \text{ then } \frac{df}{dt} = pt^{p-1} \tag{10.9}$$

where C is a constant. Then we also know that

$$\text{if } \frac{df}{dt} = pt^{p-1} \text{ then } f = t^p + C \tag{10.10}$$

10.9 Halley visits Newton

Newton's prism experiments had led him to believe that the only possible way to avoid blurring of colors in the image formed by a telescope was to avoid refraction entirely. Therefore he designed and constructed the first reflecting telescope. In 1672, he presented a reflecting telescope to the newly-formed Royal Society, which then elected him to membership.

Meanwhile, the problems of gravitation and planetary motion were increasingly discussed by the members of the Royal Society. In January, 1684, three members of the Society were gathered in a London coffee house. One of them was Robert Hooke (1635-1703), author of *Micrographia* and Professor of Geometry at Gresham College, a brilliant but irritable man. He had begun his career as Robert Boyle's assistant, and had gone on to do important work in many fields of science. Hooke claimed that he could calculate the motion of the planets by assuming that they were attracted to the sun by a force which diminished as the square of the distance.

Listening to Hooke were Sir Christopher Wren (1632-1723), the designer of St. Paul's Cathedral, and the young astronomer, Edmund Halley (1656-1742). Wren challenged Hooke to produce his calculations; and he offered to present Hooke with a book worth 40 shillings if he could prove his inverse square force law by means of rigorous mathematics. Hooke tried for several months, but he was unable to win Wren's reward.

Meanwhile, in August, 1684, Halley made a journey to Cambridge to talk with Newton, who was rumored to know very much more about the motions of the planets than he had revealed in his published papers. According to an almost-contemporary account, what happened then was the following:

"Without mentioning his own speculations, or those of Hooke and Wren, he (Halley) at once indicated the object of his visit by asking Newton what would be the curve described by the planets on the supposition that gravity diminished as the square of the distance. Newton immediately answered: an Ellipse. Struck with joy and amazement, Halley asked how he knew it? 'Why', replied he, 'I have calculated it'; and being asked for the calculation, he could not find it, but promised to send it to him."

Newton soon reconstructed the calculation and sent it to Halley; and Halley, filled with enthusiasm and admiration, urged Newton to write out in detail all of his work on motion and gravitation. Spurred on by Halley's encouragement and enthusiasm, Newton began to put his research in order. He returned to the problems which had occupied him during the plague years, and now his progress was rapid because he had invented integral calculus. This allowed him to prove rigorously that terrestrial gravitation acts as though all the earth's mass were concentrated at its center. Newton also had available an improved value for the radius of the earth, measured by the French astronomer Jean Picard (1620-1682). This time, when he approached the problem of gravitation, everything fell into place.

By the autumn of 1684, Newton was ready to give a series of lectures on dynamics, and he sent the notes for these lectures to Halley in the form of a small booklet entitled *On the Motion of Bodies*. Halley persuaded Newton to develop these notes into a larger book, and with great tact and patience he struggled to keep a controversy from developing between Newton, who was neurotically sensitive, and Hooke, who was claiming his share of recognition in very loud tones, hinting that Newton was guilty of plagiarism.

Although Newton was undoubtedly one of the greatest physicists of all time, he had his shortcomings as a human being; and he reacted by striking out from his book every single reference to Robert Hooke. The Royal Society at first offered to pay for the publication costs of Newton's book, but because a fight between Newton and Hooke seemed possible, the Society discretely backed out. Halley then generously offered to pay the publication costs himself, and in 1686 Newton's great book was printed. It is entitled *Philosophae Naturalis Principia Mathematica*, (The Mathematical Principles of Natural Philosophy), and it is divided into three sections.

The first book sets down the general principles of mechanics. In it, Newton states his three laws of motion, and he also discusses differential and integral calculus (both invented by himself).

In the second book, Newton applies these methods to systems of particles and to hydrodynamics. For example, he calculates the velocity of sound in air from the compressibility and density of air; and he treats a great variety of other problems, such as the problem of calculating how a body moves when its motion is slowed by a resisting medium, such as air or water.

