



UNIVERSITY OF NOVI SAD
FACULTY OF SCIENCES
DEPARTMENT OF PHYSICS



Implementation of Scientific Method in Treatment Theme Accelerated Motion

- Final paper -

Mentor:
Ph. D. Dušanka Obadović, full prof.

Student:
Zouhor Zekri

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1. Introduction

Since antiquity, people have tried to understand the behaviour of the natural world.

Physics (from Greek: φύσις that means "nature") is a natural science that involves the study of matter and its motion through space-time. Physics also explains all related concepts, like energy and force. It is the general analysis of nature, conducted in order to understand how the universe behaves.

Physics is one of the oldest academic disciplines, perhaps the oldest through its inclusion of astronomy.

New ideas in physics explain the fundamental mechanisms of other sciences and opening to new research areas in mathematics and philosophy. Physics is also significant because advances in its understanding lead to development of new technologies. For example, advances in the understanding of electromagnetism or nuclear physics led directly to the development of new products which have dramatically transformed modern-day society, such as television and computers.

Physicists use a scientific method to test the validity of a physical theory, using a methodical approach to compare the implications of the theory in question with the associated conclusions drawn from experiments and observations conducted to test it. Experiments and observations are to be collected and matched with the predictions and hypotheses made by a theory, thus aiding in the determination or the validity (or invalidity) of the theory.

Theories which are very well supported by data and have never failed any competent empirical test are often called scientific laws, or natural laws. Of course, all theories, including those called scientific laws, can always be replaced by more accurate, generalized statements if a disagreement of theory with observed data is ever found.

It is very important to teach physics in schools because of importance of physics as science and its significant influence to society. It is needed to teach children and get them interested so we will have good scientists in future. But maybe the most important role of teaching physics in schools is that it affects all children by helping them to develop a scientific worldview.

In this paper is written about use of scientific method in teaching physics by application of simple experiments. That innovation of use of modern teaching methods is very important and helpful in teaching process. Example of teaching about Accelerated motion is given. After theory of accelerated motion, methodology and historical background of scientific method and examples of experiments for investigation of accelerated motion through history, two simple experiments are explained: Falling objects and Brachistochronous fall. Conclusion about importance of understanding why and how scientific method should be used is given at the end of this paper.

2. Theory of Accelerated Motion

First we will give the definition of acceleration and write the basis of accelerated motion. Average and instantaneous acceleration can be defined.

2.1. Average and Instantaneous Acceleration

As a particle moves from one point to another along some path, its instantaneous velocity vector changes from \vec{v}_i at time t_i to \vec{v}_f at time t_f . Knowing the velocity at these points allows us to determine the average acceleration of the particle:

The average acceleration of a particle as it moves from one position to another is defined as the change in the instantaneous velocity vector $\Delta\vec{v}$ divided by the time Δt during which that change occurred:

$$\vec{a} = \frac{\vec{v}_f - \vec{v}_i}{t_f - t_i} = \frac{\Delta\vec{v}}{\Delta t} \quad (2.1)$$

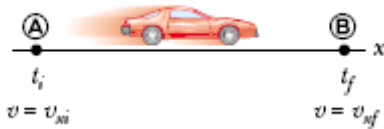
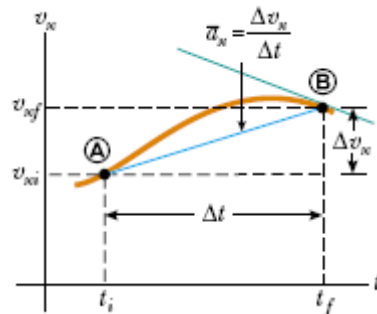


Figure 2.1 A car, modeled as a particle; moving along the x axis from A to B has velocity v_{xi} at $t = t_i$ and velocity v_{xf} at $t = t_f$.



Graph 2.1 Velocity-time graph (rust) for particle moving in a straight line. The slope of the blue straight line connecting A and B is the average acceleration in the time interval $\Delta t = t_f - t_i$.

Because it is the ratio of a vector quantity $\Delta\vec{v}$ and a scalar quantity Δt , we conclude that average acceleration is a vector quantity directed along $\Delta\vec{v}$. As indicated in Figure 2, the direction of $\Delta\vec{v}$ is found by adding the vector $-\vec{v}_i$ (the negative of \vec{v}_i), because by definition $\Delta\vec{v} = \vec{v}_f - \vec{v}_i$. When the average acceleration of a particle changes during different time intervals, it is useful to define its instantaneous acceleration \vec{a} :

The instantaneous acceleration \vec{a} is defined as the limiting value of the ratio $\frac{\Delta\vec{v}}{\Delta t}$ as Δt approaches zero:

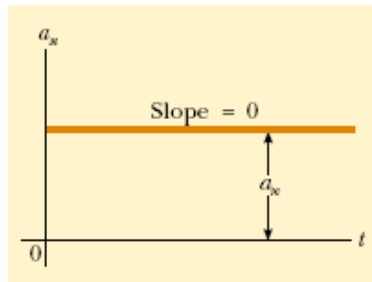
$$\vec{a} = \lim_{\Delta t \rightarrow 0} \frac{\Delta\vec{v}}{\Delta t} = \frac{d\vec{v}}{dt} \quad (2.2)$$

In other words, the instantaneous acceleration equals the derivative of the velocity vector with respect to time.

It is important to recognize that various changes can occur when a particle accelerates. First, the magnitude of the velocity vector (the speed) may change with time as in straight-line (one-dimensional) motion. Second, the direction of the velocity vector may change with time even if its magnitude (speed) remains constant, as in curved-path (two-dimensional) motion. Finally, both the magnitude and the direction of the velocity vector may change simultaneously.

2.2. Uniformly Accelerated Motion in Straight Line (Linear)

Uniform (constant) acceleration motion is a type of motion in the velocity of an object changes by an equal amount in equal time period.



