- **Galileo Galilei**'s was the first child of Vincenzo Galilei and Guilia Ammannati.

- When Galileo was about 12 he decided to become a monk, but this did not please his father who had already decided that his eldest son should become a medical doctor.

- In 1581 Vincenzo sent Galileo back to Pisa to enroll for a medical degree at the University of Pisa. Galileo never seems to have taken medical studies seriously, attending courses on his real interests which were in mathematics and natural philosophy. His mathematics teacher at Pisa was Filippo Fantoni, who held the chair of mathematics. Galileo returned to Florence for the summer vacations and there continued to study mathematics.

- In the year 1582-83 Ostilio Ricci, who was the mathematician of the Tuscan Court, taught a course on Euclid's *Elements* at the University of Pisa which Galileo attended. During the summer of 1583 Galileo was back in Florence with his family and invited Ricci to his home to meet his father. Ricci tried to persuade Vincenzo to allow his son to study mathematics since this was where his interests lay. Certainly Vincenzo did not like the idea and resisted strongly but eventually he gave way a little and Galileo was able to study the works of Euclid and Archimedes from the Italian translations which Tartaglia had made. Of course he was still officially enrolled as a medical student at Pisa but eventually, by 1585, he gave up this course and left without completing his degree.

- Galileo began teaching mathematics, first privately in Florence and then during 1585-86 at Siena where he held a public appointment. During the summer of 1586 he taught at Vallombrosa, and in this year he wrote his first scientific book *The little balance* [La Balancitta] which described Archimedes' method of finding the specific gravities (that is the relative densities) of substances using a balance. In the following year he traveled to Rome to visit Clavius who was professor of mathematics at the Jesuit College Romano there. A topic which was very popular with the Jesuit mathematicians at this time was centers of gravity and Galileo brought with him some results which he had discovered on this topic. Despite making a very favorable impression on Clavius, Galileo failed to gain an appointment to teach mathematics at the University of Bologna.

- Fantoni left the chair of mathematics at the University of Pisa in 1589 and Galileo was appointed to fill the post. The young mathematician had rapidly acquired the reputation that was necessary to gain such a position, but there were still higher positions at which he might aim. Galileo spent three years holding this post at the University of Pisa and during this time he wrote *De Motu* a series of essays on the theory of motion which he never published. It is likely that he never published this material because he was less than satisfied with it, and this is fair for despite containing some important steps forward, it also contained some incorrect ideas. Perhaps the most important new ideas which *De Motu* contains is that one can test theories by conducting experiments. In particular the work contains his important idea that one could test theories about falling bodies using an inclined plane to slow down the rate of descent.

- In 1591 Vincenzo Galilei, Galileo's father, died and since Galileo was the eldest son he had to provide financial support for the rest of the Being professor of mathematics at Pisa was not well paid, so Galileo looked for a more lucrative post. With strong recommendations from Guidobaldo del Monte, Galileo was appointed professor of mathematics at the University of the Republic of Venice in 1592 at a salary of three times what he had received at Pisa. At Padua his duties were mainly to teach Euclid's geometry and standard (geocentric) astronomy to medical students, who would need to know some astronomy in order to make use of astrology in their medical practice. However, Galileo argued against Aristotle's view of astronomy and natural philosophy in three public lectures he gave in connection with the appearance of a New Star (now known as 'Kepler's supernova') in 1604. The belief at this time was that of Aristotle, namely that all changes in the heavens had to occur in the lunar region close to the Earth, the realm of the fixed stars being permanent. Galileo used parallax arguments to prove that the New Star could not be close to the Earth. In a personal letter written to Kepler in 1598, Galileo had stated that he was a Copernican

(believer in the theories of Copernicus). However, no public sign of this belief was to appear until many years later.

- We mentioned above an error in Galileo's theory of motion as he set it out in *De Motu* around 1590. He was quite mistaken in his belief that the force acting on a body was the relative difference between its specific gravity and that of the substance through which it moved. Galileo wrote to his friend Paolo Sarpi, a fine mathematician who was consulter to the Venetian government, in 1604 and it is clear from his letter that by this time he had realized his mistake. In fact he had returned to work on the theory of motion in 1602 and over the following two years, through his study of inclined planes and the pendulum, he had formulated the correct law of falling bodies and had worked out that a projectile follows a parabolic path. However, these famous results would not be published for another 35 years.

