Galileo and the Telescope

by Rupert Holland

Three days before the death of the great Italian Michael Angelo, in the year 1564, there was born in Pisa a boy who was given the name of Galileo Galilei, and who was destined to become one of the greatest philosophers and inventors the world has ever known. He came of a noble family of Florence, which had originally borne the name of Bonajuti, but had later changed it to that of Galilei, and he is usually known by his baptismal name of Galileo, according to the Italian custom of that age. His father was a merchant, engaged in business in Pisa, a man well versed in the Latin and Greek tongues, and well known for his knowledge of mathematics. He was anxious that each of his three sons should have a good education, and so he sent Galileo, his eldest boy, to the famous monastery of Vallombrosa, situated in a beautiful wooded valley not far from Florence. But the father did not intend his son to become a priest, and so, when he found his thoughts tending in that direction, he took him away from the monastery, planning to make him a merchant like himself.

But the mind of the young Galileo was already remarkably acute. He was a good musician, a skilful draughtsman and painter, something of a poet, and had shown considerable talent in designing and building a variety of toy machines. His father soon decided that his son's bent did not lie in the direction of a dealer in cloths, and, casting about for a scientific career, chose that of medicine for Galileo. So he took up this study at the University of Pisa.

One afternoon the youth of eighteen went to the great Cathedral of the city. He knelt to make his devotions. From the roof of the nave hung a large bronze lamp, and as the boy watched he saw an attendant draw the lamp toward him to light it, and then let it swing back again. The swinging caught his attention, and he watched it with more and more interest. At first the arc of the swinging lamp was wide, but gradually it grew less and less. But what struck him as singular was that the oscillations all seemed to be made in the same time. He had no watch, so he put his fingers on his wrist in order to note the pulse-beats. As nearly as he could determine the swings of the lamp as they lessened were keeping the same times.

When he went home he began to experiment with this idea of the swinging lamp, or pendulum as it came to be called, and soon had constructed an instrument which marked with very fair accuracy the rate and variation of the pulse-beats. It was imperfect in many respects, but when he showed it to his teachers at the university they were delighted with it, and it was soon generally used by the physicians of the day under the name of the Pulsilogia.

But, to his father's dismay, the young Galileo did not show great interest in the study of medicine. Instead he spent his time studying the mathematics of Euclid, and from them went on to the writings of Archimedes and the laws of mechanics. These latter absorbed him, and fresh from reading them he constructed for himself a hydrostatic balance, the purpose of which was to ascertain accurately the relative proportions of any two metals in an alloy. He wrote an essay on his invention, and circulated it among his friends and teachers. This added to his reputation as a scientist, but brought him no money. His family were poor, and he needed a means of support, and so he applied for, and after a time obtained, appointment to the post of Professor of Mathematics at the University of Pisa.

For centuries the laws of mechanics as laid down by the Greek Aristotle had been accepted without much dispute by the civilized world. But a spirit of new thought and investigation was now rising in

Europe, and more especially in Italy. Galileo determined to study the laws of mechanics by experiment, and not, as so many earlier scientists had done, by argument or mere theoretical opinions. Therefore he undertook to establish definitely the laws relating to falling bodies.

Aristotle, almost two thousand years before, had announced that if two bodies of different weights were dropped from the same height the heavier would reach the ground sooner than the lighter, according to the proportion of their weights. Galileo doubted this, and decided to try it. Accordingly he assembled the teachers and students of the university one morning about the base of the famous Leaning Tower of Pisa. He himself climbed to the top, carrying with him a ten-pound shot and a one-pound shot. He balanced them on the edge of the tower and let them fall together. They struck the ground together. As a result of this experiment Galileo declared three laws in relation to falling bodies. He said that if one neglected the resistance of the air, or in other words supposed the bodies to fall through a vacuum, it would be found, first, that all bodies fall from the same height in equal times; second, that in falling the final velocities are proportional to the times; and third, that the spaces fallen through are proportional to the squares of the times.

The first of these laws was shown by his experiment on the Leaning Tower. To show the others he built a straight inclined plane with a groove down its centre. A bronze ball was free to move in the groove with the least possible friction. By means of this he showed that no matter how much he inclined the plane, and so changed the time, the ball would always move down it according to the laws he had stated.

