

Galileo Galilei

Background

Galileo Galilei was born on the 15th of February 1564, in Pisa, Tuscany (Galileo Galilei - Wikipedia 2008). He was a man of many talents and contributed to the fields of mathematics, astronomy, physics and philosophy. His most notable accomplishments included improvements to the design of the telescope which allowed for greater levels of magnification and led to his subsequent astronomical discoveries and his scientific exploration in the field of kinematics (Galileo Galilei - Wikipedia 2008). Galileo's life was not without controversy, as he argued in favour of Nicolaus Copernicus's theory of a sun centred universe (Galileo Galilei - Wikipedia 2008). This went directly against the Catholic Church's view of a geocentric universe with the Earth at the centre. The Catholic Church prohibited the teaching of heliocentrism as it went against the literal teachings of the Scripture. Galileo was proclaimed a heretic and was forced to deny his belief in heliocentrism and spend the latter years of his life under house arrest (Galileo Galilei - Wikipedia 2008).

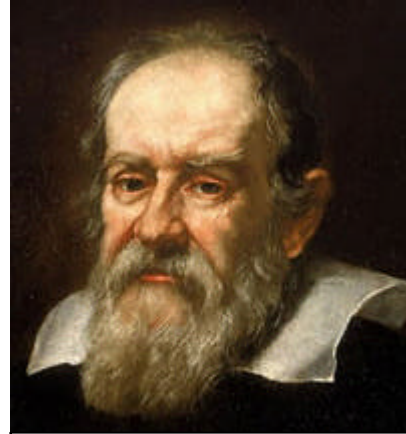


Figure 1: Portrait of Galileo

Scientific Method

Albert Einstein referred to Galileo as the father of modern science, and such a compliment can not come about without merit. The reason behind Einstein's praise is that Galileo pioneered quantitative experimentation, whose results were analysed using mathematics (Galileo Galilei - Wikipedia 2008). Before Galileo's time, science was studied qualitatively and as such precise mathematical relationships were rarely identified. Galileo is accredited as being the first person to state that the laws of nature are governed by mathematics (Galileo Galilei - Wikipedia 2008). In his first book, *The Assayer* Galileo wrote,

“Philosophy is written in this grand book, the universe ... It is written in the language of mathematics, and its characters are triangles, circles, and other geometric figures” (Stillman 1957)

Galileo was Catholic and as such he tried to remain loyal to the Catholic Church, however his belief in experimental results and their true interpretation meant that he rejected blind obedience of the Church's teachings, unlike many other scientists of his time. He was able to separate matters of science from philosophy and religion, which was a major step forward into the thinking of scientific investigation of the world around us (Galileo Galilei - Wikipedia 2008).

For Galileo to conduct his experiments he had to set up standards of length and time much like those that we use today in our scientific investigation (Galileo Galilei - Wikipedia 2008). This allowed Galileo to compare measurements made on different

days or in different laboratory environment. This meant that experiments could also be reproduced in any environment and provided similar results (Galileo Galilei - Wikipedia 2008). For these reasons it is clear why Galileo is accredited with the title of the father of modern science.

In fact Galileo's understanding of the relationships between mathematics, theoretical and experimental physics are quite remarkable. This understanding is exemplified in his work on parabolas, where he stated that the parabola was the ideal theoretical trajectory for a uniformly accelerated object in motion without the interference of frictional and other forces (Galileo Galilei - Wikipedia 2008). He also understood the limits of theory as he was able to correctly speculate that his theory of parabolas was only accurate on laboratory scales and could not be applied to planetary scale motion (Galileo Galilei - Wikipedia 2008). Furthermore Galileo also understood that mathematical theory and experimentation rarely agree exactly. He was able to hypothesise that such disagreements were due to errors in measurement and the impedance of external forces such as friction (Galileo Galilei - Wikipedia 2008).

Galileo contributed heavily to physics, for example he proposed Galilean relativity, which stated that the same definitions of motion are valid everywhere (Weisstein 2007). The resulting Galilean transformations are correct at low speeds and only need modification for relativistic speeds using the Lorentz transformations (Weisstein 2007). Galileo also stated that continuous motion could only be altered by the application of a force, which was later famously explored in depth by Isaac Newton (Weisstein 2007). Galileo also correctly identified the law for uniform acceleration by stating that the total distance travelled by an object is proportional to the square of time as well as the time law which states that velocity is proportional to time for uniform acceleration (Weisstein 2007).

