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Historical Construction Of The Kinematic Concept Involving The Falling Of Bodies

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Abstract
This article seeks to discuss the historical origins of the kinematic concept involving the "falling of bodies", aiming to contribute to a broad understanding, and ultimately, to enable the use of such an approach in Physics Teaching. Showing the construction of a concept to students is important for them to realize that science is not linear, and neither is it done by just one person; it is important for them to realize that observing, hypothesizing, making mistakes or getting things right are common in both processes. However, there is little or no reference to the use of the History of Science in High School. In view of this, this article makes a historical analysis on the theme of "falling bodies", showing that the inclusion of the History of Science in Physics teaching would be one of the tools that teachers can use to make Physics teaching more humane, thus making more sense of what students are learning and showing how, in fact, a concept is constructed.
Keywords: *Falling bodies. History of Science. Physics Teaching.*

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I. Introduction

One of the biggest problems in science teaching is that it is based solely on formulas, problem-solving and memorization of concepts, and these factors make classes less and less attractive. In view of this, the importance of using the history of science is highlighted, considering that this is one of the ways to overcome the use of formulas in the classroom (MATTHEWS, 1995). The use of the history of science is, therefore, essential to "[...] make science classes more challenging and reflective, thus allowing the development of critical thinking [...]" (MATTHEWS, 1995, p. 165).

In addition, the history of science also plays an important role in understanding that science is not linear, nor is it done by just one person, concepts that are recorded in some textbooks; "[...] these texts often seem to imply that the content of science is uniquely exemplified by the observations, laws and theories described in their pages [...]" (KUHN, 1998, p. 20).

The use of textbooks is another important point to be discussed, since many teachers consider them a guide to be followed to the letter, and not just one among several instruments to constitute their class. These books show, in fact, according to Kuhn (1998, p. 20), that "[...] scientific methods are simply those illustrated by the manipulation techniques employed in collecting data from manuals, together with logical operations [...]".

In this sense, noting a Physics teaching presented only by formulas, mathematical resolutions and leaving aside the history of science, this article will carry out a historical review on the theme Falling Bodies, so that a broad understanding of this theme can be promoted. Therefore, the objective is to discuss the historical origins of this theme, aiming to contribute to the understanding, as well as to emphasize the importance of the history of science.

II. The Construction Of The Kinematical Concept Involving The Fall Of Serious Bodies

The development of these concepts goes through the ideas of medieval science up to modern science, which required great effort in the thoughts and discussions among philosophers, to make possible a conceptualization that is understandable to all.

According to Ziman (1981, p. 17), "to understand the current state of Science, it is necessary to know how it arrived at it [...]". It is important to note, then, that philosophers and scientists also went through difficulties, mistakes, successes, scientific revolutions that overturned their ideas (KOYRÉ, 1982). All of these facts are important to understand the construction of scientific thought.

Therefore, discussions on the construction of the kinematic concept involving the Fall of Bodies began with Aristotle (384-322 BC) of Stagira, who was a very important philosopher for the advancement of scientific

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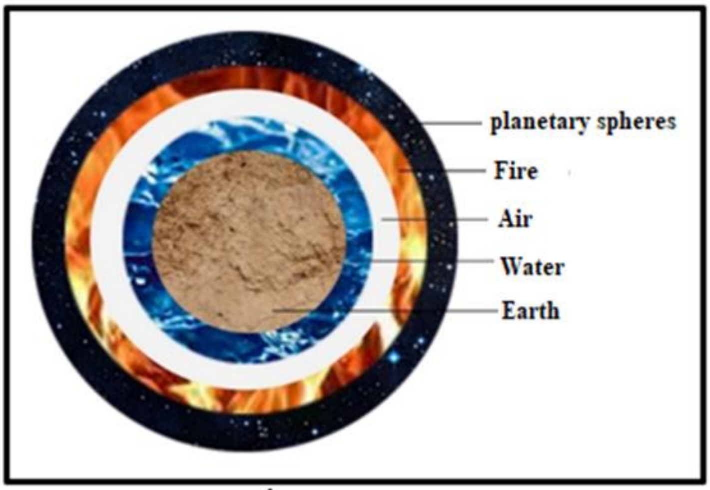
thought. According to Peduzzi (1996 p. 49), “[...] Aristotelian Physics is an indispensable reference for understanding medieval Physics and the revolution in mechanics that occurred in the 17th century”.

Aristotelian Physics of Natural Motion: For the Greek philosopher Aristotle, the world had two distinct characteristics: the sublunary (Earth) and the supralunary (heaven), and what was true for the heavens was not true for objects on Earth. Aristotle admitted that the sublunary world was made up of four elements: water, earth, air and fire. These elements only make up things on Earth (PEDUZZI, 1996). In the supralunar world, ether was the fifth element that filled it, being a pure element that does not mix with the other elements on Earth (NEVES, 2000).

According to Neves (2000), for all bodies above the sphere of the moon there was only one acceptable motion, the perfect and eternal circular motion. Therefore, when Aristotle looked at the sky, he saw perfection (PEDUZZI, 1996). And for terrestrial bodies, the motion was always rectilinear, from bottom to top or from top to bottom.

Terrestrial bodies, according to Menezes et al. (2008), had a natural motion: when a stone was thrown into the air, it ended up seeking its natural place, falling to the ground. The elements that make up all bodies in nature always tend to seek their natural places in the order of this world, as can be seen in Figure 1, an outline of a medieval conception of the universe.

Figure 1: Middle Ages conception



Source: PROJECTO FÍSICA, 1978. Author's collection.

For a body whose predominant element was the earth, and it was outside the earth, its natural motion would be to fall, like a fruit falling from a tree. In this reasoning, the natural motion of water is also downward. Fire and air would have a rectilinear motion upward, due to their natural place. Remember that, for Aristotle, the motion was always rectilinear, since the Earth occupied the center of the universe. Thus, when a body was removed from its place, its tendency would always be to return to its natural place.