But in disproving the accuracy of the old laws of Aristotle the young scientist had raised a hornet's nest about his ears. The men of the old school would not believe him, a conspiracy was set on foot against him, and finally the criticism of his new teachings grew so severe that he was forced to resign his position, and move to Florence.

In spite of his wide-spread reputation no school or university was ready to welcome the young scientist. He was known as a man of a very original turn of mind, and therefore one who would be apt to clash with those who clung to their belief in the old order of thought. At last, however, he succeeded in obtaining the chair of Professor of Mathematics at the University of Padua, then one of the greatest seats of learning in Italy. Here again he showed the great scope of his knowledge, and wrote on military architecture and fortifications, the laws of motion, of the sphere, and various branches of mechanics. He invented a machine for raising water, and was granted a patent which secured him his rights in it for twenty years, and he also produced what he called his Geometrical and Military Compass, but what was later commonly known as the Sector.

Galileo's fame as a teacher had now spread widely throughout Europe, and students began to flock to Padua to study under him. He had a large house, where a number of his private pupils lived with him, a garden, in which he delighted, and a workshop. Here he experimented on his next invention, that of the air thermometer. One of his friends, Castelli, wrote of this in a letter many years later, dated 1638. "I remember," he writes, "an experiment which our Signor Galileo had shown me more than thirty-five years ago. He took a small glass bottle about the size of a hen's egg, the neck of which was two palms long, and as narrow as a straw. Having well heated the bulb in his hand, he inserted its mouth in a vessel containing a little water, and, withdrawing the heat of his hand from the bulb, instantly the water rose in the neck more than a palm above its level in the vessel. It is thus that he constructed an instrument for measuring the degrees of heat and cold."

In 1604 the attention of all the astronomers of Europe was attracted by a new star which suddenly appeared in the constellation Serpentarius. Galileo studied it, and shortly began to lecture on the comparatively new science of astronomy. Formerly he had taught the old system of Aristotle to his classes, now, after a searching investigation, he declared his belief in the contrary conclusions of Copernicus. This study led him on and on. He became interested in the magnetic needle, and its use as a compass in navigation. Columbus' discovery of its changing its position according to its relation to the North Pole took place on his first voyage to America, and reports of this had reached Padua. All educated men were rousing to the fact that the age was fertile with new discoveries in every branch of knowledge, and Galileo and those who were working with him gave eager heed to each month's batch of news.

Mere chance is said to have brought about the making of the first telescope. The story goes that an apprentice of Hans Lipperhey, an optician of Middleburg, in Holland, was, one day in October, 1608, playing with some spectacle lenses in his master's shop. He noticed that by holding two of the lenses in a certain position he obtained a large and inverted view of whatever he looked at. He told Master Hans about this, and the optician fixed two lenses in a tube, and looking at the weathercock on a neighboring steeple saw that it seemed much nearer and to be upside down. He hung the tube in his shop as a curious toy, and one day the Marquis Spinola examined it and bought it to present to Prince Maurice of Nassau. Soon a number of Hans Lipperhey's scientific neighbors were trying to make copies of his tube, and before very long reports of it were carried to Italy. The news reached Galileo while on a visit to Venice in June, 1609. This is his account of what followed, taken from a letter written to his brother-in-law Landucci, and dated August 29, 1609.

"You must know then that about two months ago a report was spread here that in Flanders a spy-glass had been presented to Prince Maurice, so ingeniously constructed that it made the most distant objects appear quite near, so that a man could be seen quite plainly at a distance of two miles. This result seemed to me so extraordinary that it set me thinking, and as it appeared to me that it depended upon the laws of perspective, I reflected on the manner of constructing it, and was at length so entirely successful that I made a spy-glass which far surpasses the report of the Flanders one. As the news had reached Venice that I had made such an instrument, six days ago I was summoned before their Highnesses, the Signoria, and exhibited it to them, to the astonishment of the whole senate. Many of the nobles and senators, although of a great age, mounted more than once to the top of the highest church tower in Venice, in order to see sails and shipping that were so far off that it was two hours before they were seen, without my spy-glass, steering full sail into the harbor; for the effect of my instrument is such that it makes an object fifty miles off appear as large as if it were only five.