The third book is entitled *The System of the World*. In this book, Newton sets out to derive the entire behavior of the solar system from his three laws of motion and from his law of universal gravitation. From these, he not only derives all three of Kepler's laws, but he also calculates the periods of the planets and the periods of their moons; and he explains such details as the flattened, non-spherical shape of the earth, and the slow precession of its axis about a fixed axis in space. Newton also calculated the irregular motion of the

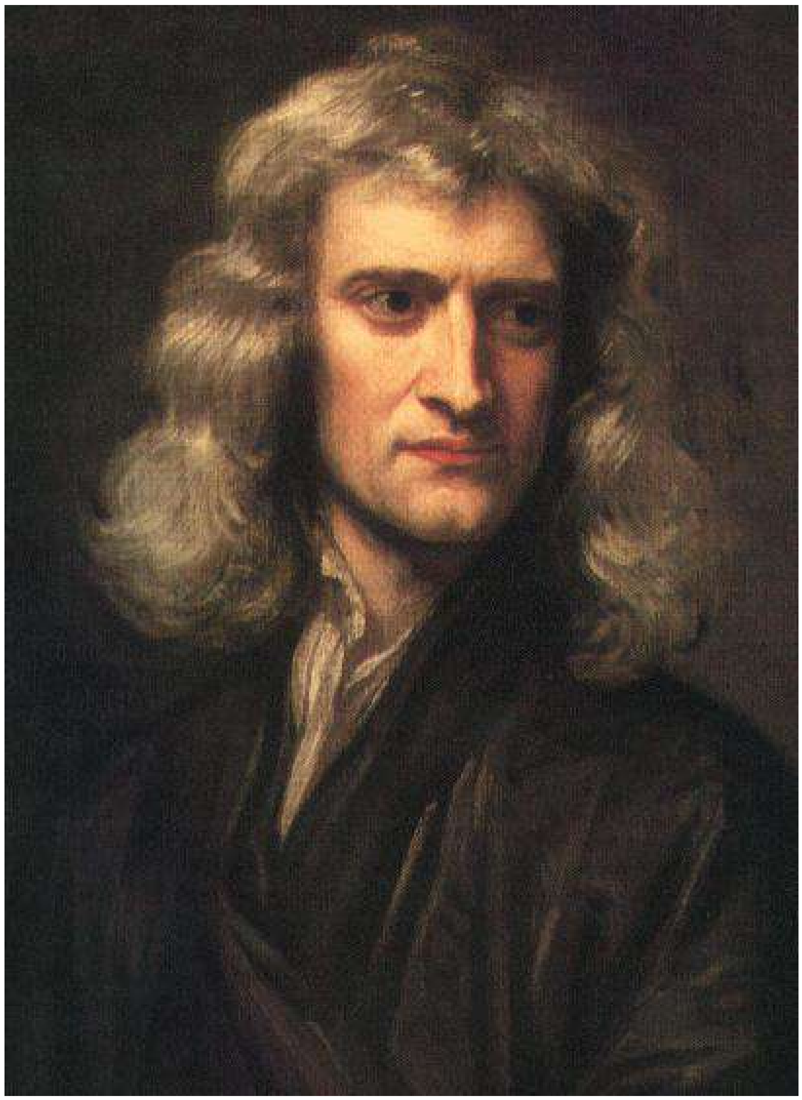

Figure 10.6: **Portrait of Isaac Newton (1642-1727) by Sir Godfrey Kneller.**

moon resulting from the combined attractions of the earth and the sun; and he determined the mass of the moon from the behavior of the tides.

Newton's *Principia* is generally considered to be the greatest scientific work of all time. To present a unified theory explaining such a wide variety of phenomena with so few assumptions was a magnificent and unprecedented achievement; and Newton's contemporaries immediately recognized the importance of what he had done.

The great Dutch physicist, Christian Huygens (1629-1695), inventor of the pendulum clock and the wave theory of light, travelled to England with the express purpose of meeting Newton. Voltaire, who for reasons of personal safety was forced to spend three years in England, used the time to study Newton's *Principia*; and when he returned to France, he persuaded his mistress, Madame du Chatelet, to translate the *Principia* into French; and Alexander Pope, expressing the general opinion of his contemporaries, wrote a famous couplet, which he hoped would be carved on Newton's tombstone:

"Nature and Nature's law lay hid in night.

God said: 'Let Newton be!', and all was light!"

The Newtonian synthesis was the first great achievement of a new epoch in human thought, an epoch which came to be known as the "Age of Reason" or the "Enlightenment". We might ask just what it was in Newton's work that so much impressed the intellectuals of the period. The answer is that in the Newtonian system of the world, the entire evolution of the solar system is determined by the laws of motion and by the positions and velocities of the planets and their moons at a given instant of time. Knowing these, it is possible to predict all of the future and to deduce all of the past.

The Newtonian system of the world is like an enormous clock which has to run on in a predictable way once it is started. In this picture of the world, comets and eclipses are no longer objects of fear and superstition. They too are part of the majestic clockwork of the universe. The Newtonian laws are simple and mathematical in form; they have complete generality; and they are unalterable. In this picture, although there are no miracles or exceptions to natural law, nature itself, in its beautiful works, can be regarded as miraculous.