According to the theory that a body always returns to its natural place, Aristotle begins to discuss the fall of objects on Earth. Thus, when a stone is dropped from a certain height, it has a natural tendency to fall towards the ground. For Aristotle, when dropping two objects of different “weights” from the same height, the “heavier” one would reach the ground first, because it has a greater tendency to seek its natural place.

This idea that a body with greater “weight” would reach the ground first was supported for several centuries. Remembering again that, for Aristotle, the motion of the fall could only happen in one way, it would always be in a straight line, because the Earth is fixed at the center of the universe. The stability of the Earth can be verified when:

[...] when an object was thrown upwards, it would return, strictly speaking, to the same place from which it had started. If, on the other hand, the Earth were in motion (rotation, or translation, or both, simultaneously) this, according to the thinking of the time, should not happen because while the object was in the air the Earth would move and, in this way, the object would fall at a point far from where it was thrown (PEDUZZI, 1996, p.50).

Aristotle did not believe that an object could fall in rectilinear motion and, at the same time, move together with the Earth; this would be impossible. Ptolemy, Tycho and other philosophers, astronomers, also confirmed Aristotle's arguments (GALILEI, 2011), who said that the Earth was immobile:

[...] because, when it was in diurnal rotation, a tower, from the top of which a stone was dropped, being carried by the rotation of the Earth, in the time it took for the stone to be used for its descent, would move many hundreds of *braccia* to the east, and for that much space the stone would have to strike the Earth away from the base of the tower [...] (GALILEI, 2011, p.208).

This theory was confirmed with several other experiments, such as the one involving the ship: dropping a lead ball from the top of the mast of an anchored ship, marking the place where it hits, and then dropping the same ball from the same place, but with the ship moving in a uniform rectilinear motion: "[...] the hit will be as far away from the other as the ship moved forward during the fall of the lead [...]" (GALILEI, 2011, p. 152), and this argument was confirmed because "[...] the natural motion of the ball occurs in a straight line towards the center of the Earth" (GALILEI, 2011, p. 152).

In view of the perspective of this and other experiments, it would be possible to confirm that the Earth is fixed and at the center of the universe, and the motions of these objects always occur in a rectilinear way.

Bodies could also perform unnatural and rectilinear motions. For example, when throwing a stone upwards, this would be contrary to its natural motion, which would be called a violent motion. In this way, for another type of motion to occur, a cause (force) would be necessary to act on the body for it to move.

Violent motion and the absence of motiont in a vacuum: For violent motion to occur, in the case of a stone thrown upwards, there must be the action of an external agent that applies a force. Thus, this object continues the motion and then the body returns to its natural place, remembering that it is the natural tendency of the object to return to the ground. This violent motion would only occur if it were associated with a force, *cessante causa cessat efectus* (once the cause ceases, the effect ceases). Another important factor about the motion of bodies is that, for Aristotle, the environment, such as air and water, also influenced the motion of a body. Furthermore, for him, motion in a vacuum did not exist (PEDUZZI, 1996). According to Aristotle:

[...] it must be borne in mind that all motion is either by violence or by nature. But the existence of violent motion necessarily presupposes that of natural motion (indeed, violent motion is against nature and, if it is against nature, it is subsequent to natural motion); so that if there is no natural motion for any physical body, neither will any of the other motions exist. But how can there be natural motion throughout the void and infinity, if no difference persists in these? (Aristotle, 1993, p. 91 *apud* Neves, 2008, p. 44).

In this way, it is possible to observe Aristotle's justification for the absence of a vacuum. According to Peduzzi (1996), this motion would be impossible, without resistance, the object would have an infinite speed. Therefore, for Aristotle, there are two main factors for motion, the driving force (F) and the resistance of the medium (R). Therefore, for motion to occur, the driving force must be greater than the resistance (COHEN, 1967).

Cohen (1967) analyzes the effects for different media and, while conserving the driving force, the experiment consists of dropping two identical steel spheres of the same weight and size freely from the same starting point into different media, that is, one sphere would fall through the air and the other into a cylinder with water. When dropping the two spheres, it is easy to see that the sphere that moved through the air had a much higher speed than the other sphere that moved into the cylinder with water.

This experiment was repeated several times with other sizes of balls and other materials, and the result was always the same. Therefore, this result can be written in the form of a mathematical expression (COHEN, 1967, p. 19):

$V \propto \frac{1}{R}$ *(Equation 1)*

Equation 1 shows that speed is inversely proportional to the resistance of the medium, and speed in water is lower than speed in air. In this way, water makes it difficult for a body to move (COHEN, 1967).

Another experiments were analyzed: dropping two spheres, one through a cylinder filled with water and the other through a cylinder filled with oil, it was observed that the speed of the sphere in water is greater than in oil. Therefore, the oil makes it difficult for the sphere to move.

Cohen (1967) also observed the effects of different driving forces, since when two spheres of different weights are dropped simultaneously from the same height into a cylinder filled with water, the sphere with the greater weight reaches the bottom faster. Thus, it is clear that the greater the weight, the greater the speed. The experiment was carried out for different media and the result produced was always the same.

In this way, the statement of this experiment can be expressed in a mathematical expression (COHEN, 1967, p.22):

$V \propto F$ *(Equation 2)*

Thus, the greater the driving force, the greater the speed. Therefore, combining equation (1) with equation (2), we have the Aristotelian law of motion, where the "speed (v) of a body moving a given distance is proportional to the ratio between the driving force (F) in direct contact with the moving body and the resistance or density of the medium (R), or in modern notation: " (ÉVORA, 1987, p. 75)

$V \propto \frac{F}{R}$ *(Equation 3)*

Equation (3) presents some problems, since it cannot be applied to all motion conditions, because, "[...] if the driving force equaled the resistance, the equation would not give the result that the velocity V would be equal to zero; nor does it give a result equal to zero when the force F is less than the resistance R [...]" (COHEN, 1987, p. 23). Therefore, equation (3) will only be valid if the driving force is greater than the resistance.