"Perceiving of what great utility such an instrument would prove in naval and military operations, and seeing that His Serenity the Doge desired to possess it, I resolved on the 24th inst. to go to the palace and present it as a free gift." So Galileo did, and as a result the senate elected him to the Professorship at Padua for life, with a salary of one thousand florins yearly.

But what were Galileo's claims to the invention of this great instrument? Here is what he wrote in 1623. "Perhaps it may be said that no great credit is due for the making of an instrument, or the solution of a problem, when one is told beforehand that the instrument exists, or that the problem is solvable. It may be said that the certitude of the existence of such a glass aided me, and that without this knowledge I would never have succeeded. To this I reply, the help which the information gave me consisted in exciting my thoughts in a particular direction, and without that, it is possible they may never have been directed that way; but that such information made the act of invention easier to me I deny, and I say more--to find the solution of a definite problem requires a greater effort of genius than

to resolve one not specified; for in the latter case hazard, chance, may play the greater part, while in the former all is the work of the reasoning and intelligent mind. Thus, we are certain that the Dutchman, the first inventor of the telescope, was a simple spectacle-maker, who, handling by chance different forms of glasses, looked, also by chance, through two of them, one convex and the other concave, held at different distances from the eye; saw and noted the unexpected result; and thus found the instrument. On the other hand, I, on the simple information of the effect obtained, discovered the same instrument, not by chance, but by the way of pure reasoning. Here are the steps: the artifice of the instrument depends either on one glass or on several. It cannot depend on one, for that must be either convex, or concave, or plain. The last form neither augments nor diminishes visible objects; the concave diminishes them, the convex increases them, but both show them blurred and indistinct. Passing then to the combination of two glasses, and knowing that glasses with plain surfaces change nothing, I concluded that the effect could not be produced by combining a plain glass with a convex or a concave one; I was thus left with the two other kinds of glasses, and after a few experiments I saw how the effect sought could be produced. Such was the march of my discovery, in which I was not assisted in any way by the knowledge that the conclusion at which I aimed was a verity."

The telescope that Galileo presented to the Doge of Venice, and which was later lost, consisted of a tube of lead, with what is called a plano-concave eye-glass and a plano-convex object glass, and had a magnifying power of three diameters, which made objects look three times nearer than they actually were, and as a result nine times larger. The tube was about seventy centimeters long and about forty-five millimeters in diameter. It was first used in public from the top of the campanile in the piazza at Venice on August 21, 1609, and the most distant object that could be seen through it was the campanile of the church of San Giustina in Padua, about thirty-five kilometers away.

As soon as Galileo returned to his home in Padua he busied himself with improving his invention. First he constructed a new telescope, which as he said "made objects appear more than sixty times larger." Soon he had a still better one, which enlarged four hundred times. He used this to examine the moon, and said that it brought that body "to a distance of less than three semi-diameters of the earth, thus making it appear about twenty times nearer and four hundred times larger than when seen by the unaided eye." To use the instrument more accurately he built a support which held it firmly. He had also now learned to make the lenses adjustable, by fixing the tubes that held them so that they could be drawn out of, or pushed into the main tube of the telescope. To see objects not very far distant very clearly he would push the glasses a little way apart, and to see things very far distant he drew the glasses together.

But this last telescope did not altogether satisfy him, and so he built a still larger one. This brought objects more than thirty times closer and showed them almost a thousand times larger in size. With this he discovered the moons of Jupiter, and some of the fixed stars, and added much to what was already known concerning the Milky Way, a region of the sky which had long been a puzzle to astronomers.

He spent a great part of his time now in his workshop, making and grinding glasses. They were expensive and very difficult to prepare properly. Out of more than one hundred that he ground at first he found only ten that would show him the newly found moons of Jupiter. The object glasses were the more difficult, for it was this glass which had to bring to a focus as accurately as possible all the rays of light that passed into the telescope.