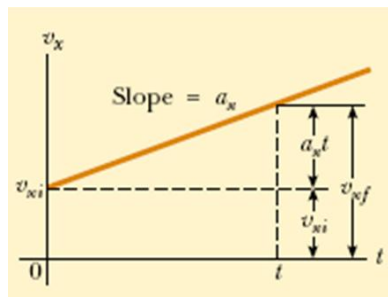
Graph 2.2 Acceleration-time graph for uniformly accelerated motion in straight line

Due to the unique algebraic properties of constant acceleration, mathematicians have derived formulae:

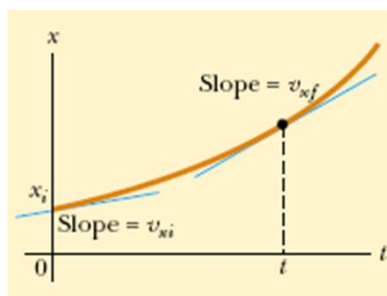
$$v = v_0 + at \quad (2.3)$$

$$s = v_0t + \frac{at^2}{2} \quad (2.4)$$

$$v = \sqrt{v_0^2 + 2as} \quad (2.5)$$



Graph 2.3 Velocity-time graph for uniformly accelerated motion in straight line



Graph 2.4 Displacement-time graph for uniformly accelerated motion in straight line

Where s is for displacement, v_0 -initial velocity, v -final velocity, a -acceleration and time.

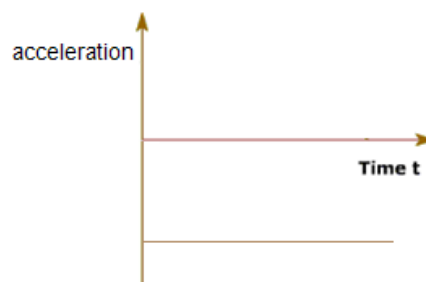
The most frequently cited example of uniform acceleration is object in free fall when its acceleration (in the absence of resistances to motion) is dependent only on the gravitational field strength g (also called acceleration due to gravity).

The above graphs are for positive acceleration when velocity increases.

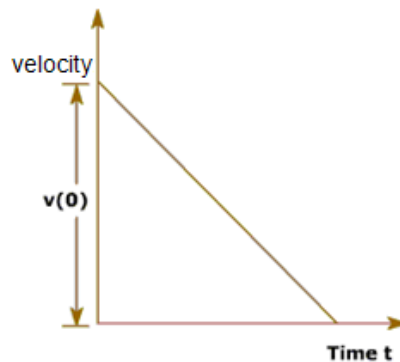
In physics, acceleration is not just an increase in velocity, but also a decrease in velocity.

Even though it can be heard that people use the word deceleration to describe an object slowing down, this isn't really proper physics. Instead, a decrease in velocity should be called negative acceleration. This actually helps when one is doing calculations and also gives more meaning to acceleration.

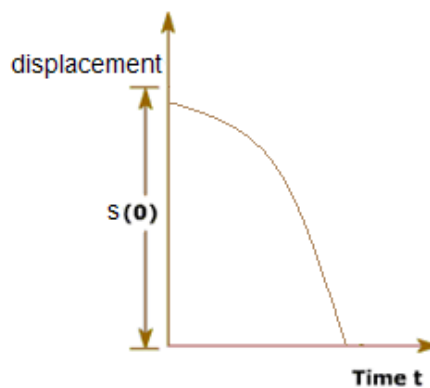
For negative acceleration we have:



Graph 2.5 Acceleration-time graph for uniformly accelerated motion in straight line, with negative acceleration



Graph 2.6 Velocity-time graph for uniformly accelerated motion in straight line, with negative acceleration



Graph 2.7 Displacement-time graph for uniformly accelerated motion in straight line, with negative acceleration

3. Methodology

A common misconception in science is that science provides facts or "truth" about a subject. Science is not collection of facts; rather, it is a process of investigation into the natural world and the knowledge generated through that process. This process of investigation is often referred to as the scientific method and it is typically defined in many textbooks and science courses as a linear set of steps through which a scientist moves from observation through experimentation and to a conclusion as shown below:



Figure 3.1 Science is not a linear process

However, this classic portrayal has a number of problems. Science is not a linear process – it doesn't have to start with an observation or a question, and it commonly does not even involve experiments. Instead, the scientific method is a much more dynamic and robust process (Figure 1). Scientists get their inspiration from the natural world, from reading what others have done, from talking to colleagues, or from experience. They use multiple types of research toward investigating phenomena, including experimentation, description, comparison, and modeling. Some scientific investigations employ one of these methods, but many involve multiple methods, or some studies may even have characteristics of more than one method. Results from one research study may lead in directions not originally anticipated, or even in multiple directions as different scientists pursue areas of interest to them.

Inquiry-based Learning and Scientific Method in Schools

Importance of inquiry is great because memorizing facts and information is not the most important skill in today's world. (Facts change, and information is readily available - what's needed is an understanding of how to get and make sense of the mass of data.)

Infants begin to make sense of the world by inquiring. The process of inquiring begins with gathering information and data through applying the human senses - seeing, hearing, touching, tasting, and smelling.

An old adage states: "Tell me and I forget, show me and I remember, involve me and I understand." The last part of this statement is the essence of inquiry-based learning.

"Inquiry" is defined as "a seeking for truth, information, or knowledge - seeking information by questioning."

Key principles of inquiry learning are those listed here:

1. All learning activities should focus on using information-processing skills (from observations to synthesis) and applying the discipline "ground rules" as a means to learn content set in a broad conceptual context.

2. Inquiry learning puts the learner at the center of an active learning process, and the systemic elements (the teacher, instructional resources, technology, and so forth) are prepared or aligned to support the learner.
3. The role of the teacher becomes one of facilitating the learning process. The teacher also becomes a learner by finding out more about the learner and the process of inquiry learning.
4. What is assessed is what is valued. Therefore, more emphasis needs to be placed on assessing the development of information-processing skills, nurtured habits of mind, or "ground rules" of the discipline, and conceptual understandings -- rather than just the content of the field.

A good way to implement inquiry learning is use of scientific method in classroom. That's why experiments and scientific method must be well known by teachers.

Today in schools all over the world there is attempt for achieving those goals and we will see now an example.

