Galileo Galilei

Zenith Purisha

Contents

1 Background

1.1 Galileo Galilei's Childhood

A 'father of modern observational astronomy', the 'father of modern physics', the 'father of science', and 'the father of modern science', those are predicate for Galileo Galilei. He was born on February 15, 1564 in Pisa. When he was eight, his parents left him in Pisa to be taken care by his aunt and uncle while they returned to Florence. When he turned to ten years old, he rejoined his parents in Florence. After he took some basic education in Florence, he also learnt the Latin classics at a monastery at Vallombrosa (20 miles east of the city). He was also so skilled in drawing and in playing the lute. Galileo was attracted by the peacefulness in monastery circumference. So then he decided to study for the priesthood. When Galileo was fifteen, his father, Vincenzio Galilei withdrew him from the monastery because his father wish that he could be a doctor as it would bring a good income for the family.

1.2 Galileo in college

Galileo was growing as a good Catholic and and started studied medicine at the University of Pisa as his father asked in 1581. Unfortunately, Galileo had no passion in studying medicine. Galileo was pretending to study the medicine since he was very interested to study mathematics and natural philosophy. He met the grand duke's mathematician, Ostillio Ricci. Ricci had lent Galileo mathematical texts by Euclid and Archimedes (Greek masters of 2000 years earlier). Galileo had been finishing pretending passing the medicine and philosophy for three months after Ricci convinced Vincenzio that Galileo had real talent in mathematics and would probably not succeeded as a doctor. A furious father that came to Florence then grudgingly accept what Ricci said and gave an opportunity and one year fund support to Galileo to study mathematics. Galileo Galilei was quite optimistic to show his father to be a really good mathematician and become as famous as a doctor. Maybe MORE FAMOUS!

In that time, universities only trained men for three professions: theology, law, and medicine. However, all students was obligatory to study philosophy along with their professional training. The philosophy study was concentrated on the writings of Aristotle. This Greek had given a number of works which covered the knowledge at his time. in 1300, one of the scholars, Thomas Aquinas an Italian Dominican friar and Catholic priest revised part of the Aristotle's writings to be adapted to Christian teachings. Thereupon, they were used for the foundation in universities studies for more than 300 years.

All of Aristotle's ideas and these lectures had been studied by Galileo in Pisa. They used the framework for knowing the world which was the common way of educated people all over Europe. The churches at that time, both Catholic and Protestant, gave the support of authority for them. However, Galileo neglected accepting those ideas which came from say-so dull professors and an old Greek who had died 2000 years earlier. He followed the example of his father that wrote an important nook that contradicts the traditional theories of music. Somehow Galileo had influenced the attitude of Vincenzio of attending to the real experience instead of oversimplified theory.

In the late winter 1583, Galileo found a way to learn much more interesting that Aristotle's. He was caught in learning a logic of the geometry of Euclid. Only few study of mathematics that was discussed in the curriculum of the Faculty of Arts and Medicine. It was more taught about the Tuscan court. Every year the grand duke and his retinue dispatched the period between Christmas ad Easter in Pisa.

However, even thought Ricci, the court mathematician, was an acquaintance of Galileo's father, but Vinzencio tried to keep his son from mathematics since he considered that suppress the music theory. When Galileo was away from his father, he visited Ricci in the court and found out the mathematics of Euclid. Euclid's geometry had been the standard textbook of mathematics since about 300 BC which was written in Alexandria. Its compelling logic impressed Galileo and it might be that his feeling was the same as Thomas Hobbes's did 45 years later. Thomas Hobbes was an important English philosopher and had reaction of Euclid's geometry which was recorded in a contemporary sketch of his life:

He was 40 years old before he saw any Geometry, and it happened by accident. Waiting in a gentleman's library one day, Thomas Hobbes saw Euclid's Elements lying open at the Pythagorean theorem (Book 1, Proposition 47). He read the statement of the theorem. By G–, he said (from time to time he would swear for emphasis) ***this is impossible!*** *So he read the theorem through, and found it referred him back to earlier ones; which he also read. And so on, until at last he was thoroughly convinced of the truth of the original theorem. That made him in love with Geometry.*