As the voyage of Columbus had brought a new world in the western ocean to the notice of Europe, so Galileo's discoveries with his telescope brought forth a new world in the skies. Galileo wrote out

statements of his discoveries, and sent these, with his new telescopes, to the princes and learned men of Italy, France, Flanders, and Germany. At all the courts and universities the telescopes were received with the greatest enthusiasm, and put to instant use in the hope of discovering new stars. But again the followers of Aristotle, those who were unwilling to admit that anything new could be learned about the laws of nature or the universe, arose in wrath. They attacked Galileo and his discoveries. They would not admit that Jupiter had four attendant moons, although these satellites could be seen by any one through the telescope, and a little later, when Galileo stated that the planet Saturn was composed of three stars which touched each other (later found to be one planet with two rings) they rose up to denounce him. But as yet these protests against the discoverer had little effect. Europe was too much interested in what he was showing it to realize how deeply he might affect men's views of the universe.

Fame was now safely his. Men came from all parts of Europe to study under this wonderful professor of Padua. But teaching gave him too little time to carry on his own researches. So he looked about for some other position that would give him greater leisure, and finally stated his wishes to Cosimo II, Duke of Florence. Galileo had named the satellites of Jupiter after the house of Medici, to which this Duke belonged, and Cosimo was much flattered at the compliment. As a result he was soon after made First Mathematician of the University of Pisa, and also Philosopher and Mathematician to the Grand Duke's Court of Florence.

Settled at last at Florence his work as an astronomer steadily went forward. He discovered that the planet Venus had a varying crescent form, that there were small spots circling across the face of the sun, which he called sun-spots, and later that there were mountains on the moon. He also visited Rome, where he was received with the greatest good-will by Pope Paul V and his cardinals, and where he met the leading scientists of the capital.

But Galileo's course was no less flecked with light and shade than were the sun and moon he studied. The envy of rivals soon spread false reports about him, and the professors at Pisa refused to accept the results of his studies. Then one of the latter stirred the religious scruples of the Dowager Grand Duchess by telling her that Galileo's conclusion that the earth had a double motion must be wrong, since it was opposed to the statements of the Bible. Galileo heard of this, and wrote a letter in reply, in which he said that in studying the laws of nature men must start with what they could prove by experiments instead of relying wholly on the Scriptures. This was enough to set the machinery of his enemies in motion. Galileo's teachings were pointed out as dangerous to the teachings of the Church, and the officers of the Inquisition began to consider how they might best deal with him. Certain of his writings were declared false and prohibited, and he was admonished that he must follow certain lines in his teachings. He went to Rome himself, and saw the Pope again, but found that his friends were fewer and his enemies growing more powerful.

The theory of Copernicus that the earth and planets are in constant motion was the very foundation of Galileo's scientific studies, and yet the order of the Church now forbade him to use this theory. He went back to Florence out of health and despondent. His old students were falling away from him through fear of the Pope's displeasure, and he was left much alone. But his thirst for knowledge would not let him rest. He took up his residence in the fine old Torre del Gallo, which looks down on Florence and the river Arno, and went on with his work. He wrote out the results of his discoveries, and made a microscope from a model he had seen. Soon he had greatly improved upon his model, and had an instrument, which, as he said, "magnifies things as much as 50,000 times, so that one sees a fly as large as a hen." He sent copies to some friends, and shortly his microscopes were as much in demand as his telescopes had been.

In 1632 he published what he called “The Dialogues of Galileo Galilei.” This divided the world of Italy into two camps, the one those who believed in Aristotle and the old learning, the other those who followed Copernicus, Galileo, and Kepler. The Jesuits took up the gage he had thrown down, and Galileo found the Church of Rome arrayed against him. The sale of his book was forbidden, a commission was appointed to bring charges against him, and he was ordered to go to Rome for trial. The commission reported that Galileo had disobeyed the Church’s orders by maintaining that the earth moves and that the sun is stationary, that he had wrongly declared that the movements of the tides were due to the sun’s stability and the motion of the earth, and that he had failed to give up his old beliefs in regard to the sun and the earth as he had been commanded.