Project La main à la pâte, which means a collaborative, hands-on work in French, was founded in 1996 by Georges Charpak, Nobel prize winner, Pierre Léna, Yves Quéré and the French Academy of Sciences - Institute of France with the support of the French Ministry of Education. Today, it is managed in partnership with the French National Institute for Pedagogical Research (INRP) and the École normale supérieure of Paris.

La main à la pâte aims to renew and expand science teaching in school in France and to contribute to achieving this aim in a large number of countries.

The international action of La main à la pâte has been an integral part of the French program from the very beginning. Far from being merely an extension of the progress made in France, it was an essential dimension from the outset. Today, all over the world there is tendency for this way of introducing science in schools that is based on the use of scientific method.

Teaching the Scientific Method is a fundamental way for students to practice thinking critically. By performing science experiments and analyzing the resultant data, you are helping to build the next generation of creative thinkers.

Through the six steps of the Scientific Method, students learn how to define a problem, observe situations, take notes, synthesize the results, and come to a logical conclusion based on objective results.

The six steps of the Scientific Method are actually the tasks that we give our students to do and a students' worksheets should contain them:

1. Problem – What are you trying to figure out? Write this in the form of a question.
2. Hypothesis – What do you think you are going to find out?
3. Materials – List the materials you will use in the experiment.
4. Procedures – Make a detailed list of the steps in your experiment.
5. Results – What did you observe when you performed the experiment?
6. Conclusion – From what you observed, how would you answer your original question?

This way of teaching science is very effective and as we have already said can easily be carried out by implementation of experiments (laboratory work) and simple experiments that can always be done with students from the youngest age and for what we don't need expensive equipment.

4. Historical Background

"One of the most controversial issues in the history of science has been the question of how far Galileo's achievement in mechanics was dependent on the use of experiment" (Naylor). When this statement was published, the controversy was almost settled. Whilst in the beginning of the 20th century, most historians of science followed in particular Mach's notion of Galileo being the father of experimental practice, things changed when the philosopher Alexandre Koyré questioned whether Galileo had actually performed the experiments he described in his publications. In 1961, Thomas Settle used a reconstruction in order to show that it is possible in principle to carry out the experiments described by Galileo. Moreover, he also used this set-up to develop an understanding of the experimental procedures as well as the skills necessary for the experiment. The question of whether Galileo actually did experiments or not came almost to an end with Drake's finding of a manuscript page obviously containing experimental data.

4.1. Galileo and Scientific Method

Galileo devised a method that exhibits some provocative similarities to, and differences from, a Rasch approach to instrument design: Viewed as a whole, Galileo's method then can be analyzed into three steps, intuition or resolution, demonstration, and experiment; using in each case his own favorite terms.

That Galileo actually followed these three steps in all of his important discoveries in dynamics is easily ascertainable from his frank biographical paragraphs, especially in the "Dialogues Concerning Two New Sciences."

Galileo's first step is organized observation: Facing the world of sensible [perceptible by sense] experience, we isolate and examine as fully as possible a certain typical phenomenon, in order first to intuit those simple, absolute elements in terms of which the phenomenon can be most easily and completely translated into mathematical form; which amounts (putting the matter in another way) to a resolution of the sensed fact into such elements in quantitative combinations.

The term elements is ambiguous. Initially elements appear to correspond to test items, survey questions or rating scales, but in the next sentence those same elements are already quantities. This leap from the ephemeral specifics of the data (sensed facts) into quantities is what Edmund Husserl terms Galileo's "fateful omission" of the means by which nature is mathematicized.

The means of quantification seemed self-evident to Galileo (as well as Descartes and Newton). There is also a common willingness in the social and human sciences to assume that one's intuitions of a variable's content and structure are enough to resolve (bring into focus) its quantitative elements (i.e., to separate them from all other variables, thus

satisfying Rasch's separability theorem). But this self-evidence has proven to be unwarranted.

Burt presents us with Galileo's formulation of what Ronald Fisher called "sufficiency": [If we have] performed this step [the intuition of elements] properly, we need the sensible facts no more; the elements thus reached are their real constituents, and deductive demonstration from them by pure mathematics (second step) must always be true of similar instances of the phenomenon, even though at times it should be impossible to confirm them empirically.

Once the quantitative status of the variable has been treated as a hypothesis, substantiated, and its elements derived from data, we need the sensible facts no more... Deductive demonstration from them [the sensible facts] by pure mathematics ... must always be true of similar instances. A continuing basis of all science is that quantitative differences among different aspects of the phenomenon should hold constant across similar observations. This requires that scale values be invariant, even when empirical evidence is unavailable (as, for example, relating to items not administered in computer-adaptive testing).

Galileo also perceived the value of descending from the world of mathematical manipulation of quantities into that of sensory perception: For the sake of more certain results, however, and especially to convince by sensible illustrations those who do not have such implicit confidence in the universal applicability of mathematics, it is well to develop, where possible, demonstrations whose conclusions are susceptible of verification by experiments [his third step]. Then, with the principles and truths thus acquired, we can proceed to more complex related phenomena and discover what additional mathematical laws are there implicated.

Since there are many who do not have such implicit confidence in the universal applicability of mathematics, it is necessary to substantiate with evidence what Galileo would intuit. Galileo's deductive, logical necessity of the way quantitative elements follow from sensible facts is for us experimental. We must add, as Galileo did not, that deduction is circularly complemented by induction, that logic is not simply rational, but also metaphorical, poetical, social, economic, political, and cultural.

Galileo contributed to Western culture's mind/body dualism by discrediting the trustworthiness of sensible facts in favor of intuited elements, deductive demonstrations, and experimental verification of how elements (quantitative units of measurement) follow from sensible facts. We, however, need to realize that our scientific instruments are extensions of our bodies' sense organs. The elements read off these extensions are also sensible facts dependent upon the existence of particular kinds of technology and on people who value them.

The technical aspects of Galileo's methods have been continually improved. Even his "fateful omission" of the step from observation to quantification has been remedied. Now it is up to us to give science a human face - to flesh out these technical advances with the meaning and sensitivity required to make measurement work in the complex applications we face today.

4.2. Galileo's Contribution

When speaking of accelerated motion or scientific method must be said about Galileo's contribution to science. Because of that here is written about Galileo's life and work.