Hobbes then fell in love with Geometry. Twenty years later, he became a mathematical tutor for the Prince of Wales (later Charles II). So did Galileo, twenty years after he encountered with geometry, he tutored mathematics to the heir of the grand duchy of Tuscany. Ricci gave some instructions to Galileo and lent him books to continue by Galileo. Ricci had been devoting his all energy to study the geometry. He also introduced Galileo to the writings of Archimedes, the greatly mathematician of ancient times. From Archimedes writings, Galileo learned how to implement geometrical reasoning to real object like levers and floating bodies.

Galileo had been staying in Pisa until spring 1585. He skipped the exam and then left the university without a degree. He set off to earn his living as a mathematician. Occasionally, he managed to get assignments as a private tutor. The rest of the time, he was continuing learning the work of Archimedes and tried to extend the ideas. At some point, he managed to build a theorem to improve the calculations which is used in finding the gravity of solids, and object balances on its gravity center. For a complicated shape, this calculation is a robust mathematical problem.

To some mathematicians, Galileo sent his theorem to get their approval and support. One of them was a noble-man in Urbino, Guidobaldo del Monte. His brother was a cardinal prominent in the affairs of Florence. They saw the talent of Galileo and gave him a position in teaching in mathematics full time. In the fall 1587, Galileo traveled to Rome to meet Christoph Clavius, the chief of the Roman College (*Collegio Romano*), the Jesuit's paramount training center. Clavius was famed for his work in creating the Gregorian calendar. In 1582, the Church under Pope Gregory XIII did a revision to the calendar to conform closer to the actual length of the year. The number of leap years was decreased a little and ten days were omitted from October 1582. Since Clavius was so impressed by Galileo, then he wrote Galileo a recommendation letter.

1.3 Career in universities

In the fall 1589, from his sponsor, he could come back to University of Pisa to teach mathematics. He belonged to the same staff as his old professors after four years leaving without degree. His salary was 60 florins a year, while philosophy professors got 600 or more florins. In modern terms, Galileo's salary would be around $ 10,000 while the prominent professors earns around $ 100,000 a year. His duties in teaching were not heavy. He used his spare time to implement the Archimedes methods to study the moving bodies. A He argued what Aristotle said that a heavy object would fall faster that the lighter one since weight of an object is caused the rate of the falling object. Galileo did an observation that Aristotle's theory contradicted experience. Even though he found that there were some difference rate of falling object, but he thought that it was caused by the buoyancy of the air. He was then extending Archimedes's idea about the buoyancy of water.

He began his career as lonely mathematician at University of Pisa. He created a thermoscope, a pioneer of thermometer and when he was twenty four, Galileo published a book about hydrostatic scale which then brought him to the attention of scientific world.

At the beginning of century, physics is treated as natural philosophers in the universities. Many kinds of knowledge are treated as aspects of philosophy.

The general principles are used to explain nature, religion, and society. Along the time it belonged to it anymore. Galileo and others proposed new methods to examine the world of nature. The came out as experimenters in scientist communities. They added experiments, measurements, and calculations so then take the study of nature belonged to science. Galileo who worked in physics contributed a lot to make measurement in experiment and calculations in mathematics much more prominent in all sciences.

The methods of measuring and calculating that Galileo used to study nature on earth are still used today. He implemented these methods in his study of motions, for example falling stone, swinging pendulum and comparing with his heartbeat which he found that the time of swinging back and forth of the pendulum is the same as the heartbeat. Galileo has interests in knowing how objects move because he found Aristotle taught about motion in unconvinced because Aristotle was only concentrating on why objects move. Based on that reason, Galileo did a transformation Aristotle's logic of nature into mathematical point of view and also experimental physics.