Thus, if the density of the medium tends to zero, the velocity would tend to infinity, and for Aristotle, this would constitute a practical and logical impossibility, since, for him, the vacuum is non-existent and, therefore, what does not exist, does not exist. According to Neves (2008), the velocity of a falling body is determined by the weight of the body and the density of the medium, therefore, in Aristotelian kinematic theory, the concept of acceleration does not exist. This guarantees the non-existence of the non-existent (vacuum).

Later, some changes were proposed in Aristotelian theory, in the 5th century AD, Johannes Philoponus suggests that (NEVES, 2008, p. 103):

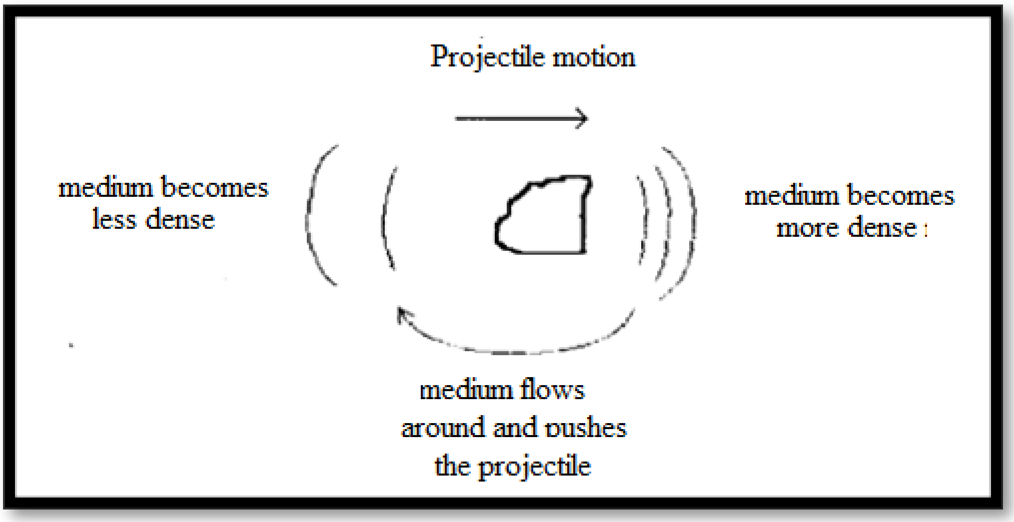
$V \propto (P - R)$ *(Equation 4)*

In view of this, it can be seen that the speed of a body must be obtained by subtracting the resistance of the medium and not by dividing as shown in equation (3), the medium decreases the speed of the body. In view of equation (4), it is possible to see the viability of a motion in a vacuum.

Through the experiments presented, it can be understood that, when releasing two bodies into the air from the same initial position, but with different weights, the heavier body will reach the ground first, and the heavier body will acquire greater speed. In view of this reasoning, in Aristotelian Physics, when releasing two spheres, considering that the weight of one is twice that of the other, the speed of the heavier body will have to be twice the speed of the lighter body. However, when carrying out this experiment, it is seen that the difference in speeds between the bodies is minimal. As commented by Neves (2008), Aristotelian Physics still has other concepts to be addressed, for example: an object continued to move even when it no longer had contact with the external agent, and this motion was only possible because there was another motor, "[...] that is, the air, even immediately after the passage of the body, closed, moving from the front to the back of the body; this was the notion of antiperistasis". In this way, Aristotle began to study the motions of projectiles after they were launched.

For Aristotle, the driving force is the cause for the motion s, *cessante causa cessat effectus*, (once the cause ceases, the effect ceases) (NEVES, 2008). Therefore, to keep the projectile moving after launch, the action of the external agent is necessary. In this way, the motion of this object continued through a process that Aristotle called antiperistasis. Therefore, the air displaced by the passage of the object goes around it to fill the void left by it, which also allows it to be propelled forward as illustrated in Figure 2.

Figure 2: *Antiperistasis.*



Source: CAMARGO, 2000, p.33.

As this process is not perfect, since there is resistance and the object has a tendency to return to its natural place, it gradually falls. In this way, "[...] this violent motion continues until the driving force originally imprinted on this portion of air dissipates. Thus, the medium, for Aristotle, offers both the driving force and the resistance" (ÉVORA, 1987, p. 77). With this idea of Aristotle, it is possible to perceive, once again, the impossibility of motion in a vacuum, since this cannot preserve motion, in the case of a projectile.

Aristotle's ideas remained unrefuted for a long time, until, in the transition between Antiquity and the Middle Ages, discussions about his ideas began, and Philoponus of Alexandria was one of the first to counter them. It is important to note, however, that before Philoponus, some points of Aristotelian dynamics were discussed by Hipparchus in ancient Greece, which did not agree with Aristotle's idea of *antiperistasis*.

Hipparchus discussed the idea of *antiperistasis*. For him, there was an "[...] impressed force that passed from the mover to the mover and that diminished as the body moved through a dissipative medium. It was a kind of impulse, internal impetus [...]" (NEVES, 2008, p.47). This concept of impetus was discussed in the 6th century by Philoponus, and later by Jean Buridan in the 14th century.

Philoponus criticizes Aristotle's idea of *antiperistasis*, he did not agree that air could make three motions. Thus, he comments:

[...] the air in question must make three distinct motions: it must be pushed by the arrow, it must move backwards, and finally it must turn and proceed forwards again. Since the air is easily moved, and moves to a considerable distance, how, in consequence, can the air, pushed by the arrow, not move in the direction of the impulse impressed, but, instead, turn backwards, by some command, and retrace its course? Furthermore, how can the air, turning backwards, avoid escaping into the (surrounding) space, and impress precisely upon the end of the arrow, and again push it? (GRANT, 1983, p. 58 apud NEVES, 2008, p. 47).