- In May 1609, Galileo received a letter from Paolo Sarpi telling him about a spyglass that a Dutchman had shown in Venice. Galileo wrote in the *Starry Messenger* (Sidereus Nuncius) in April 1610:-

- From these reports, and using his own technical skills as a mathematician and as a craftsman, Galileo began to make a series of telescopes whose optical performance was much better than that of the Dutch instrument. His first telescope was made from available lenses and gave a magnification of about four times. To improve on this Galileo learned how to grind and polish his own lenses and by August 1609 he had an instrument with a magnification of around eight or nine. Galileo immediately saw the commercial and military applications of his telescope for ships at sea. A demonstration for the Venetian Senate gave Galileo gave the sole rights for the manufacture of telescopes to the Venetian Senate. It seems a particularly good move on his part since he must have known that such rights were meaningless, particularly since he always acknowledged that the telescope was not his invention!

- By the end of 1609 Galileo had turned his telescope on the night sky and began to make remarkable discoveries. *In about two months, December and January, he made more discoveries that changed the world than anyone has ever made before or since.*

- The astronomical discoveries he made with his telescopes were described in a short book called the *Starry Messenger* published in May 1610. Galileo claimed to have seen mountains on the Moon, to have proved the Milky Way was made up of tiny stars, and to have seen four small bodies orbiting Jupiter.

- Galileo first turned his telescope on Saturn on 25 July 1610 and it appeared as three bodies (his telescope was not good enough to show the rings but made them appear as lobes on either side of the planet). Continued observations were puzzling indeed to Galileo as the bodies on either side of Saturn vanished when the ring system was edge on. Also in 1610 he discovered that, when seen in the telescope, the planet Venus showed phases like those of the Moon, and therefore must orbit the Sun not the Earth. This did not enable one to decide between the Copernican system, in which everything goes round the Sun, and that proposed by Tycho Brahe in which everything but the Earth (and Moon) goes round the Sun which in turn goes round the Earth. Most astronomers of the time in fact favored Brahe's system and indeed distinguishing between the two by experiment was beyond the instruments of the day. However, Galileo knew that all his discoveries were evidence for Copernicanism, although not a proof. In fact it was his theory of falling bodies which was the most significant in this respect, for opponents of a moving Earth argued that if the Earth rotated and a body was dropped from a tower it should fall behind the tower as the Earth rotated while it fell. Since this was not observed in practice this was taken as strong evidence that the Earth was stationary. However Galileo already knew that a body would fall in the observed manner on a rotating Earth.

- Other observations made by Galileo included the observation of sunspots. Although Galileo put forward many revolutionary correct theories, he was not correct in all cases. In particular when three comets appeared in 1618 he became involved in a controversy regarding the nature of comets. He argued that they were close to the Earth and caused by optical refraction. A serious consequence of this unfortunate argument was that the Jesuits began to see Galileo as a dangerous opponent.
- Despite his private support for Copernicanism, Galileo tried to avoid controversy by not making public statements on the issue. However he was drawn into the controversy through Castelli who had been appointed to the chair of mathematics in Pisa in 1613. Castelli had been a student of Galileo's and he was also a supporter of Copernicus. At a meeting in the Medici palace in Florence in December 1613 with the Grand Duke Cosimo II and his mother the Grand Duchess Christina of Lorraine, Castelli was asked to explain the apparent contradictions between the Copernican theory and Holy Scripture. Castelli defended the Copernican position vigorously and wrote to Galileo afterwards telling him how successful he had been in putting the arguments. Galileo, less convinced that Castelli had won the argument, wrote *Letter to Castelli* to him arguing that the Bible had to be interpreted in the light of what science had shown to be true. Galileo had several opponents in Florence and they made sure that a copy of the *Letter to Castelli* was sent to the Inquisition in Rome. However, after examining its contents they found little to which they could object.
- The Catholic Church's most important figure at this time in dealing with interpretations of the Holy Scripture was Cardinal Robert Bellarmine. He seems at this time to have seen little reason for the Church to be concerned regarding the Copernican theory. The point at issue was whether Copernicus had simply put forward a mathematical theory which enabled the calculation of the positions of the heavenly bodies to be made more simply or whether he was proposing a physical reality. At this time Bellarmine viewed the theory as an elegant mathematical one which did not threaten the established Christian belief regarding the structure of the universe.
- In 1616 Galileo wrote the *Letter to the Grand Duchess* which vigorously attacked the followers of Aristotle.. In this Galileo stated quite clearly that for him the Copernican theory is not just a mathematical calculating tool, but is a physical reality:-