Galileo moved to University of Padua in December 1592 and began to teach mechanics, geometry, astronomy. When his age was 18 years old, he claimed that the later was the best eighteen years of his life. He met some colleagues who are very important in keeping active in mind and began lifelong friendship. Paolo Sarpi (a member of a small order of Catholic priests), Giovanfrancesco Sagredo (a young Venetian aristocrat), Benedetto Castelli (a member of the Benedictine order), Cesare Cremonini are both Galileo's colleagues and good friends. They were collaborating on several scientific research.

In University of Padua, Galileo got salary 180 florins a year. As his contract was renewed in 1599, he earned 320 florins and in 1606 his salary was increased again up to 520 florins.This funds are use to support himself and also his family back in Florence. Also, he had also still debt fro about 1,000 florins for his sister Virginia's dowry. In 1601, Livia, his younger sister, married Taddeo Galletti and her dowry gave another burden for Galileo. He borrowed 600 florins for the down payment and had contracted to pay Galletti 200 florins a year for five years. It was more that half his annual salary.

1.4 Relationship

Galileo was quite often visiting Venice for his social activities, went around many beautiful palaces along the Grand Canal by taking the gondola. There he met a Venetian woman, Marina Gamba and fell in love with her. Even though they are not married, the have three children: Virginia (born in August 1600), Livia (born in August 1601), and Vincenzio (born in August 1606).

1.5 Galileo on Trial

In 22 June, 1633. The Dominican convent of Santa Maria sopra Minerva in Rome. A white -robed penitent kneeled prior to seven Cardinal-Inquisitors and reads a ready-confession:

I, Galileo, son of the Vincenzio Galilei of Florence, seventy years of age,...swear that I have always believed, and will continue to believe all that Holy Catholic and Apostolic Church holds, preaches, and teaches,...

I have been judged strongly suspected of heresy, in having held and believed that the sun is motionless in the center of the world, and the earth is not the center and moves...

With a sincere heart and unfeigned faith, I abjure, curse, and detest there above-named errors and heresies ... I swear that in future I will never again say or assert, orally or in writing, anything that may cause a similar suspicion about me.

How can Galileo do this? We need to come back to the year 1610. In mid-1613, Galileo who had influenced at the court, persuaded Cosimo II to appoint his colleague Benedetto Castelli as a professor of mathematics in University of Pisa. The university warned Castelli not to teach the idea of Copernican about earth's motion. In December, when Castelli was invited to have breakfast with the grand duke and his family, the grand duchess Christina give a question to Castelli about if the idea of moving-earth is contradicted with the Bible.

After Castelli told Galileo about this, then Galileo claimed by sending Castelli a long letter that religion and science should not be mixed. He said that God authored the Holy Scriptures and the Book of Nature, and he considered that both are equally true. He considered that sometimes the language in the Bible has been adjusted to match with common understanding but not for the Nature. If Nature show that the earth is moving, the we cannot elude it.

Castelli made some copies of this letter and distributed them to his friends. Unfortunately, one of the letter came to Galileo's opponents in the Pigeon League. Then in December 1614, the league met the priest, Tommaso Caccini, to preach against Galileo and this theory. With this sermon, the Pigeon League members made a tactics against Galileo. Since they could not discredit Galileo in point of view of philosophy, they moved to religion. Not more than two months, after Caccini's sermon, Father Niccolo Lorini (a fellow Dominican in Florence) sent a copy of Galileo's letter to Castelli to the Inquisition in Rome and Lorini said that the Dominicans felt that the letter contained heretical pronouncement against the Christian faith.

In December 1615, Galileo traveled to Rome to protect himself from authorities which can charge him with heresy. In Rome, he gave explanations about his idea of moving-earth in many occasion, his logic overwhelmed his audience but his opponents. Pope Paul V asked Cardinal Belarmino to warn Galileo to abandon his Copernican opinions (Galileo said that Copernicus had suggested that the earth could be moving even though we do not feel it) and never again "to hold, teach, or defend it in any way whatever, whether orally or in writing." Then Galileo returned to Florence and continued studying about longitudes and motion.