According to Évora (1987), Philoponus rejects the idea that air can produce both the driving force and the resistance of motion. Therefore, Philoponus explained the motion of projectiles in another way, since, for him, the motion was carried out by means of an incorporeal driving force.

[...] it is necessary to assume that some incorporeal motive force is given from the projector to the projectile, and that the air set in motion contributes nothing or very little to the motion of the projectile... And no agent external to the projector will be necessary (GRANT, 1958, p.58 *apud* NEVES, 2008, p. 47-48).

Therefore, for Philoponus, the driving force will gradually decrease. This decrease occurs due to the environment and also due to the body's natural tendency to always return to its natural place. This decrease in driving force can occur even in a vacuum.

Philoponus' ideas were developed by Avicenna, an Arab thinker. According to Neves (2008), Avicenna explained that a body could receive a push in the same proportion as its weight. This push could be permanent in the absence of external resistance. However, the experiments did not reveal these described motions; therefore, Avicenna also denied the impossibility of motion in a vacuum.

In the 12th century, the Arab-Spanish Avempace discussed the laws of motion, which denied Aristotle's theory, in which "[...] the time of fall of a heavy body is directly proportional to the density and, therefore, to the resistance of the environment in which the body falls" (NEVES, 2008, p. 48).

Later, Jean Buridan developed the theory of incorporeal driving force and driving force, under the name of impetus theory. Buridan commented that the impetus impressed on a certain object would cause it to tend towards infinity, that is, if it were not corrupted by some external resistance. In this way, it is still possible to perceive the notion of the cause ceasing, the effect ceasing (NEVES, 2008). For Buridan, a heavier body contained more matter; therefore, it would receive a greater impetus than a lighter body, and could therefore last longer in the air.

It is important to highlight that, despite the criticism, Aristotle's theory remained for centuries. Another important point was the fact that Aristotle was an empiricist; his knowledge was acquired through the senses and perception; he did not seek mathematical reasoning to prove his theories.

III. Leonardo Da Vinci And Studies On Falling Bodies

During the Renaissance period, on April 15, 1452, in the city of Vinci, Italy, Leonardo da Vinci was born. Da Vinci was a painter, sculptor, architect, engineer, anatomist, botanist, astronomer, scientist, musician, geologist, and writer. According to Koyré (1982), Da Vinci made an important contribution to human evolution, leaving manuscripts containing several geometric and mechanical drawings for the construction of machines. These manuscripts were written from right to left, to keep them protected, in addition to remaining secret for a long time.

At the end of the 19th century, Da Vinci's manuscripts were found and transcribed, then translated and finally published by Jean-Paul Richter, Ravaisson-Mollien, Mac Curdy and others. Da Vinci became known as the founder of modern science and technology (KOYRÉ, 1982).

In Da Vinci's work, he did not address theory, being more practical. Da Vinci did not explain his perceptions through formulas or laws, but he was able to understand the subject through his perception. Thus, Da Vinci was a man of praxis, since he built machines and not theories.

Among the studies carried out by Da Vinci, a work on the Fall of Bodies was found. In it, Da Vinci explains that, when a body "[...] descends freely, it acquires a degree of motion with each degree of time, and with each degree of motion, it acquires a degree of speed" (DA VINCI, 2004, p. 67). This explanation by Da Vinci is shown in Table 1.

Table 1: Explanation of the fall of bodies by Da Vinci

Fall time	Space covered
1	1
2	1 + 2 = 3
3	1 + 2 + 3 = 6
4	1 + 2 + 3 + 4 = 10
5	1 + 2 + 3 + 4 + 5 = 15

Source: NEVES, 2008

According to Table 1, Neves (2008) comments that the spaces traveled in consecutive periods of time were proportional to whole numbers. Thus, when a heavy body moves a unit of time, it travels a unit of space and so on.

Leonardo Da Vinci deserved the credit for having understood the structure of the acceleration of the motion of Falling Bodies, although he was unable to explain his understanding in mathematical terms. It cannot be avoided, however, that his intuition was essentially correct (KOYRÉ, 1982).

Thus, Da Vinci's thinking differs from Aristotle's, in that, for him, there is a viability of a variation in speed during the falling motion. Therefore, this issue was not so simple and persisted until Galileo Galilei pointed out another solution.

IV. Galileo Galilei And The Book: Two New Sciences

The biography of Galileo, presented here, is based on the book Two New Sciences. Galileo Galilei was born on February 15, 1564. He studied medicine in Pisa in 1581, but did not complete it, since his main interests were in Physics and Mathematics. Therefore, he dropped out of medical school and returned to Florence. In 1589, he was appointed professor of Mathematics in Pisa and, during this time, he was able to research natural and violent motions, in order to arrive at the law of the Fall of Heavy Bodies. Due to the death of his father and also to his meager salary, Galileo left his position and resumed his application for the Chair of Mathematics in Padua. From the time of his appointment, his work was divided into three periods: the Paduan period (1560-1610), the controversial period (1610-1633), and the resumption of his work on the motion t (1633-1642).

The book *Two New Sciences*, originally titled *Discorsi e Dimostrazioni Matematiche intorno a Due Nuove Scienze*, was Galileo's last and most important work, written while he was confined after his conviction in 1633.

This book was written in the form of a dialogue, with the interlocutors being: Salviati, who was one of Galileo's closest friends and was also his student in Padua. In the book, he represents Galileo's new ideas; Sagredo had a great deal of contact and familiarity with Galileo, and he represents a character who was anxious to learn; Simplicio was a Greek philosopher, known as one of Aristotle's most important commentators. Thus, in the book, he is an Aristotelian representative.