- Pope Paul V ordered Bellarmine to have the Sacred Congregation of the Index decide on the Copernican theory. The cardinals of the Inquisition met on 24 February 1616 and took evidence from theological experts. They condemned the teachings of Copernicus, and Bellarmine conveyed their decision to Galileo who had not been personally involved in the trial. Galileo was forbidden to hold Copernican views but later events made him less concerned about this decision of the Inquisition. Most importantly Maffeo Barberini, who was an admirer of Galileo, was elected as Pope Urban VIII. This happened just as Galileo's book *Il saggiatore* (The Assayer) was about to be published by the Accademia dei Lincei in 1623 and Galileo was quick to dedicate this work to the new Pope. The work described Galileo's new scientific method and contains a famous quote regarding mathematics:-
- Pope Urban VIII invited Galileo to papal audiences on six occasions and led Galileo to believe that the Catholic Church would not make an issue of the Copernican theory. Galileo, therefore, decided to publish his views believing that he could do so without serious consequences from the Church. However by this stage in his life Galileo's health was poor with frequent bouts of severe illness and so even though he began to write his famous *Dialogue* in 1624 it took him six years to complete the work.
- Galileo attempted to obtain permission from Rome to publish the *Dialogue* in 1630 but this did not prove easy. Eventually he received permission from Florence, and not Rome. In February 1632 Galileo published *Dialogue Concerning the Two Chief Systems of the World - Ptolemaic and Copernican*. It takes the form of a dialogue between Salviati, who argues for the Copernican system, and Simplicio who is an Aristotelian philosopher. The climax of the book is an argument by Salviati that the Earth moves which was based on Galileo's theory of the tides. Galileo's theory of the tides was entirely false despite being postulated after Kepler had already put forward the correct explanation. It was unfortunate, given the remarkable truths the *Dialogue* supported, that the argument which Galileo thought to give the strongest proof of Copernicus's theory should be incorrect.

- Shortly after publication of *Dialogue Concerning the Two Chief Systems of the World - Ptolemaic and Copernican* the Inquisition banned its sale and ordered Galileo to appear in Rome before them. Illness prevented him from traveling to Rome until 1633. Galileo's accusation at the trial which followed was that he had breached the conditions laid down by the Inquisition in 1616. However a different version of this decision was produced at the trial rather than the one Galileo had been given at the time. The truth of the Copernican theory was not an issue therefore; it was taken as a fact at the trial that this theory was false. This was logical, of course, since the judgment of 1616 had declared it totally false.
- Found guilty, Galileo was condemned to lifelong imprisonment, but the sentence was carried out somewhat sympathetically and it amounted to house arrest rather than a prison sentence. He was able to live first with the Archbishop of Siena, then later to return to his home in Arcetri, near Florence, but had to spend the rest of his life watched over by officers from the Inquisition. In 1634 he suffered a severe blow when his daughter Virginia, Sister Maria Celeste, died. She had been a great support to her father through his illnesses and Galileo was shattered and could not work for many months. When he did manage to restart work, he began to write *Discourses and mathematical demonstrations concerning the two new sciences.*
- After Galileo had completed work on the *Discourses* it was smuggled out of Italy, and taken to Leyden in Holland where it was published. It was his most rigorous mathematical work which treated problems on impetus, moments, and centres of gravity. Much of this work went back to the unpublished ideas in *De Motu* from around 1590 and the improvements which he had worked out during 1602-1604. In the *Discourses* he developed his ideas of the inclined plane writing:-
- He then described an experiment using a pendulum to verify his property of inclined planes and used these ideas to give a theorem on acceleration of bodies in free fall:-
- *The time in which a certain distance is traversed by an object moving under uniform acceleration from rest is equal to the time in which the same distance would be traversed by the same movable object moving at a uniform speed of one half the maximum and final speed of the previous uniformly accelerated motion.*
- After giving further results of this type he gives his famous result that the distance that a body moves from rest under uniform acceleration is proportional to the square of the time taken.
- One would expect that Galileo's understanding of the pendulum, which he had since he was a young man, would have led him to design a pendulum clock. In fact he only seems to have thought of this possibility near the end of his life and around 1640 he did design the first pendulum clock. Galileo died in early 1642 but the significance of his clock design was certainly realized by his son Vincenzo who tried to make a clock to Galileo's plan, but failed.
- It was a sad end for so great a man to die condemned of heresy. His will indicated that he wished to be buried beside his father in the family tomb in the Basilica of Santa Croce but his relatives feared, quite rightly, that this would provoke opposition from the Church. His body was concealed and only placed in a fine tomb in the church in 1737 by the civil authorities against the wishes of many in the Church. On 31 October 1992, 350 years after Galileo's death, Pope John Paul II gave an address on behalf of the Catholic Church in which he admitted that errors had been made by the theological advisors in the case of Galileo. He declared the Galileo case closed, but he did not admit that the Church was wrong to convict Galileo on a charge of heresy because of his belief that the Earth rotates round the sun