Cosimo II died in 1621 and in 1623 a new pope was elected. Cardinal Maffeo Barberini become Pope Urban VIII in August. Galileo went to Rome in spring 1624 to give homage for the new pope and he got permission from pope to write about the Copernican system comparing to Ptolemy's. Galileo started to do a great work by writing a dialogue among three characters to explain the details of Copernican hypothesis. He used the name Salviati (his great good friend) as Copernicus, Simplicio (ancient commentator of Aristotles) as Aristotelians, and Sagredo (Galileo's Venetian friend) as men of common sense. He had been writing it for about 5 years (1625 - 1630).

In February 1632, the book called *Dialogue* were printed a thousand copies. Galileo's enemies whispered into Urban that Galileo made fun of him by using Simplicio in the *Dialogue*. Then, a month later, Galileo was reported by the committee to the Inquisition that he should be called into account.

Galileo died in January 8, 1642 and the ceremony was only little in a small crypt in Santa Croce chapel in Florence.

2 Science

2.1 Equals Speed of Fall

The Greek Aristotle had claimed that heavy objects fall faster than lighter ones. In Galileo's time, philosophers still believed it. But Galileo came to doubt. He still remembered in watching the hailstones when he was young. He saw that all of the hailstones, with different size, are hitting the ground at the same time and so Galileo decided that they were falling at the same speed. What he could not believe was that they fell at different speed, then they would always start out at just the right times and places to ground together.

Galileo gave an argument in his essay *On Motion* that objects which have different weights fall at the same rate. It means, their weight does not influence the speed of the falling objects. Galileo gave an illustration by having two objects with different weights, let say 1 pound and 5 pounds. If they are dropped from a height of 100 feet, the Aristotle's followers would say when the heavier block hits the ground, the lighter one would not hit the ground but only fall at 20 feet height because the weights determine the speeds of the blocks.

Galileo then asked, what would Aristotle determined the speed of fall to be if the two blocks were tied together? Probably, in one hand he would say they the 1-pound block when sustains the 5-pound block. Consequently, the combined-two-blocks would fall slower than the 5-pound block by itself. But another hand, by Aristotle's rule, the combination weighs 6 pounds blocks should fall faster than 5-pound block. The contradiction appears! Slower or faster?

Galileo wrote:

What clearer proof do we need of the error of Aristotle's opinion? Who, I ask, will not recognize the truth at once, looking at the matter simply and naturally? For, if suppose the blocks equal and close together, all agree they will fall with equal speed. Now imagine them joining together while falling. Why should they double their speed ad Aristotle's claimed?

Therefore, there is no reason why blocks of the same material but of different weights should fall at unequal rates.

Galileo allowed for shape or density to affect the rate of fall through the air. He claimed that a lock of wool and a piece of lead would fall together at the same time in a vacuum. Scientist demonstrated the Galileo's claim with vacuum pump which is invented in 1650.

Also, in August 2, 1971, *Apollo 15* an astronaut David R. Scott showed this test to the moon and this experiment was broadcast live on TV. As the camera rolled, people could see that a feather and a hammer falling side by side to the surface of the airless moon. Colonel Scott then remarked,"This proves that Mr. Galileo was correct."

2.2 Speed and Distance in Falling

Galileo built the measurement and calculations that the distance an object falls from a resting position is increasing as the squared of the elapsed of time. He wanted to describe how the speed increases during a fall. His problem is to find a rule for an object's speed increased as it fell. He did experimental trials to build a theory for the increase in speed since he could not measure the speed. Hence, he had to use a mathematical deduction for the measurements. He assumes a rule of speeds and calculated what distances his rule would come up. The he could check the calculations of the distances against the measured ones.