4.2.1. Galileo Galilei

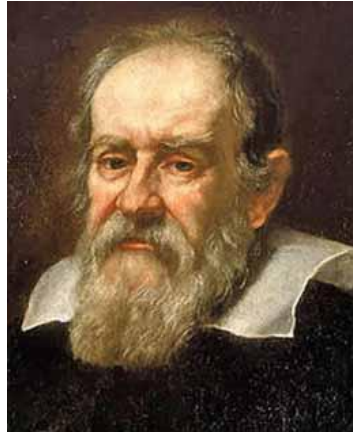


Figure 4.1 Galileo Galilei

Galileo Galilei (February 15, 1564 - January 8, 1642) was an Italian physicist, mathematician, astronomer, and philosopher who played a major role in the Scientific Revolution. His achievements include improvements to the telescope and consequent astronomical observations, and support for Copernicanism.

Galileo has been called the "father of modern observational astronomy", the "father of modern physics", the "father of science", and "the Father of Modern Science." The motion of uniformly accelerated objects, taught in nearly all high school and introductory college physics courses, was studied by Galileo as the subject of kinematics. His contributions to observational astronomy include the telescopic confirmation of the phases of Venus, the discovery of the four largest satellites of Jupiter, named the Galilean moons in his honor, and the observation and analysis of sunspots. Galileo also worked in applied science and technology, improving compass design.

Galileo's championing of Copernicanism was controversial within his lifetime. The geocentric view had been dominant since the time of Aristotle, and the controversy engendered by Galileo's presentation of heliocentrism as proven fact resulted in the Catholic Church's prohibiting its advocacy as empirically proven fact, because it was not empirically proven at the time and was contrary to the literal meaning of Scripture. Galileo was eventually forced to recant his heliocentrism and spent the last years of his life under house arrest on orders of the Roman Inquisition.

His formulation of (circular) inertia, the law of falling bodies, and parabolic trajectories marked the beginning of a fundamental change in the study of motion.

His insistence that the book of nature was written in the language of mathematics changed natural philosophy from a verbal, qualitative account to a mathematical one in which experimentation became a recognized method for discovering the facts of nature.

Finally, his discoveries with the telescope revolutionized astronomy and paved the way for the acceptance of the Copernican heliocentric system, but his advocacy of that system eventually resulted in an Inquisition process against him.

Early life and career

Galileo was born in Pisa, Tuscany, on February 15, 1564, the oldest son of Vincenzo Galilei, a musician who made important contributions to the theory and practice of music and who may have performed some experiments with Galileo in 1588-89 on the relationship between pitch and the tension of strings.

The family moved to Florence in the early 1570s, where the Galilei family had lived for generations. In his middle teens Galileo attended the monastery school at Vallombrosa, near Florence, and then in 1581 matriculated at the University of Pisa, where he was to study medicine.

However, he became enamored with mathematics and decided to make the mathematical subjects and philosophy his profession, against the protests of his father. Galileo then began to prepare himself to teach Aristotelian philosophy and mathematics, and several of his lectures have survived.

In 1585 Galileo left the university without having obtained a degree, and for several years he gave private lessons in the mathematical subjects in Florence and Siena.

During this period he designed a new form of hydrostatic balance for weighing small quantities and wrote a short treatise, *La bilancetta* ("The Little Balance") that circulated in manuscript form.

He also began his studies on motion, which he pursued steadily for the next two decades.

In 1588 Galileo applied for the chair of mathematics at the University of Bologna but was unsuccessful.

His reputation was, however, increasing, and later that year he was asked to deliver two lectures to the Florentine Academy, a prestigious literary group, on the arrangement of the world in Dante's *Inferno*.

He also found some ingenious theorems on centers of gravity (again, circulated in manuscript) that brought him recognition among mathematicians and the patronage of Guidobaldo del Monte (1545-1607), a nobleman and author of several important works on mechanics.

As a result, he obtained the chair of mathematics at the University of Pisa in 1589.

There, according to his first biographer, Vincenzo Viviani (1622-1703), Galileo demonstrated, by dropping bodies of different weights from the top of the famous Leaning Tower, that the speed of fall of a heavy object is not proportional to its weight, as Aristotle had claimed.

The manuscript tract *De motu* (On Motion), finished during this period, shows that Galileo was abandoning Aristotelian notions about motion and was instead taking an Archimedean approach to the problem.

But his attacks on Aristotle made him unpopular with his colleagues, and in 1592 his contract was not renewed.

His patrons, however, secured him the chair of mathematics at the University of Padua, where he taught from 1592 until 1610.

Although Galileo's salary was considerably higher there, his responsibilities as the head of the family (his father had died in 1591) meant that he was chronically pressed for money.

His university salary could not cover all his expenses, and he therefore took in well-to-do boarding students whom he tutored privately in such subjects as fortification.

He also sold a proportional compass, or sector, of his own devising, made by an artisan whom he employed in his house. Perhaps because of these financial problems, he did not marry, but he did have an arrangement with a Venetian woman, Marina Gamba, who bore him two daughters and a son.

In the midst of his busy life he continued his research on motion, and by 1609 he had determined that the distance fallen by a body is proportional to the square of the elapsed time (the law of falling bodies) and that the trajectory of a projectile is a parabola, both conclusions that contradicted Aristotelian physics.

Galileo believed that the Sun is the centre of the universe and that the Earth is a planet, as Copernicus had argued. Galileo's increasingly overt Copernicanism began to cause trouble for him. In 1613 he wrote a letter to his student Benedetto Castelli (1528-1643) in Pisa about the problem of squaring the Copernican theory with certain biblical passages. Inaccurate copies of this letter were sent by Galileo's enemies to the Inquisition in Rome, and he had to retrieve the letter and send an accurate copy. Several Dominican fathers in Florence lodged complaints against Galileo in Rome, and Galileo went to Rome to defend the Copernican cause and his good name.