In the book, Galileo is not represented only by Salviati, since the latter begins to have his own positions and doubts. Sagredo also represents Galileo in many doubts that are not answered by Salviati and Simplicio, he has a common sense naivety with difficulties in understanding mathematical reasoning (GALILEI, 1988). Among the various questions addressed in the book Two New Sciences, we come to the discussion about the Fall of Heavy Bodies. For Aristotle, "the speeds of bodies in free fall are proportional to their weights and inversely proportional to the resistance of the medium in which they move, hence the impossibility of motion in a vacuum" (KOYRÉ, 1982, p. 210). In view of this, an excerpt from the dialogue between Simplicio, Salviati and Sagredo about whether motion in a vacuum would really be possible is presented.

Simplicius – Aristotle, as far as I remember, attacks some ancient philosophers who introduced a vacuum as being necessary for motion, saying that the latter could not take place without the former. Aristotle, opposing this, demonstrates that, on the contrary, by taking place (as we see), motion destroys the supposition of a vacuum; and his argument is as follows. He makes two suppositions: the first concerns different weights moving in the same medium; the other concerns the same object moving in different media. As for the first, he supposes that objects of different weights move in the same medium with unequal velocities, which maintain the same proportion to each other as the weights; so that, for example, an object ten times heavier than another moves with ten times greater velocity. In the second proposition, he admits that the velocities of the same object in different media are inversely proportional to each other's thickness and density. Thus, assuming, for example, that the density of water is ten times greater than that of air, it is assumed that the velocity in air is ten times greater than that in water. And from this second assumption the following demonstration is derived: since the subtlety of the vacuum differs infinitely from the corporeality, however subtle it may be, of any plenum, every moving object that moves in a plenum, traveling a certain distance in a certain time, should move instantaneously in the void: however, instantaneous motiont is impossible; therefore it is impossible to introduce the vacuum as the basis of motion.

Salviati – It is clear that the argument is *ad hominem*, that is, against those who considered the vacuum as necessary for motion; even if I were to grant that the argument is conclusive, while granting at the same time that motion does not take place in a vacuum, the supposition of the vacuum, taken absolutely and not in relation to motion, would not be destroyed. However, to say what the ancient philosophers might have answered, and to better understand what allows us to conclude Aristotle's demonstration, it seems to me that one could contest the assumptions made, denying both of them. As for the first, I seriously doubt that Aristotle ever verified experimentally whether it is true that two stones, one of which weighs ten times more, dropped at the same time from a height of, for example, a hundred *braccia*, have such different speeds that, by the time the heavier one reaches the ground, the other would not have traveled even ten *braccia*.

Simplicio – We can see from his own words that he did the experiment, because he says: "we see the heavier one"; now, this "seeing" alludes to an experiment that was carried out.

Sagredo – But I, Mr. Simplício, who did not perform the test, assure you that a cannonball weighing a hundred, two hundred or more pounds will not precede the arrival of a half-pound musket ball by even a hand's breadth, even if the height of the fall is two hundred *braccia* (GALILEI, 1988, p.55).

In the speech above, Galileo conducts a thought experiment to convince Aristotle that he was wrong in saying that a heavier stone would reach the ground before a lighter stone. However, everyone doubted that Aristotle would have actually performed such an experiment.

This term, thought experiment, used here, refers to the fact that "[...] Mach called them "thought experiments" and to which Popper draws our attention, they played a very important role in the history of scientific thought" (POPPER, 1959, p. 442 apud KOYRÉ, 1982, p. 209). It is worth noting that some experiments are difficult to perform, or some of them require very elaborate equipment; thus, imagination eliminates all the difficulties encountered, and even performs experiments with perfect objects, imagination obtains precise results (KOYRÉ, 1982).

In the experiment conceived and carried out by Galileo on the cannonball and the musket ball, it is clear that he knew the implications of the resistance of the environment, since the environment influences the Fall of Bodies. Therefore, when dropping two objects with different weights, they reach the ground with a minimal difference, and this difference is caused by air resistance. Galileo then presents several thought experiments to challenge Aristotle's theory, including:

Salviati - – Without resorting to other experiments, we can clearly prove, through a brief and conclusive demonstration, that it is not true that a heavier object moves at a greater speed than a lighter object, assuming that both are made of the same material, as is the case with those mentioned by Aristotle. However, tell me, Mr. Simplicio, do you admit that each heavy falling object has a naturally determined speed, so that it cannot be increased or decreased except by using violence or by opposing some resistance?

Simplicio – There can be no doubt that the same object in the same environment has the same speed fixed and determined by nature, which cannot be increased except by adding a new impetus, nor decreased except by some impediment that slows it down.

Salviati – If, then, we had two pieces of furniture whose natural speeds were unequal, it is evident that if we were to unite the slower one with the faster one, the latter would be partially retarded and the slower one would increase its speed in part due to the faster one. Do you not agree with my opinion?

Simplicio – It seems to me that this is undoubtedly the case.

Salviati – But if this is so, and if it is also true that a large stone moves, for example, with a speed of eight degrees and a smaller one with a speed of four degrees, then by uniting them, the compound will move with a speed less than eight degrees. However, the two stones together form a larger stone than the one that moved with eight degrees of speed; from which it follows that this compound (which is also larger than the first stone) will move more slowly than the first stone, which is smaller, which contradicts your supposition. We see, then, how, assuming that the heavier object moves at a greater speed than the lighter object, I conclude that the heavier object moves at a slower speed.

Simplicio – I am completely confused, because it seems to me that the smaller stone, when joined to the larger one, increases its weight, and by increasing its weight, I do not see how its speed should not also increase or, at least, not decrease.

Salviati – Here, Mr. Simplicio, you are making another mistake, because it is not true that the smaller stone increases the weight of the larger one.