Astronomy

Galileo was able to construct telescopes based on the crude descriptions of the original telescopes invented in the Netherlands in 1608 (Galileo Galilei - Wikipedia 2008). He began with telescopes that provided 3x magnification and in his latter years was able to develop telescopes with up to 32x magnification (Bellis 2008). His telescopes allowed observation of magnified upright images of the Earth and the sky. At his peak he was one of the few inventors with adequate skills to develop telescopes which allowed for the clear magnification of images. His work in telescopes allowed him to amass wealth through sales to merchants who would use them for shipping (Bellis 2008).

On January the 7th 1610 Galileo was able to observe through his telescope, "three fixed stars" as he described them which were not visible by naked eye due to their smallness, that were all in a short distance from Jupiter and also lying in a "straight line through it" (Bellis 2008). Galileo kept careful observation of the position of these "stars" over the preceding nights and showed that the position of these relative to Jupiter could not be explained if they were really fixed stars as was the thinking of the time (Galileo Galilei - Wikipedia 2008). Furthermore on January the 10th Galileo noticed that one of the "stars" disappeared, and he correctly deduced that this was due to it being hidden by Jupiter (Galileo Galilei - Wikipedia 2008). Galileo within the space of a few days was able to correctly conclude that these "stars" were in fact orbiting Jupiter, and it is now known that he found Jupiter's three largest moons, Io,

Europa and Callisto (Galileo Galilei - Wikipedia 2008). Galileo went on to discover Ganymede on January the 13th (Galileo Galilei - Wikipedia 2008). These four largest satellites went on to be named the Galilean satellites in honour of Galileo by later astronomers.

Galileo's observation that Jupiter had moons orbiting about it upset the accepted geocentric belief of the time that all celestial bodies revolve around a static Earth. As such many of his contemporary astronomers and philosophers refused to believe his discoveries. Galileo continued to carefully observe the satellites of Jupiter over an eighteen month period, and by the middle of 1611 he had obtained very accurate predictions for the periods of Jupiter's moons (Galileo Galilei - Wikipedia 2008).

Galileo was also able to identify other astronomical phenomenon which supported Copernicus's heliocentric model. For example from September 1610 onwards Galileo observed Venus to have a full set of phases similar in the way of the moon (Weisstein 2007). The heliocentric model predicted that all phases should be visible, because when Venus was on the opposite side of the Sun it would cause its illuminated hemisphere to face the Earth and when Venus was on the Earth side of the Sun the illuminated hemisphere would face away from the Earth (Weisstein 2007). However the accepted Ptolemaic model of the universe predict the that only the crescent and new phases of Venus would be observed as Venus was believed to remain between the Earth and Sun during its orbit about the Earth (Galileo Galilei - Wikipedia 2008).

Galileo also contributed to astronomy in many other ways, for example he was one of the first Europeans to observe sunspots. Such was his intellect that he was able to reinterpret a sunspot observation from the time of Charlemagne (747-814AD) which was previously thought to be the motion of Mercury (Galileo Galilei - Wikipedia 2008). In fact the discovery of sunspots had a tumultuous history, due to Galileo and Jesuit Christoph Scheiner bitterly arguing over who was first to discover them. It is now known that both were beaten to the discovery as David Fabricius and his son were in fact the first to observe sunspots (Galileo Galilei - Wikipedia 2008). Galileo was also able to make startling revelations about the surface structure of the moon, as he was the first man to identify lunar craters and mountains using the patterns of light and shadow to infer his conclusions (Galileo Galilei - Wikipedia 2008). He was even able to identify the heights of the mountains from his observations. These lunar observations lead him to the idea that the Moon surface was rough like that of the Earths rather than a perfect sphere as Aristotle had proclaimed (Galileo Galilei - Wikipedia 2008). Galileo also observed the Milky Way galaxy (our galaxy), which had always been thought to be a nebulous and found that it had many stars packed closely together that made it look as if it were a cloud from Earth (Galileo Galilei - Wikipedia 2008). He went on to discover many stars which were too dim to be visible by naked eye and unknowingly discovered Neptune in 1612 (Galileo Galilei - Wikipedia 2008). He did not realise it was a planet but rather wrote in his notebook that it was just another dim star in the night sky.