After several exchanges, mainly with Orazio Grassi (1583-1654), a professor of mathematics at the Collegio Romano, he finally entered the argument under his own name *Il saggiaiore* (The Assayer), published in 1623, was a brilliant polemic on physical reality and an exposition of the new scientific method. Galileo here discussed the method of the newly emerging science, arguing:

Philosophy is written in this grand book, the universe, which stands continually open to our gaze. But the book cannot be understood unless one first learns to comprehend the language and read the letters in which it is composed.

It is written in the language of mathematics, and its characters are triangles, circles, and other geometric figures without which it is humanly impossible to understand a single word of it.

In the Dialogue's witty conversation between Salviati (representing Galileo), Sagredo (the intelligent layman), and Simplicio (the dyed-in-the-wool Aristotelian), Galileo gathered together all the arguments (mostly based on his own telescopic discoveries) for the Copernican theory and against the traditional geocentric cosmology.

As opposed to Aristotle's, Galileo's approach to cosmology is fundamentally spatial and geometric: the Earth's axis retains its orientation in space as the Earth circles the Sun, and bodies not under a force retain their velocity (although this inertia is ultimately circular).

But in giving Simplicio the final word, that God could have made the universe any way he wanted to and still made it appear to us the way it does, he put Pope Urban VIII's favorite argument in the mouth of the person who had been ridiculed throughout the dialogue. The reaction against the book was swift.

Galileo was summoned to Rome in 1633.

During his first appearance before the Inquisition, he was confronted with the 1616 edict recording that he was forbidden to discuss the Copernican theory.

In his defense Galileo produced a letter from Cardinal Bellarmine, by then dead, stating that he was admonished only not to hold or defend the theory.

The case was at somewhat of an impasse, and, in what can only be called a plea bargain, Galileo confessed to having overstated his case.

He was pronounced to be vehemently suspect of heresy and was condemned to life imprisonment and was made to abjure formally.

There is no evidence that at this time he whispered, "Eppur si muove" ("And yet it moves").

It should be noted that Galileo was never in a dungeon or tortured; during the Inquisition process he stayed mostly at the house of the Tuscan ambassador to the Vatican and for a short time in a comfortable apartment in the Inquisition building.

After the process he spent six months at the palace of Ascanio Piccolomini (c. 1590-1671), the archbishop of Siena and a friend and patron, and then moved into a villa near Arcetri, in the hills above Florence. He spent the rest of his life there.

Galileo's daughter Sister Maria Celeste, who was in a nearby nunnery, was a great comfort to her father until her untimely death in 1634.

Galileo was then 70 years old. Yet he kept working. In Siena he had begun a new book on the sciences of motion and strength of materials.

There he wrote up his unpublished studies that had been interrupted by his interest in the telescope in 1609 and pursued intermittently since.

The book was spirited out of Italy and published in Leiden, Netherlands, in 1638 under the title *Discorsi e dimostrazioni matematiche intorno a due nuove scienze attenenti alla meccanica* *Dialogues Concerning Two New Sciences*.

Galileo here treated for the first time the bending and breaking of beams and summarized his mathematical and experimental investigations of motion, including the law of falling bodies and the parabolic path of projectiles as a result of the mixing of two motions, constant speed and uniform acceleration.

By then Galileo had become blind, and he spent his time working with a young student, Vincenzo Viviani, who was with him when he died on January 8, 1642.

4.2.2. Galileo's Falling Bodies Experiment

Maybe the most famous scientific experiment is Galileo Galilei's dropping objects from the leaning tower of Pisa in order to prove that all objects fall at the same rate, whatever their mass.

Many think that this experiment was never performed by Galileo and it is only a legend, since there is no in existence an account by Galileo himself of such an experiment conducted by him, and it is accepted by many science historians that this experiment was

at most a thought experiment which did not actually take place. To learn more about this dispute see the link section below.

In his *Two New Sciences* (1634) Galileo discusses the mathematics (first to apply mathematics for physics analysis) of a simple type of motion what we call today uniform acceleration or constant acceleration. Then he proposes that heavy bodies actually fall in just that way and that if it was possible to create a vacuum, any two falling bodies would travel the same distance in the same time.

On the basis of this proposal, he predicts about balls rolling down an inclined plane. Finally, he describes some inclined plane experiments corroborating his theory.

4.2.3. Galileo's Inclined Plane Experiment

Galileo used inclined planes for his experiment to slow the acceleration enough so that the elapsed time could be measured. The ball was allowed to roll a known distance down the ramp, and the time taken for the ball to move the known distance was measured. The time was measured using a water clock.

Galileo showed that the motion on an inclined plane had constant acceleration, dependent only on the angle of the plane and not the mass of the rolling body. Galileo then argued, but couldn't prove that free-fall motion behaved in an analogous fashion. Using Newton's laws, we can prove Galileo's theory by decomposing the gravitational force, acting on the rolling balls, into two vectors, one perpendicular to the inclined plane and one parallel to it.



Figure 4.2 Incline plane

We can find a video of this experiment at:

<http://catalogue.museogalileo.it/multimedia/InclinedPlane.html>.

Galileo revolutionized basic scientific principles which were posited by Aristotle and held firmly by scholars of the High Middle Ages and Renaissance using this simple equipment. One of his most important experiments was the inclined plane experiment. Galileo used his inclined plane, a simple board with a groove down which he rolled a small metal ball, to examine Aristotelian ideas about motion. Galileo's inclined plane experiment radically changed these ideas by concentrating on acceleration, a stage of motion ignored by Aristotle and most of his followers.

We can use experiment with incline plane to see motion with constant acceleration. The experiment procedure will be explained. Analysis of this experiment can be used to determine g .

The purpose of this lab is to measure the acceleration due to gravity.

Procedure:

- 1 Set up the inclined plane using the track, wooden blocks or books under the track, and something at the end to stop the marble.