Simplicio – Oh! This is something that is beyond my understanding! (GALILEI, 1988, p. 55-56).

In the dialogue, it is possible to see how confused Simplicio is when he realizes that Aristotle's theory is inconsistent and contradictory. It is difficult for Simplicio to try to believe in the theory proposed by Galileo, for him, it is almost impossible for two objects of different weights to reach the ground at the same time. For Simplicio, the heavier object falls before a lighter object, and this thought is confirmed when he says:

Simplicio – Your reasoning is indeed well-conducted; however, it seems difficult to me to believe that a drop of lead can move as quickly as a cannonball.

Salviati – [...] Aristotle says: "A hundred-pound iron ball that falls from a height of a hundred *braccia* reaches the ground before a one-pound ball has descended only one *braccia*"; I affirm that they both arrive at the same time. It is found, by doing the experiment, that the larger one precedes the smaller one by two fingers, that is, that at the moment when the larger one reaches the ground, the other one is two fingers away: now, you want to hide Aristotle's ninety-nine *braccia* under these two fingers and, speaking only of my small error, keep silent about the enormity of the other (GALILEI, 1988, p. 57).

This dialogue between Simplicio and Salviati allows us to understand that bodies of different weights do not reach the ground at the same time, but Galileo wants to show and make Simplicio understand that the arrival time of these bodies is very close to each other, and the difference is almost imperceptible. Next, Salviati presents Simplicio with several other experiments, such as, for example: making objects fall in different environments, and imagining an object falling in a vacuum. After presenting several experiments, Salviati concludes that without air resistance, objects fall at the same time. After this statement, Simplicio comments that:

Simplicio – A remarkable statement, Mr. Salviati. I would never believe that even in a vacuum, if motion were possible in it, a flake of wool would move at the same speed as a piece of lead.

Salviati – Slowly, Mr. Simplicio [...]. We are trying to investigate what would happen to pieces of furniture of very different weights in a medium whose resistance was zero, so that any difference in speed found between these pieces of furniture should be related solely to the inequality of weight. Since only a space completely empty of air and of any other body, however subtle and penetrable, could show us perceptively what we seek, and since we do not have such a space, we will observe what happens in the subtlest and least resistant media by comparison with what is seen to happen in the least subtle and most resistant media. If we effectively observe that objects of different specific weights differ less and less in speed as the medium becomes less and less resistant, and that, finally, although extremely unequal in weight, in the most tenuous medium, even if not empty, the inequality of speeds is very small and almost unobservable, it seems to me that we can admit, as a highly probable conjecture, that in a vacuum their speeds would be completely equal (GALILEI, 1988, p. 62).

In this way, Galileo's theory that two bodies of different weights fall together in a vacuum was proven years after his death, with the invention of the vacuum pump. Today, it is easy to verify this motion in laboratories. Figure 3 shows an image of two spheres with different weights, using stroboscopic photography.

Figure 3: Stroboscopic photography of two spheres

Source: PROJECTO FISICA, 1978.

Therefore, with today's resources, it is easy to understand this phenomenon. However, in Galileo's time, it was very hard work to explain it without resources; Galileo had to use his imagination to understand it. Therefore, "learning what to ignore was almost as important for the development of science as learning what to consider" (PHYSICS PROJECT, 1978, p.48). Therefore, to understand a certain phenomenon, at that time, it was necessary to use imagination; it was not enough to simply observe what was happening around us.

According to the Physics Project (1978), for Galileo to be able to convince people that Aristotle was wrong in his theory, it was necessary to have a lot of experimental skill and mathematical talent to describe this motion.

V. Definitions For Uniformly Accelerated Motion

Galileo demonstrated how to write the motion of bodies mathematically. He made the following observation: "[...] a stone that falls from a certain height from rest gradually acquires new increases in speed, so why can't I believe that such increases in speed do not occur according to the simplest and most obvious proportion?" (GALILEU, 1988, p.127).

According to Galileo (1988), uniform motion is that in which an object travels equal spaces in equal times, and uniformly accelerated motion is when, in equal times, equal variations in speed occur, with the second type of motion being that which characterizes the Fall of Bodies (ignoring or minimizing air resistance).

Thus, Galileo admits that this would not be the only way to define uniform acceleration. He comments that he also thought of other ways to define this term, which could be "[...] if the speed increased proportionally to the distance traveled, instead of being proportionally to time" (PROJECTO FÍSICA, 1978, p.51). In this sense, Galileo's two descriptions of uniformly accelerated motion seem to be in agreement with the understanding of acceleration. However, Galileo had to choose only one of the statements.

According to Cohen (1967), Galileo had to establish a criterion for choosing the description of uniformly accelerated motion; thus, for Galileo, speed could not increase proportionally to distance, as this would lead to a "logical inconsistency", which would not happen with the other definition, in which speed increases proportionally to time. Cohen (1967) commented on this logical inconsistency, saying that "[...] there is no logical inconsistency here: the problem is simply that this relationship is incompatible with the hypothesis that the body starts from rest" (COHEN, 1967, p. 99).

After Galileo had defined uniformly accelerated motion, in which the speed of a falling body is proportional to the time of fall, he looked for a way to describe the observed motions, since he needed to present which definition was adequate for those observed motions. Galileo, however, had some difficulties, considering that it would be impossible to carry out measurements to verify that speed increases in proportion to time. Since he would be able to directly measure the speed and also the time it takes for an object to fall, even objects left in very high places gain speed too quickly to be measured accurately with the equipment available at the time (PHYSICS PROJECT, 1978).

Despite this difficulty, Galileo tried to prove his hypothesis in other ways, making other relationships that he could prove. In view of this, he tried to relate the total distance traveled by an object and its total time. In this line of reasoning, Galileo concluded: "[...] in uniformly accelerated motion initiated from rest, the distance traveled is proportional to the square of the time elapsed" (PHYSICS PROJECT, 1978, p.54).