Newton's contemporaries knew that there were other laws of nature to be discovered besides those of motion and gravitation; but they had no doubt that, given time, all of the laws of nature would be discovered. The climate of intellectual optimism was such that many people thought that these discoveries would be made in a few generations, or at most in a few centuries.

In 1704, Newton published a book entitled *Opticks*, expanded editions of which appeared in 1717 and 1721. Among the many phenomena discussed in this book are the colors produced by thin films. For example, Newton discovered that when he pressed two convex lenses together, the thin film of air trapped between the lenses gave rise to rings of colors ("Newton's rings"). The same phenomenon can be seen in the in the colors of soap bubbles or in films of oil on water.

In order to explain these rings, Newton postulated that "..every ray of light in its passage through any refracting surface is put into a transient constitution or state, which in the progress of the ray returns at equal intervals, and disposes the ray at every return to be easily transmitted through the next refracting surface and between the returns to be easily reflected from it."

Newton's rings were later understood on the basis of the wave theory of light advocated by Huygens and Hooke. Each color has a characteristic wavelength, and is easily reflected when the ratio of the wavelength to the film thickness is such that the wave reflected from the bottom surface of the film interferes constructively with the wave reflected from the top surface. However, although he ascribed periodic "fits of easy reflection" and "fits of easy transmission" to light, and although he suggested that a particular wavelength is associated with each color, Newton rejected the wave theory of light, and believed instead that light consists of corpuscles emitted from lumi Newton believed in his corpuscular theory of light because he could not understand on the basis of Huygens' wave theory how light casts sharp shadows. This is strange, because in his *Opticks* he includes the following passage:

"Grimaldo has inform'd us that if a beam of the sun's light be let into a dark room through a very small hole, the shadows of things in this light will be larger than they ought to be if the rays went on by the bodies in straight lines, and that these shadows have three parallel fringes, bands or ranks of colour'd light adjacent to them. But if the hole be enlarg'd, the fringes grow broad and run into one another, so that they cannot be distinguish'd"

After this mention of the discovery of diffraction by the Italian physicist, Francesco Marea Grimaldi (1618-1663), Newton discusses his own studies of diffraction. Thus, Newton must have been aware of the fact that light from a very small source does not cast completely sharp shadows!

Newton felt that his work on optics was incomplete, and at the end of his book he included a list of "Queries", which he would have liked to have investigated. He hoped that this list would help the research of others. In general, although his contemporaries were extravagant in praising him, Newton's own evaluation of his work was modest. "I do not know how I may appear to the world", he wrote, "but to myself I seem to have been only like a boy playing on the seashore and diverting myself in now and then finding a smoother pebble or a prettier shell than ordinary, whilst the great ocean of truth lay all undiscovered before me."

10.10 The conflict over priority between Leibniz and Newton

In this chapter, we have used the modern notation, which is much closer to the notation used by the great German mathematician and universal genius, Gottfried Wilhelm von Leibniz than to that used by Newton.

Newton did not publish his work on differential and integral calculus. Slightly later, Leibniz invented these two branches of mathematics independently. Thus a bitter dispute over priority was precipitated, from which Leibniz suffered when his patron, the Elector of Hanover, left Germany to become King George I of England.

Figure 10.7: **Christian Huygens (1629-1695).**

Huygens and Leibniz

On the continent of Europe, mathematics and physics had been developing rapidly, stimulated by the writings of René Descartes. One of the most distinguished followers of Descartes was the Dutch physicist, Christian Huygens (1629-1695).

Huygens was the son of an important official in the Dutch government. After studying mathematics at the University of Leiden, he published the first formal book ever written about probability. However, he soon was diverted from pure mathematics by a growing interest in physics.

In 1655, while working on improvements to the telescope together with his brother and the Dutch philosopher Benedict Spinoza, Huygens invented an improved method for grinding lenses. He used his new method to construct a twenty-three foot telescope, and with this instrument he made a number of astronomical discoveries, including a satellite of Saturn, the rings of Saturn, the markings on the surface of Mars and the Orion Nebula.

Huygens was the first person to estimate numerically the distance to a star. By assuming the star Sirius to be exactly as luminous as the sun, he calculated the distance to Sirius, and found it to be 2.5 trillion miles. In fact, Sirius is more luminous than the sun, and its true distance is twenty times Huygens' estimate.