For some times, Galileo felt that the increase in speed was proportional to the distance of fallen. Then he found out that this is wrong. Later he assumed a new rule, that is the speed increased to elapsed time proportionally. The graph below represents travelled-object at a constant speed of 7 meters per second for 4 seconds. The traveled-distance is

$$7\frac{m}{s} \times 4s = 28m$$

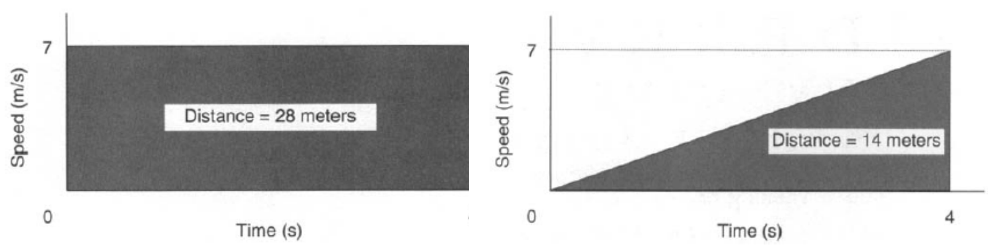


Figure 1: Graph and algebra formula of speed and distance

By multiplying the values of speed and time you will get the distance. If those values are presented by the height and width of a rectangle, then their product produces the area of the rectangle. We could sat the distance is represented by the area on a speed-time graph.

The top-right graph is representing an object adds its speed from 0 to 7 meters per second in 4 seconds uniformly. The 14 meters is the distance-traveled.

1. $v = kt$
2. $d = \frac{1}{2} vt$
3. $d = \frac{1}{2} kt^2$

Figure 2: Graph and algebra formula of speed and distance

The formula below describes the relation between speed, time, and distance, which is written by v, t, and d, where k is the multiplication value which is applied to the time in order getting the speed. For fall near the earth's surface, k is the gravity acceleration $g = 9,8m/s^2$.

By combining equation 1 and 2, we get the equation 3 which shows increased-distance that is proportional to the square of time. This experimental measurements and the graphs are based on the description of accelerated moon which Galileo gave in his book *Two New Science* (1638).

2.3 Tides

Galileo thought that tides that happened in the sea or ocean could be result from the shaking of the earth. It might be the theory of Nicolaus Copernicus is correct that the result is because the motions of the earth respect to its axis and around the sun. Galileo explained the tides phenomenon by combining the earth's daily and annual motions. He wanted to explain it to be entirely mechanical instead of some mysterious force from the mood around the oceans. The detailed description below is a Galileo's initial idea based on four paragraphs of Paolo Sarpi's diary from 1595.

The center of the earth moves forward 1 degree per day in its orbit where 1 degree equals to 60 minutes. Because the diameter of the earth is about 6 minutes of its orbit around the sun, then in one side, a point on its night side advances by twenty percent more than 30 minutes and in the other side, a point on the day said is also late 20 percent. It means that each part of the earth's surface moves now fast, and then average, and then slowly with respect to the stars.

Galileo gave a description by giving an example of water in in a basin. The moving basin that carried water stays behind at the beginning of motion and rises at the rear because the motion is not transferred to it completely. As the basis stop moving, the water continues moving and rising to the front. The movement of the seas is like waters in basins. By combining the action of the daily and annual motions of the earth, these basins move swiftly and there slower. The sea in the earth, which is more that a quarter of the earth's circumference is partly in the earth's swifter motion and partly the slower. The lakes and small seas will not show the tides since the variation of the speed in them in very small. In a large sea, the effect of the tidal effects differ depending on whether their length is along or across the changing motion of the earth.

There are two parts of the composition of the tides of the seas. First, the water falls behind and when the earth speeds up, it rises at the rear. Second, when the earth movement is slower, the water continues moving forward and rises in the front. Both movements are followed by natural tendency of the water to tend to equilibrium. Therefore, after in the sea or ocean will move back and forth at a rate that depends on the diameter of its basin.