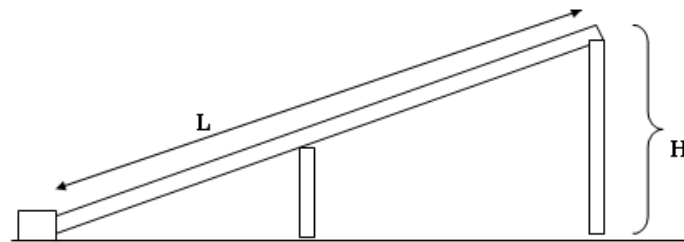


Figure 4.3 Incline plane

2. Measure and record the total length “L” and the height of the top of the track. The distance the marble rolls down is recorded as “S”. The 1st run of the marble is to be the entire length of the track. Record this total length as “L” at the top of your data table. Measure the height of the track “H” and record this at the top of the table. Once you have set up your track and recorded your value for “H” do not change the height of your track.

Since H and L are constants, if we measure the acceleration down the incline we can get a value for the acceleration due to gravity using equation:

$$g = a \frac{L}{H} \quad (4.1)$$

That is, we can calculate g by measuring H and L (figure 4.4), but that is only if we assume that friction is negligible. In that case we have inclined plane where:

$$a = g \sin \alpha \quad (4.2)$$

$$\sin \alpha = \frac{H}{L} \quad (4.3)$$

and according to equations (4.2) and (4.3):

$$g = a \frac{L}{H} \quad (4.4)$$

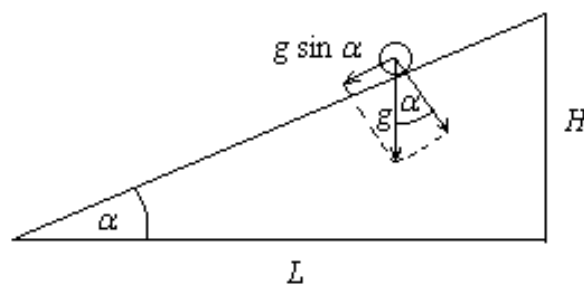


Figure 4.4 Acceleration of a body moving on incline plane

3. Sign out a marble and stop watch from your instructor.
4. Measure and record the length of the incline "L" and the height "H".
5. Set the marble on the incline, record "s" the distance-in cm-it will roll to the bottom of the track. The marble must always roll to the bottom of the track.
6. Release the marble and time it down the track. Do not push the marble. Record this as T1. Have your partner release the marble from the same place and time it. Record this as T2. Think about using the stopwatch effectively to minimize human error.
7. Change the distance and repeat steps 5 and 6 at least 5 times over a wide range of distances so you have a total of 6 distances. (For example if your track is 200cm long you might use 50cm, 100cm, 150cm, 175cm, and 200cm.) As the marble rolls less distance it must take less time. If it doesn't, repeat the measurement.
8. Repeat steps 5-7 with a different sized marble.

We can see that mass does not affect the result.

Introduction of the Experiment

As it could be understood from the above, Galileo performed his free fall experiments with the inclined plane in 1603 and published them in his Discourses on Two New Sciences (1638). The setup consists of a "piece of wooden moulding or scantling, about 12 cubits long, half a cubit wide, and three fingerbreadths thick" with a channel cut in it, and a bronze ball rolling down. The running time was measured (by a variety of means) dependent on the inclination of the plane, and so the law of the "retarded" free fall could be determined.

Without a doubt one of the best known experiments with respect to the discussion of free fall is the inclined plane experiment that was published by Galileo Galilei.

This experiment has been analysed by the Oldenburg group with the replication method. Currently, it is being worked on teaching material that will give access to our experiences with this set-up for teachers and students. Moreover, a demonstration apparatus was being developed in the 18th century to teach free fall and the superposition principle.

The Oldenburg Version of the Inclined Plane

In order to develop an understanding of Galileo's practice as well as to develop potential teaching materials, it was decided to analyse the inclined plane experiment with the replication method.

According to the dimensions given by Galileo in his publication our replica consists of a wooden block of 666.5 cm x 28 cm x 9 cm. A channel shaped like a semicircle was cut into it, 3.5 cm wide and 1.5 cm deep (fig.1 and 2). One end of the inclined plane was lifted by the help of a cuboid, its measures were 110cm * 55cm * 28cm.



Figure 4.5 Reconstructed inclined plane

The channel was lined with a parchment-like paper to smooth it, the transitions between the pages were smoothed by fine sandpaper. We use brass balls of 20, 25, and 30 mm diameter (fig.3); Galileo did not give the size of the balls he used.



Figure 4.6 Details of the inclined plane and the semicircle shaped channel



Figure 4.7 Brass balls used in the experiments placed in the reconstructed semicircle of the inclined plane

Time Measurement

As already mentioned, in the description of his experiment Galileo refers to a method of time measurement called the water clock. In our experiments we used a similar device (fig.4). The water clock consists of a 25 l plastic vessel which can be opened and closed at the lower end by the help of a stopcock. Provided that the filling height is sufficient there is

a linear relationship between past time and the quantity of water which can be determined by weighing or with the help of a measuring cylinder. As it turns out while redoing the experiment, a central experimental difficulty is the coordination between the signal of the running ball and starting and stopping the clock.



Figure 4.8 Water clock

In the experiments, opening and closing the stopcock of the water clock turned out to be by far too imprecise so that the procedure was modified: Instead of using the stopcock, the flow of water through the flexible tube behind the stopcock was suspended with the thumb of one hand. In the experiment, the ball was released with the other hand and at the same time, the water clock was started by removing the thumb. When the ball reached the end of the inclined plane, the sound was taken as the signal to suspend the flow of water with the thumb again. In series of measurements, the ball was released in a manner that it had to roll $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, and the entire length of the plane until it reached the end.

The gathered data shows that the time deviation of the measurement between two individual runs can be up to 2.5 ml. This amount corresponds to 0.25 seconds and is longer than the value given by Galileo who had claimed to have gotten results with a deviation of no more than a tenth of a pulse (about one tenth of a second). Thus, it appeared to be questionable whether our set-up differs in some relevant detail from Galileo's, whether we have to develop necessary skills in order to achieve data with a deviation as little as indicated by Galileo, or whether Galileo's claim with respect to the accuracy of his measurements can be taken as justified.