$D \propto t^2$ *(Equation 5)*

This shows that the distance traveled by an object in free fall is proportional to the square of the time of fall. Galileo comments that for an object starting from rest and with uniformly accelerated motion, the displacements D1, D2, D3 and so on, with equal time intervals, are proportional to the odd numbers, 1, 3, 5, and so on (COHEN, 1967). Therefore, Galileo concludes that "[...] during equal intervals of time, the velocities increase with the natural numbers, the increases in the distances traveled during these intervals of equal times are among themselves as the odd numbers, starting with unity" (COHEN, 1967, p. 101). It can be concluded, then, that this statement by Galileo is contrary to that of Leonardo da Vinci, who said that spaces traveled in equal times were proportional to the whole numbers. After this explanation by Galileo, Simplicio comments:

Simplicio – [...] I am fully convinced that things happen this way, once the definition of uniformly accelerated motion has been announced and accepted. But whether this is the acceleration that nature uses in the falling motion of the bass, I have my doubts at the moment. It seems to me, for what concerns me and others who think like me, that it would have been appropriate in this place to present one of the many experiments that, in several cases, agree with the conclusions demonstrated (GALILEU, 1988, p. 140).

Galileo presents one of his famous experiments, that of the inclined plane, from which he was able to prove his hypotheses. The definition of uniformly accelerated motion Galileo obtained through rationality, and this experiment of the inclined plane came only to corroborate his hypotheses. Therefore, according to Neves (2008), one can have two views on Galileo, one rationalist and the other empiricist.

VI. The Inclined Plane Experiment

Galileo proposed the inclined plane experiment in order to compare it with the results he had obtained rationally about uniformly accelerated motion. Before presenting the experiment, the theorems and propositions deduced by Galileo will be presented.

Sagredo – [...] it seems to me that up to now we have managed to establish the definition of uniformly accelerated motion, which is the subject of the continuation. This definition is: we call equally accelerated or uniformly accelerated motion that which, starting from rest, acquires equal moments of speed in equal times (GALILEI, 1988, p.133).

Therefore, Galileo begins to demonstratively deduce his theorems and propositions, which are:

Theorem I – Proposition I: the time in which a given space is traveled by a mobile that starts from rest with a uniformly accelerated motion is equal to the time in which that same space would be traveled by the same mobile with a uniform motion, whose speed is half the highest and last speed achieved in the uniformly accelerated motion.

Theorem II – Proposition II: If a mobile, starting from rest, falls with a uniformly accelerated motion, the spaces traveled by it in any time are among themselves in the double ratio of the times, namely, as the squares of these times (GALILEI, 1988, p.136).

After stating the theorems, Galileo demonstrates them using geometric resources. Then, in dialogue with Sagredo, Salviati, who represents Galileo, explains how this inclined plane experiment was carried out to prove that his previous definitions are true.

Salviati – [...] In a slat, or rather, in a wooden beam approximately 12 *braccia* long, half a *braccia* wide on one side and three fingers wide on the other, a channel was dug on this narrower side, a little more than a finger wide. Inside this perfectly straight channel, to make it well polished and clean, a sheet of parchment was placed and polished until it was very smooth; we lowered a very hard bronze ball, perfectly round and smooth, through it. The apparatus having been constructed, it was placed in an inclined position, raising one of its ends above the horizon to the height of one or two *braccia*, and the ball was allowed to descend (as I have stated) through the gutter, noting, as I shall explain later, the time it took for a complete descent; repeating the same experiment many times in order to determine exactly the quantity of time, in which a difference of not even a tenth of a pulse beat was never found. This operation having been carried out and established with precision, we allowed the same ball to descend only a quarter of the total length of the gutter; and, measuring the time of fall, it always turned out to be exactly equal to half that of the other. By then varying the experiment, and comparing the time required to travel the entire length with the time required to travel half, or two-thirds, or three-quarters, or to complete any other fraction, through experiments repeated more than a hundred times, it was always found that the spaces traveled were between themselves like the squares of the times, and this at all the inclinations of the plane, that is, of the gutter, through which the ball was lowered. We also observed that the fall times for the different inclinations of the plane maintained exactly that proportion between themselves which, as we will see later, was found and demonstrated by the author (GALILEI, 1988, p. 140).

This description of the inclined plane experiment was carried out so carefully that other people could also carry out the experiment. After Galileo had carried out the experiment several times and with different inclinations of the plane, it was possible to conclude that his definition was correct, in which, "[...] the spaces traveled were between themselves like the squares of time" (GALILEI, 1988, p. 140).

An important point to highlight is how Galileo measured time, given that, at that time, clocks did not exist. Initially, he tried to measure time using his own heartbeats, but was unsuccessful. Therefore, he used a water clock.

Salviati – [...] As regards the measurement of time, we used a large container filled with water, suspended from above, which, through a small hole made in the bottom, let fall a thin stream of water, which was collected in a small cup during the entire time that the ball was descending through the gutter or through its parts. The quantities of water thus collected were weighed each time with a very precise balance, the differences and proportions between the weights corresponding to the differences and proportions between the times; and this with such precision that, as I have said, these operations, repeated many times, never differed significantly (GALILEI, 1988, p. 141).

It is important to emphasize that the water clock used by Galileo in his experiment was not invented by him. The results obtained using this clock were confirmed some time later with the appearance of other clocks (PROJECTO FÍSICA, 1978).

Regarding his experiment, there were some comments that said there was a big difference between the free fall of an object and the fall of a sphere on an inclined plane. During the experiment, at no time did Galileo refer to the angles used to perform the experiment. It can be concluded, then, that, to perform the measurements, he used only small angles, since increasing the angle also meant increasing the speeds, which would make it difficult to measure the time taken for the sphere to descend (PROJECTO FÍSICA, 1978).