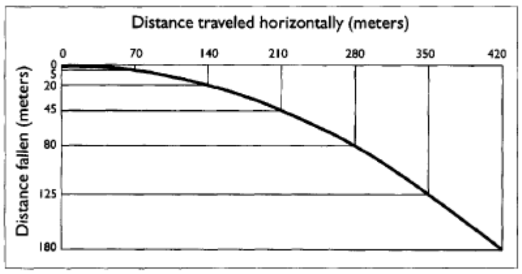
2.4 The Motion of Projectiles

In 1608, Galileo found a way to explain the path of object thrown off at an angle by describing the motion in term of a vertical and a horizontal component. He describe the projectiles motion as cannon shots. In the introduction of his last book *Two New Sciences* (1638), he wrote:

I imagine a moving object projected on a horizontal plane, assuming no impediments. If the plane were of infinite extent, the speed of the object would be constant. But if it ends, and has some elevation, the object (which I conceived being endowed with heaviness), going beyond the end od the plane, will have added to its uniform horizontal motion a downward tendency from its own heaviness. The resulting compound motion, which I call 'projection', will have a definite shape. That is:

'When a projectile is carried in a motion compounded from constant horizontal and naturally downward accelerated motions, it describes a parabolic line in its motion'.

He also provided the diagram as Fig. 3.



Time (s)	Time² (s²)	Vertical distance (m)	Horizontal distance (m)
0	0	0	0
1	1	5	70
2	4	20	140
3	9	45	210
4	16	80	280
5	25	125	350
6	36	180	420

Figure 3: Diagram of fired-projectiles

The normal acceleration of gravity is almost 10 m/sec^2 and the distances the falling object increase proportionally to the square of the elapsed time. For oblique projections, it needs more complicated mathematics, however the projectiles fires at the angle will still form a parabolic path. In this case, these paths do not take into account the air resistance or the curvature of the earth.

2.5 Measuring Motions

One day, Galileo got the inspiration from a ball gather speed when it rolls down in a gently inclined plane. The diameter of the ball is about an inch rolled in a board about six feet long. He observed the distances that passed by the ball in each equal times as a sequence : 1, 3, 5, 7, 9, 11, 13, 15. Galileo found that the successive sums of these numbers were squares of the elapsed times form the initial point. The sums are 1, 4, 9, 16, 25, 36, 49, 64 which are the squares of 1,2,3,4,5,6,7,8. It means that the distances the ball traversed form the beginning is proportional to the squares of the elapsed times. He used a water clock to measure varying time intervals and measured the water in grains. A grain is $\frac{1}{480}$ ounce. He established a unit of time by the rate of the water flow about $\frac{1}{100}$ second. The length unit that he used was very near to one millimeter. The table in Fig. 4 below, which is taken form Galileo's note, has been converted to his measurements to seconds and meters.

Another observation is a swinging pendulum. He tried to swing two identical pendulum, and he found that each complete swing (over and back) takes the same time. The half swing (from releasing to the vertical) take a quarter

Time from start	Distance in unit time	Distance from start
0	0	0
1	1	1
2	3	4
3	5	9
4	7	16
5	9	25
6	11	36
7	13	49
8	15	64

Length of pendulum (m)	Time for a quarter swing (seconds)	Square of the time	Length/time^2
0.818	0.45	0.203	4.03
1.636	0.64	0.410	3.99
[3.272]	[0.90]	[0.810]	[4.04]

Figure 4: Left: Rolling ball. Right: Swing Pendulum.

of the the time for a complete swing. He observes for several full swings and calculated for a quarter swing. Galileo showed that the time for a pendulum 0.818 meters long to be 0.45 seconds and for a pendulum 1.636 meters long took 0.64 seconds.

A pendulum which has a double length takes $\sqrt{2}$ times longer for a quarter swing.