4.2.4. Scientific Method in Galileo's Acceleration Experiment

Summarizing Aristotle's View

Aristotle held that there are two kinds of motion for inanimate matter, natural and unnatural. Unnatural (or "violent") motion is when something is being pushed, and in this case the speed of motion is proportional to the force of the push. (This was probably deduced from watching ox carts and boats.) Natural motion is when something is seeking its natural place in the universe, such as a stone falling, or fire rising. (We are only talking here about substances composed of earth, water, air and fire, the "natural circular motion" of the planets, composed of aether, is considered separately).

For the natural motion of heavy objects falling to earth, Aristotle asserted that the speed of fall was proportional to the weight, and inversely proportional to the density of the medium the body was falling through. He did also mention that there was some acceleration, as the body approached more closely its own element, its weight increased and it speeded up. However, these remarks in Aristotle are very brief and vague, and certainly not quantitative.

Actually, these views of Aristotle did not go unchallenged even in ancient Athens. Thirty years or so after Aristotle's death, Strato pointed out that a stone dropped from a greater height had a greater impact on the ground, suggesting that the stone picked up more speed as it fell from the greater height.

Two New Sciences

Galileo set out his ideas about falling bodies, and about projectiles in general, in a book called "Two New Sciences". The two were the science of motion, which became the foundation-stone of physics, and the science of materials and construction, an important contribution to engineering.

The ideas are presented in lively fashion as a dialogue involving three characters, Salviati, Sagredo and Simplicio. The official Church point of view, that is, Aristotelianism, is put forward by the character called Simplicio, and usually demolished by the others. Galileo's defense when accused of heresy in a similar book was that he was just setting out all points of view, but this is somewhat disingenuous-Simplicio is almost invariably portrayed as simpleminded.

For example, on "Two New Sciences" page 62, Salviati states:

I greatly doubt that Aristotle ever tested by experiment whether it be true that two stones, one weighing ten times as much as the other, if allowed to fall, at the same instant, from a height of, say, 100 cubits, would so differ in speed that when the heavier had reached the ground, the other would not have fallen more than 10 cubits.

Simplicio's response to this is not to think in terms of doing the experiment himself to respond to Salviati's challenge, but to scrutinize more closely the holy writ:

SIMPLICIO: His language would seem to indicate that he had tried the experiment, because he says: We see the heavier; now the word see shows he had made the experiment.

Sagredo then joins in:

SAGREDO: But I, Simplicio, who have made the test, can assure you that a cannon ball weighing one or two hundred pounds, or even more, will not reach the ground by as much as a span ahead of a musket ball weighing only half a pound, provided both are dropped from a height of 200 cubits.

This then marks the beginning of the modern era in science - the attitude that assertions about the physical world by authorities, no matter how wise or revered, stand or fall by experimental test. Legend has it that Galileo performed this particular experiment from the leaning tower of Pisa .

Galileo goes on to give a detailed analysis of falling bodies. He realizes that for extremely light objects, such as feathers, the air resistance becomes the dominant effect, whereas it makes only a tiny difference in the experiment outlined above.

Naturally Accelerated Motion

Having established experimentally that heavy objects fall at practically the same rate, Galileo went on to consider the central question about speed of fall barely touched on by Aristotle - how does the speed vary during the fall?

The problem is that it's very difficult to answer this question by just watching something fall- it's all over too fast. To make any kind of measurement of the speed, the motion must somehow be slowed down. Of course, some falling motions are naturally slow, such as a feather, or something not too heavy falling through water. Watching these motions, one sees that after being dropped the body rapidly gains a definite speed, then falls steadily at that speed. The mistake people had been making was in assuming that all falling bodies followed this same pattern, so that most of the fall was at a steady speed. Galileo argued that this point of view was false by echoing the forgotten words of Strato almost two thousand years earlier:

("Two New Sciences", page 163) But tell me, gentlemen, is it not true that if a block be allowed to fall upon a stake from a height of four cubits and drive it into the earth, say, four finger-breadths, that coming from a height of two cubits it will drive the stake a much less distance; and finally if the block be lifted only one finger-breadth how much more will it accomplish than if merely laid on top of the stake without percussion? Certainly very little. If it be lifted only the thickness of a leaf, the effect will be altogether imperceptible. And since the effect of the blow depends upon the velocity of this striking body, can any one doubt the motion is very slow- whenever the effect is imperceptible?

Galileo's Acceleration Hypothesis

Having established by the above arguments and experiments that a falling body continues to pick up speed, or accelerate, as it falls, Galileo suggested the simplest possible hypothesis (paraphrasing the discussion on "Two New Sciences" page 161):

A falling body accelerates uniformly: it picks up equal amounts of speed in equal time intervals, so that, if it falls from rest, it is moving twice as fast after two seconds as it was moving after one second, and moving three times as fast after three seconds as it was after one second.

This is an appealingly simple hypothesis, but not so easy for Galileo to check by experiment - how could he measure the speed of a falling stone twice during the fall and make the comparison?

Slowing Down the Motion

The trick is to slow down the motion somehow so that speeds can be measured, without at the same time altering the character of the motion. Galileo knew that dropping something through water that fell fairly gently did alter the character of the motion, it would land as gently on the bottom dropped from ten feet as it did from two feet, so slowing down the motion by dropping something through water changed things completely.

Galileo's idea for slowing down the motion was to have a ball roll down a ramp rather than to fall vertically. He argued that the speed gained in rolling down a ramp of given height didn't depend on the slope. His argument was based on an experiment with a pendulum and a nail, shown on page 171 of *Two New Sciences*. The pendulum consists of a thread and a lead bullet. It is drawn aside, the string taut, to some point C.

A nail is placed at E directly below the top end of the thread, so that as the pendulum swings through its lowest point, the thread hits the nail and the pendulum is effectively shortened, so that the bullet swings up more steeply, to G with the nail at E. Nevertheless, the pendulum will be seen to swing back up to almost the same height it started at, that is, the points G and C are the same height above level ground. Furthermore, when it swings back, it gets up as far as point C again, if we neglect a slight loss caused by air resistance. From this we can conclude that the speed with which the ball passes through the lowest point is the same in both directions. To see this, imagine first the situation without the nail at E. The ball would swing backwards and forwards in a symmetrical way, an ordinary pendulum, and certainly in this case the speed at the lowest point is the same for both directions (again ignoring gradual slowing down from air resistance). When we do put the nail in, though, we see from the experiment that on the swing back, the ball still manages to get to the beginning point C.