According to Cohen (1967), another important point is that when the inclined plane reaches a very large angle, this does not allow the sphere to roll equally as on the inclined plane. By increasing the angles of the plane, a certain point is reached where the sphere begins to roll and slide together, and this is a point that Galileo does not comment on.

According to Neves *et al* (2008), Galileo arrived at the law of falling bodies through his studies, and his inclined plane experiment was only to prove his law, which he had found theoretically. It is therefore worth noting that his experiment was not carried out to formulate a law, but rather to confirm that his reasoning was correct. According to Cohen (1967, p. 107), Galileo defined uniformly accelerated motion as an object "[...] starting from rest, in which the speed over the same change at equal intervals of time corresponds to traveling distances that are proportional to the squares of the times [...]", and then showed that his law was correct, through the inclined plane experiment. Given these results, Galileo says that, in the absence of air resistance, an object in free fall will always be accelerated. His results were confirmed thirty years later, when Robert Boyle managed to produce a vacuum in a cylinder and thus confirm that bodies of different weights fall at the same speed (COHEN, 1967).

Cohen (1967) also comments that Galileo not only measured the time of a body in free fall using the inclined plane, as he said that he had already made this measurement when he dropped an object from the Tower of Pisa, but Father Mersenne, a contemporary of Galileo, comments that he tried to carry out this experiment, but was unable to obtain the same results as Galileo. The experiment is somewhat controversial, since many people do not believe that Galileo actually carried it out.

VII. Did The Tower Of Pisa Experiment Actually Happen?

When we talk about Galileo Galilei, the image of the Leaning Tower (Tower of Pisa) immediately comes to mind, since in many books, this image shows that Galileo performed the free fall experiment there. The facts say that Galileo climbed to the top of the famous Tower and from there he dropped two objects of different weights, and they reached the ground at the same time.

Galileo would have performed this experiment to refute Aristotle's ideas. Aristotle reports that when dropping objects from the same height, but with different weights, they would reach the ground at different times, the heavier one would arrive before the lighter one, and therefore, the speed of the object is proportional to its weight. In this way, Galileo wanted to prove to everyone that Aristotle was wrong. Thus, Galileo climbed the leaning tower "[...] calm and tranquil, despite the laughter and shouts of the crowd, he dropped the two iron balls. All eyes turned upward. Silence! And what was seen: the two balls left together, fell together and together touched the ground at the foot of the tower" (KOYRÉ, 1982, p. 200).

This story that Galileo climbed the tower to perform the experiment was told by his biographer Viviani, and continues to this day (COHEN, 1967). According to Cohen (1967), there is no other document that shows that Galileo actually performed this experiment; therefore, many scholars doubt that it actually happened. So, how is it possible that no one else commented on it, not even Galileo's own friends? There is only one explanation for this silence: "[...] if Galileo never talks about the Pisa experiment, it is because he did not do it. In fact, fortunately for him, because if he had done it, formulating the challenge that historians who dealt with it formulated for him, the experiment could have left him confused" (KOYRÉ, 1982, p. 202).

However, if Galileo had really carried out the leaning tower experiment in front of everyone, he would have confirmed Aristotle's idea that heavy bodies reach the ground before lighter ones. However, what many did not understand was that this difference occurred due to air resistance. Galileo explains that by letting two objects with different weights fall freely in a vacuum, they would reach the ground together. Regarding motion in the air, this could not be considered free; in this case, the object has to overcome this resistance, which is small but not negligible (KOYRÉ, 1982).

This pseudo-experiment is widely used in textbooks as an empirical example of something that has never been done before. When two balls of different weights were dropped, they would not reach the ground together. Therefore, the experiment of the Leaning Tower of Pisa can be considered a legend, since it is not written anywhere that this actually happened, other than the account of Galileo's biographer.

VIII. Final Considerations

Physics teaching is characterized by linear teaching, followed by mathematical and memoristic formalism (NEVES, 1992). In this sense, Physics teaching is not important to students, because the way it is approached disconnects the teaching from the student's reality. Therefore, it is necessary to break with the Newtonian-Cartesian thinking that fragments knowledge, leading teachers to use methodologies centered on memorizing content.

The inclusion of the History of Science would be one of the tools that teachers can use to make the teaching of Physics more human, thus making more sense of what students are learning and showing how a concept is actually constructed. It should also be added that the History of Science contributes to teaching, since:

[...] (1) motivates and attracts students; (2) humanizes the subject; (3) promotes a better understanding of scientific concepts by tracing their development and improvement; (4) there is an intrinsic value in understanding certain fundamental episodes in the history of science – the Scientific Revolution, Darwinism, etc.; (5) demonstrates that science is changeable and unstable and that, therefore, current scientific thought is subject to transformations that (6) oppose the scientistic ideology; and, finally (7) history allows a more fruitful understanding of the scientific method and presents the patterns of change in the current methodology. (MATTHEWS, 1995, p. 172).

As can be seen in Matthews (1995), there are several arguments in favor of using the History of Science; however, teachers should be aware of the type of history that is included in textbooks. Regarding the concept of Falling Bodies, it is difficult to find the entire historical construction of this concept in textbooks. Thus, teachers present their students only with the mathematical part, without addressing how the law known today was arrived at.

In this sense, it is also clear that many students maintain an Aristotelian view of the concept of Falling Bodies, since this is a phenomenon that is difficult to imagine without air resistance. This is one of the important reasons for presenting students with the construction of this concept through the History of Science, so that they can understand that their thinking is a common sense conception. It is interesting for students to realize that their thoughts are in line with Aristotelian ideas. And finally, show students the importance of Galileo's imaginary experiments, these being his main contributions to the understanding of the Fall of Bodies, and then the results of the imaginary experiments were proven with the experiments.

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