Galileo, although he was ill, went to Rome, and was placed on trial before the Inquisition. After weeks of weary waiting and long examinations he was ordered to take a solemn oath, forswearing his belief in his own writings and rejecting the conclusion that the sun was stationary and that the earth moved. Rather than suffer the pains of the Inquisition he agreed, and made his solemn declaration. According to an old story, now discredited, as he rose from his knees after the ceremony he whispered to a friend “_Eppur si muove_” (It does move, nevertheless). Whether he said this or not there can be no doubt but that the great astronomer knew the performance was a farce, and that the world did move in spite of all the Inquisition could declare.

The Inquisition did its work ruthlessly. Notices of the sentence prohibiting the reading of Galileo’s book and ordering all copies of it to be surrendered, and copies of the declaration he had made denying his former teachings, were sent to all the courts of Europe and to many of the universities. In Padua the documents were read to teachers and students at the university where for so many years Galileo had been the greatest glory of learning, and in Florence the Inquisitor read the sentence publicly in the church of Santa Croce, notices having been sent to all who were known to be friends or followers of Galileo, ordering them to attend. Thus his humiliation was spread broadcast, and in addition he was ordered to be held at Rome as a prisoner.

After a time he was permitted to go on parole to the city of Siena, which was at least nearer his home outside Florence. There he stayed until the Grand Duke Cosimo, who had stood by him, persuaded the Church that Galileo’s health required that he be allowed to join his friends. At last he reached his home, and again took up his studies. His eyesight was failing, and eventually he became entirely blind, but meanwhile his speculations covered the widest fields of science, he studied the laws of motion and equilibrium, the velocity of light, the problems of the vacuum, of the flight of projectiles, and the mathematical theory of the parabola. He wrote another book, dealing with two new sciences, and was busy with designs for a pendulum clock at the time of his death in 1642. He was buried in the church of Santa Croce, the Pantheon of Florence, under the same roof with his great fellow countryman, Michael Angelo.

What is known as the modern refracting telescope is based upon a different combination of lenses than that used by Galileo. Kepler studied Galileo’s instrument, and then designed one consisting of two convex lenses. The modern telescope follows Kepler’s arrangement, but Galileo’s adjustment is still suitable where only low magnifying powers are needed, and is used to-day in the ordinary field- and opera-glass.

Galileo knew nothing of what we call the reflecting telescope. He found that by using a convex-lens as an object-glass he could bring the rays of light from any distant object to a focus, and it did not apparently occur to him that he could achieve the same end by the use of a concave mirror. James Gregory, a Scotchman, designed the first reflector in 1663, and described it in a book, but he was too

poor to construct it. Nine years later Sir Isaac Newton, having studied Gregory's plans, built the first reflecting telescope, which is now to be seen in the hall of the Royal Society in London. But invention has gone yet farther in perfecting these instruments with which to study the skies, and the great telescopes of modern times have in most instances discarded Newton's reflector for the refracting instrument. And these are built on a tremendous scale. The Yerkes telescope at Williams Bay, Wisconsin, has a refractor of forty inches, and the one built for the Paris Exposition of 1900, one of fifty inches. In numerous other details they have changed, and yet each is chiefly indebted to that simple spy-glass of Galileo, by which he was able to show the nobles and senators of Venice full-rigged ships, which without it were barely distant specks on the horizon. Or, going still farther back, the men who make our present telescopes are following the trail that was first blazed on the day when the Dutch apprentice of Middleburg chanced to pick up two spectacle lenses and look through the two of them at once.

Galileo made many great discoveries and inventions; there was hardly a field of science that he did not enter and explore; but his greatest work was to open a new world to men's attention. It was this that brought him before the Inquisition and that branded him as a dangerous heretic, and it was this that placed him in the forefront of the world's discoverers. Men might say that the earth stood still, because it suited them best to believe so, but Galileo gave the world an instrument by which it could study the matter for itself, and the world has gone on using that instrument and that method ever since.

Source:

Holland, Rupert. "Galileo and the Telescope." *Historic Inventions*. Philadelphia: George W. Jacobs & Company, 1911. 53 – 69. Electronic.