2.6 Optic and Telescope

Galileo reported his sights in the sky which is never seen before in his *Starry Messenger*. He published that the moon is not smooth sphere, but it has uneven boundary and it is because where there are mountains, valleys, and craters on it. This feature cannot be seen by the unaided eye, but Galileo had built a telescope that could magnify them twenty times. He could also marked 80 stars, more than anyone had ever imagined. The telescope even also showed the Milky way to be not just a nebulous patch but clusters of myriads of stars. The most astonishing report is that he could catch the four tiny moons are circling Jupiter on January 13, 1610. Three moons were on the west and one moon on the east.

In the summer 1609, Paolo Sarpin Venice wrote Galileo that spectacle makers in Holland had recently made spyglasses that could magnify the object up to three or four times. Sarpi was confident that Galileo could improve it. In early August, Galileo and his artisan built the convex objective lens weaker that is less curves with a longer focal length and the concave eyepiece stronger.

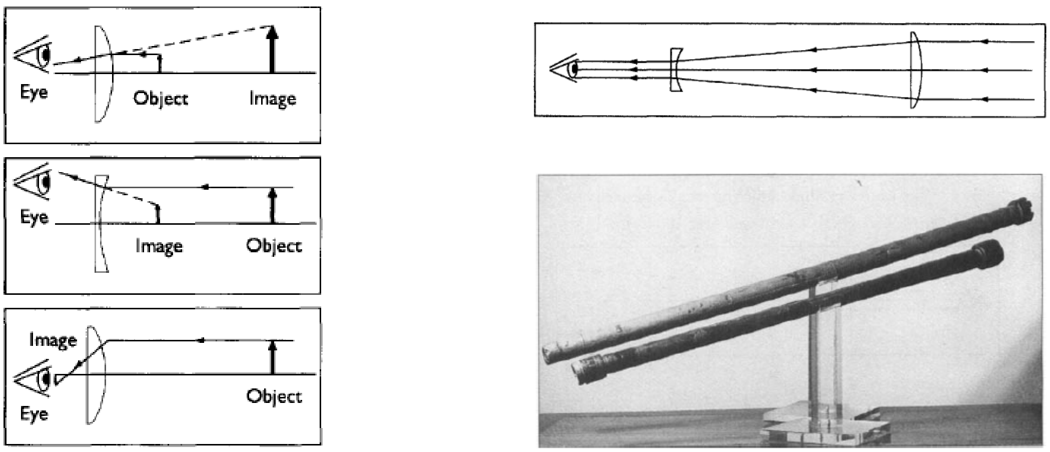


Figure 5: The spyglasses and the illustrations

Lenses are curved pieces of glass that can change the direction of the light. The image of the object will appear larger or smaller when we look through the lens. He used a thinner convex objective lens (a longer focal length of about 4 feet) and shorter for the concave one to improve the original Dutch design. He made his product with a telescope of about twenty power.

2.7 Floating on the Surface of Water

Based on Archimedes' principle of flotation. The force to upward is equal to the weight of the water the object displaces. An object that less dense than the water will submerge only until the object displaces an amount of water to its own weight. An object which has the same density as the water will float with its upper surface level with the water's surface.

The opponents of Galileo that their broad shape causes the water floated is less denser than small chips. Galileo did not agree with this idea that the shape matters with it. He claimed that the flotation principle of Archimedes can still be applied.

Galileo gave some illustrations by presented several experiments (the numbers corresponds with the picture from top to bottom).

1. An object that denser that water, a small chip of ebony, can be putted gently at the surface of the water. The chip will push down a bit into the water and float there if it is not wetted.

2. According to Galileo's idea, the chip 'attaches' to the air within the depression. The combination of the chip and the air gives the same volume as the water displaced. The chip which is included the air is floating because its density equal to water density.

3. An inverted cone will float for the same reason as the chip. The 'attached' air in the space above the base of the flat will reduce the density of the floating cone.

4. The the cone is place on the water in the other way around from the number 3. The wall of the water closes in on the sloping sides of the cone.

5. The amount of the water is small enough in the space around the point to be 'attached' to reduce the cone density so that the cone will float. Because of that, when the cone is placed base down on the water, it sinks.

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