Controversy

The Christian bible has many references to the way in which it believes the universe to be modelled, some examples include:

Psalm 93:1 - “the world is firmly established, it cannot be moved”
(Galileo Galilei - Wikipedia 2008)

Psalm 104:5 - “the Lord set the Earth on its foundations, it can never
be moved” (Galileo Galilei - Wikipedia 2008)

These passages if understood literally imply that the Earth is fixed and is the centre of the universe, with all other celestial bodies orbiting about it, following the Ptolemaic model of the universe. However, Galileo who was a passionate Catholic implored people to understand that the solar system was heliocentric, and that this belief did not go against Scripture. He believed in the view of Augustine, a Christian bishop during the 4th and 5th century, who believed that not every passage in Scripture was to be taken literally (Bellis 2008). This was especially true when the Scripture that references the Earth was Psalms which is a book of songs and poetry rather than a history of creation (Galileo Galilei - Wikipedia 2008). The writers of such Scripture wrote from a terrestrial viewpoint where it seemed that the sun rises in the morning and sets at night.

Personal attacks on Galileo reached their peak during 1616, and Galileo travelled to Rome to persuade the Church authorities who controlled science and information at the time to not ban his astronomical ideas (Galileo Galilei - Wikipedia 2008). At this time there existed an Inquisition, which was a Roman Catholic tribunal which passed down judgment of heresy against individuals or ideas.

On the orders of the Inquisition Cardinal Bellarmine, instructed Galileo to not “hold or defend” the idea that the Earth moves and that the sun was stationary at the centre. On these orders Galileo stayed away from controversy and disputes for many years (Galileo Galilei - Wikipedia 2008). However in 1623 Cardinal Barberini a friend of Galileo was elected as Pope Urban VIII. This gave Galileo the freedom that he sought to revive his theories and he wrote a book entitled *Dialogue Concerning the Two Chief World Systems* in 1632, which was given authorisation from the Inquisition and the Pope (Galileo Galilei - Wikipedia 2008). Pope Urban VIII asked Galileo to give arguments supporting both heliocentrism and geocentrism in his book and to make sure that he did not support one view over the other (Galileo Galilei - Wikipedia 2008). Pope Urban VIII also made the request that the book expresses his own views on the matter (Galileo Galilei - Wikipedia 2008). Galileo only carried out the latter request, and the book was made to appear as if it advocated heliocentrism. This was because Galileo wrote under the guise of a fictional character Simplicio when supporting the Aristotelian view in his book (Bellis 2008). The fictional Simplicio often made errors and came across as a man of little intelligence (Bellis 2008). Furthermore Galileo expressed the words of Pope Urban VIII, under the guise of Simplicio (Bellis 2008). The Pope did not take the public ridicule lightly or the fact that Galileo had not carried out his primary request of



Figure 2: Galileo facing the Roman Inquisition, painted by Cristiano Banti

keeping the book unbiased (Bellis 2008). Galileo lost a friend in Pope Urban VIII and as such was once again called to Rome to answer to the Inquisition (Bellis 2008).

In 1633 Galileo travelled to Rome and stood trial on the suspicion of heresy (Galileo Galilei - Wikipedia 2008). He was found guilty and his sentence carried three major rulings (Galileo Galilei - Wikipedia 2008). The first was that Galileo was ordered to renounce his belief that the Sun is stationary at the centre of the universe and that the Earth is not at the centre but rather moves about the sun (Galileo Galilei - Wikipedia 2008). They imparted a rule for future trials that the idea that the Sun is stationary was to be condemned and its belief was heretical (Galileo Galilei - Wikipedia 2008). The Inquisition pronounced the following:

“The proposition that the sun is in the centre of the world and immovable from its place is absurd, philosophically false, and formally heretical; because it is expressly contrary to Holy Scriptures.”
(Halsall 1999)

Galileo was also ordered to be imprisoned, but his sentence was reduced later to that of house arrest. Galileo's book *Dialogue Concerning the Two Chief World Systems* was banned and although it was not formally announced at the trial all his future work would be banned from publication (Galileo Galilei - Wikipedia 2008).