Another of Huygens' important inventions is the pendulum clock. Improving on Galileo's studies, he showed that for a pendulum swinging in a circular arc, the period is not precisely independent of the amplitude of the swing. Huygens then invented a pendulum with a modified arc, not quite circular, for which the swing was exactly isochronous. He used this improved pendulum to regulate the turning of cog wheels, driven by a falling weight; and thus he invented the pendulum clock, almost exactly as we know it today.

In discussing Newton's contributions to optics, we mentioned that Huygens opposed Newton's corpuscular theory of light, and instead advocated a wave theory. Huygens believed that the rapid motion of particles in a hot body, such as a candle flame, produces a wave-like disturbance in the surrounding medium; and he believed that this wavelike disturbance of the "ether" produces the sensation of vision by acting on the nerves at the back of our eyes.

In 1678, while he was working in France under the patronage of Louis XIV, Huygens composed a book entitled *Traité de la Lumiere*, (Treatise on Light), in which he says:

"...It is inconceivable to doubt that light consists of the motion of some sort of matter. For if one considers its production, one sees that here upon the earth it is chiefly engendered by fire and flame, which undoubtedly contain bodies in rapid motion, since they dissolve and melt many other bodies, even the most solid; or if one considers its effects, one sees that when light is collected, as by concave mirrors, it has the property of burning as fire does, that is to say, it disunites the particles of bodies. This is assuredly the mark of motion, at least in the true philosophy in which one conceives the causes of all natural effects in terms of mechanical motions..."

"Further, when one considers the extreme speed with which light spreads on every side, and how, when it comes from different regions, even from those directly opposite, the rays traverse one another without hindrance, one may well understand that when we see a luminous object, it cannot be by any transport of matter coming to us from the object, in the way in which a shot or an arrow traverses the air; for assuredly that would too greatly impugn these two properties of light, especially the second of them. It is in some other way that light spreads; and that which can lead us to comprehend it is the knowledge which we have of the spreading of sound in the air."

Huygens knew the velocity of light rather accurately from the work of the Danish astronomer, Ole Rømer (1644-1710), who observed the moons of Jupiter from the near and far sides of the earth's orbit. By comparing the calculated and observed times for the moons to reach a certain configuration, Rømer was able to calculate the time needed for light to propagate across the diameter of the earth's orbit. In this way, Rømer calculated the velocity of light to be 227,000 kilometers per second. Considering the early date of this first successful measurement of the velocity of light, it is remarkably close to the accepted modern value of 299,792 kilometers per second. Thus Huygens knew that although the speed of light is enormous, it is not infinite.

Huygens considered the propagation of a light wave to be analogous to the spreading of sound, or the widening of the ripple produced when a pebble is thrown into still water. He developed a mathematical principle for calculating the position of a light wave after a short interval of time if the initial surface describing the wave front is known. Huygens considered each point on the initial wave front to be the source of spherical wavelets, moving outward with the speed of light in the medium. The surface marking the boundary between the region outside all of the wavelets and the region inside some of them forms the new wave front.

If one uses Huygens' Principle to calculate the wave fronts and rays for light from a point source propagating past a knife edge, one finds that a part of the wave enters the shadow region. This is, in fact, precisely the effect which was observed by both Grimaldi and Newton, and which was given the name "diffraction" by Grimaldi. In the hands of Thomas Young (1773-1829) and Augustin Jean Fresnel (1788-1827), diffraction effects later became a strong argument in favor of Huygens' wave theory of light.

(You can observe diffraction effects yourself by looking at a point source of light, such as a distant street lamp, through a piece of cloth, or through a small slit or hole. Another type of diffraction can be seen by looking at light reflected at a grazing angle from a phonograph record. The light will appear to be colored. This effect is caused by the fact that each groove is a source of wavelets, in accordance with Huygens' Principle. At certain angles, the wavelets will interfere constructively, the angles for constructive interference being different for each color.)

Interestingly, modern quantum theory (sometimes called wave mechanics) has shown that *both* Huygens' wave theory of light and Newton's corpuscular theory contain aspects of the truth! Light has both wave-like and particle-like properties. Furthermore, quantum theory has shown that small particles of matter, such as electrons, also have wave-like properties! For example, electrons can be diffracted by the atoms of a crystal in a manner exactly analogous to the diffraction of light by the grooves of a phonograph record. Thus the difference of opinion between Huygens and Newton concerning the nature of light is especially interesting, since it foreshadows the wave-particle duality of modern physics.