Galileo was eventually allowed by the Inquisition to return to his villa in Florence in 1638 to be closer to his doctors (Helden 1995), where he spent the rest of his life under house arrest. Whilst under house arrest Galileo spent his time on one of his greatest texts, *Discourses and Mathematical Demonstrations Relating to Two New Sciences* (Helden 1995). This text summarised the work he had done in the fields of kinematics and material strength over forty years before (Helden 1995). This text is widely regarded as the reason that Galileo is accredited with the title of the father of modern science.

On the 8th of January 1642 Galileo died and the Grand Duke of Tuscany, Ferdinando II wanted him to be buried in the main body of the Basilica of Santa Croce, next to Galileo's father and ancestors (Galileo Galilei - Wikipedia 2008). This wish was not granted under the orders of Pope Urban VIII, however in 1737 he was reburied in the main body of the Basilica after a monument was put up to honour his accomplishments (Galileo Galilei - Wikipedia 2008). In 1718 the ban on the publication of Galileo's work was lifted, except for *Dialogue Concerning the Two Chief World Systems* (Galileo Galilei - Wikipedia 2008). In 1741 Pope Benedict XIV allowed the publication of an edition of Galileo's full scientific work including a censored version of the *Dialogue* (Galileo Galilei - Wikipedia 2008). In 1939 Galileo was vindicated when Pope Pius XII in his first speech to the Pontifical Academy of Sciences described Galileo as being among the

"most audacious heroes of research... not afraid of the stumbling blocks and the risks on the way, nor fearful of the funereal monuments" (Galileo Galilei - Wikipedia 2008)

Such was the Churches stubbornness that it was not until the 31st of October 1992 when Pope John Paul II expressed regret over how Galileo was treated and officially

accepted that the Earth was not stationary (Bellis 2008). Galileo has truly contributed to science, astronomy and physics. He was a man of remarkable talent and intellect and is the one of the proponents of how science has advanced so rapidly over the last 400 years. He will always be remembered for his contributions and his struggles to fight for what he believed in.

References

Augustine of Hippo – Wikipedia, the free encyclopaedia 25 April 2008, *Augustine of Hippo*, Wikimedia Foundation. Available from: <http://en.wikipedia.org/wiki/Augustine_of_Hippo> [25 April 2008].

Bellis, M 2008, *Galileo Galilei - Biography*, The New York Times Company. Available from: <<http://inventors.about.com/library/inventors/blgalileo1.htm>> [25 April 2008].

Charlemagne – Wikipedia, the free encyclopaedia 24 April 2008, *Augustine of Hippo*, Wikimedia Foundation. Available from: <<http://en.wikipedia.org/wiki/Charlemagne>> [25 April 2008].

Galileo Galilei – Wikipedia, the free encyclopaedia 25 April 2008, *Galileo Galilei*, Wikimedia Foundation. Available from: <http://en.wikipedia.org/wiki/Galileo_Galilei> [26 April 2008].

Halsall, P January 1999, *Modern History Sourcebook: The Crime of Galileo: Indictment and Abjuration of 1633*, Available from: <<http://www.fordham.edu/halsall/mod/1630galileo.html>> [23 April 2008].

Inquisition – Wikipedia, the free encyclopaedia 25 April 2008, *Inquisition*, Wikimedia Foundation. Available from: <<http://en.wikipedia.org/wiki/Inquisition>> [26 April 2008].

Nicolaus Copernicus – Wikipedia, the free encyclopaedia 26 April 2008, *Nicolaus Copernicus*, Wikimedia Foundation. Available from: <http://en.wikipedia.org/wiki/Nicolaus_Copernicus> [26 April 2008].

Stillman, D 1957, *Discoveries and Opinions of Galileo*, Doubleday & Co, New York.

Van Helden 1995, *The Galileo Project*, Available from: <<http://galileo.rice.edu/>> [25 April 2008].

Weisstein, E 2007, *Galileo Galilei (1564-1642)*, Wolfram Research. Available from: <<http://scienceworld.wolfram.com/biography/Galileo.html>> [25 April 2008].