Among the friends of Christian Huygens was the German philosopher and mathematician Gottfried Wilhelm Leibniz (1646-1716). Leibniz was a man of universal and spectacular ability. In addition to being a mathematician and philosopher, he was also a lawyer, historian and diplomat. He invented the doctrine of balance of power, attempted to unify the Catholic and Protestant churches, founded academies of science in Berlin and St. Petersburg, invented combinatorial analysis, introduced determinants into mathematics, independently invented the calculus, invented a calculating machine which could multiply and divide as well as adding and subtracting, acted as advisor to Peter the Great and originated the theory that "this is the best of all possible worlds" (later mercilessly satirized by Voltaire in *Candide*).

Leibniz learned mathematics from Christian Huygens, whom he met while travelling as an emissary of the Elector of Mainz. Since Huygens too was a man of very wide interests, he found the versatile Leibniz congenial, and gladly agreed to give him lessons. Leibniz continued to correspond with Huygens and to receive encouragement from him until the end of the older man's life.

In 1673, Leibniz visited England, where he was elected to membership by the Royal Society. During the same year, he began his work on calculus, which he completed and published in 1684. Newton's invention of differential and integral calculus had been made much earlier than the independent work of Leibniz, but Newton did not publish his discov-

Figure 10.8: **Portrait of Gottfried Wilhelm Leibniz by J.F. Wentzel.**

eries until 1687. This set the stage for a bitter quarrel over priority between the admirers of Newton and those of Leibniz. The quarrel was unfortunate for everyone concerned, especially for Leibniz himself. He had taken a position in the service of the Elector of Hanover, which he held for forty years. However, in 1714, the Elector was called to the throne of England as George I. Leibniz wanted to accompany the Elector to England, but was left behind, mainly because of the quarrel with the followers of Newton. Leibniz died two years later, neglected and forgotten, with only his secretary attending the funeral.

10.11 Pascal and Leibniz

If civilization survives, historians in the distant future will undoubtedly regard the invention of computers as one of the most important steps in human cultural evolution - as important as the invention of writing or the invention of printing. The possibilities of artificial intelligence have barely begun to be explored, but already the impact of computers on society is enormous.

The first programmable universal computers were completed in the mid-1940's; but they had their roots in the much earlier ideas of Blaise Pascal (1623-1662), Gottfried Wilhelm Leibniz (1646-1716), Joseph Marie Jacquard (1752-1834) and Charles Babbage (1791-1871).

In 1642, the distinguished French mathematician and philosopher Blaise Pascal completed a working model of a machine for adding and subtracting. According to tradition, the idea for his "calculating box" came to Pascal when, as a young man of 17, he sat thinking of ways to help his father (who was a tax collector). In describing his machine, Pascal wrote: "I submit to the public a small machine of my own invention, by means of which you alone may, without any effort, perform all the operations of arithmetic, and may be relieved of the work which has often times fatigued your spirit when you have worked with the counters or with the pen."

Pascal's machine worked by means of toothed wheels. It was much improved by Leibniz, who constructed a mechanical calculator which, besides adding and subtracting, could also multiply and divide. His first machine was completed in 1671; and Leibniz' description of it, written in Latin, is preserved in the Royal Library at Hanover: "There are two parts of the machine, one designed for addition (and subtraction), and the other designed for multiplication (and division); and they should fit together. The adding (and subtracting) machine coincides completely with the calculating box of Pascal. Something, however, must be added for the sake of multiplication..."

"The wheels which represent the multiplicand are all of the same size, equal to that of the wheels of addition, and are also provided with ten teeth which, however, are movable so that at one time there should protrude 5, at another 6 teeth, etc., according to whether the multiplicand is to be represented five times or six times, etc."

"For example, the multiplicand 365 consists of three digits, 3, 6, and 5. Hence the same number of wheels is to be used. On these wheels, the multiplicand will be set if from the right wheel there protrude 5 teeth, from the middle wheel 6, and from the left wheel 3."

Figure 10.9: **Blaise Pascal (1623-1662) was a French mathematician, physicist, writer, inventor and theologian. Pascal, a child prodigy, was educated by his father, who was a tax-collector. He invented his calculating box to make his father's work less tedious.**

Figure 10.10: **The German mathematician, philosopher and universal genius Gottfried Wilhelm von Leibniz (1646-1716) was a contemporary of Isaac Newton. He invented differential and integral calculus independently, just as Newton had done many years earlier. However, Newton had not published his work on calculus, and thus a bitter controversy over priority was precipitated. When his patron, the Elector of Hanover moved to England to become George I, Leibniz was left behind because the Elector feared that the controversy would alienate the English. Leibniz extended Pascal's calculating box so that it could perform multiplication and division. Calculators of his design were still being used in the 1960's.**

Suggestions for further reading

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