We conclude that it must have been going the same speed as it swung back through the lowest point as when the nail wasn't there, because the instant it leaves the nail on the return swing it is just an ordinary pendulum, and how far it swings out from the vertical depends on how fast it's moving at the lowest point.

Galileo argues that a similar pattern will be observed if a ball rolls down a ramp which is smoothly connected to another steeper upward ramp, that is, the ball will roll up the second ramp to a level essentially equal to the level it started at, even though the two ramps have different slopes. It will then continue to roll backwards and forwards between the two ramps, eventually coming to rest because of friction, air resistance, etc.

Thinking about this motion, it is clear that (ignoring the gradual slowing down on successive passes) it must be going the same speed coming off one ramp as it does coming off the other. Galileo then suggests we imagine the second ramp steeper and steeper---and we see that if it's steep enough, we can think of the ball as just falling! He concludes that for a ball rolling down a ramp, the speed at various heights is the same as the speed the ball would have attained (much more quickly!) by just falling vertically from its starting point to that height. But if we make the ramp gentle enough, the motion will be

slow enough to measure. (Actually, there is a difference between a rolling ball and a smoothly sliding or falling ball, but it does not affect the pattern of increase of speed, so we will not dwell on it here.)

Galileo's Acceleration Experiment

Let us now consider Galileo's experiment in which he tested his hypothesis about the way falling bodies gain speed. Here is the quote of the account from *Two New Sciences*, page 178:

A piece of wooden moulding or scantling, about 12 cubits long, half a cubit wide, and three finger-breadths thick, was taken; on its edge was cut a channel a little more than one finger in breadth; having made this groove very straight, smooth, and polished, and having lined it with parchment, also as smooth and polished as possible, we rolled along it a hard, smooth, and very round bronze ball. Having placed this board in a sloping position, by raising one end some one or two cubits above the other, we rolled the ball, as I was just saying, along the channel, noting, in a manner presently to be described, the time required to make the descent. We repeated this experiment more than once in order to measure the time with accuracy such that the deviation between two observations never exceeded one-tenth of a pulse-beat. Having performed this operation and having assured ourselves of its reliability, we now rolled the ball only one-quarter the length of the channel; and having measured the time of its descent, we found it precisely one-half of the former. Next we tried other distances, compared the time for the whole length with that for the half, or with that for two-thirds, or three-fourths, or indeed for any fraction; in such experiments, repeated a full hundred times, we always found that the spaces traversed were to each other as the squares of the times, and this was true for all inclinations of the plane, i.e., of the channel, along which we rolled the ball. We also observed that the times of descent, for various inclinations of the plane, bore to one another precisely that ratio which, as we shall see later, the Author had predicted and demonstrated for them.

For the measurement of time, we employed a large vessel of water placed in an elevated position; to the bottom of this vessel was soldered a pipe of small diameter giving a thin jet of water which we collected in a small glass during the time of each descent, whether for the whole length of the channel or for part of its length; the water thus collected was weighed, after each descent, on a very accurate balance; the differences and ratios of these weights gave us the differences and ratios of the times, and this with such accuracy that although the operation was repeated many, many times, there was no appreciable discrepancy in the results.

4.3. The Atwood Machine

The Atwood machine was invented in 1784 by George Atwood as a laboratory experiment to verify the mechanical laws of motion with constant acceleration. Atwood's machine is a common classroom demonstration used to illustrate principles of physics, specifically mechanics.

The ideal Atwood Machine consists of two objects of mass m_1 and m_2 , connected by an inextensible massless string over an ideal massless pulley. The pulley should be nearly

frictionless. The machine is used to measure the acceleration produced by an arbitrarily chosen force acting on a given mass.

When $m_1 = m_2$, the machine is in equilibrium regardless of the position of the weights. When $m_1 \neq m_2$ both masses experience uniform acceleration.

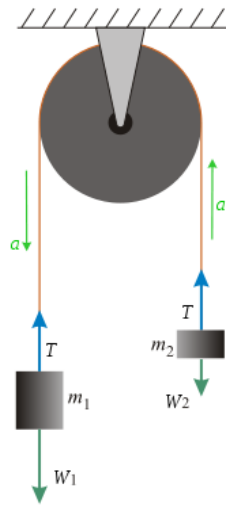


Figure 4.9 Atwood machine

As a sign convention, we assume that a is positive when downward for m_1 , and that a is positive when upward for m_2 . Weight of m_1 and m_2 is simply $W_1 = m_1g$ and $W_2 = m_2g$ respectively.

Forces affecting m_1 :

$$m_1g - T = m_1a \quad (4.5)$$

Forces affecting m_2 :

$$T - m_2g = m_2a \quad (4.6)$$

and adding the two previous equations we obtain

$$m_1g - m_2g = m_1a + m_2a \quad (4.7)$$

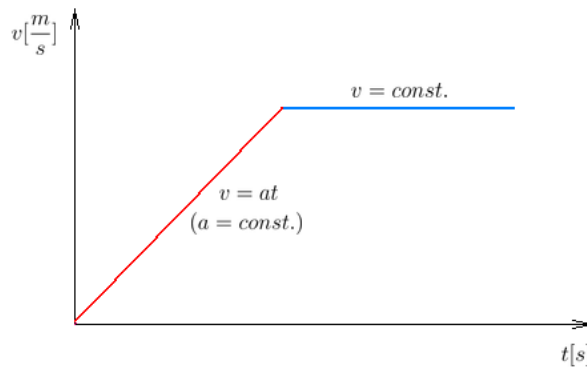
and our concluding formula for acceleration

$$a = g \frac{m_1 - m_2}{m_1 + m_2} \quad (4.8)$$

Conversely, the acceleration due to gravity, g , can be found by timing the movement of the weights, and calculating a value for the uniform acceleration a :

$$d = \frac{1}{2}at^2 \quad (4.9)$$

If we use weights with equal masses and on one weight we add additional weight which can be removed (by using a loop, through which a weight is passing) we can study the motion with uniform acceleration and motion with constant velocity (inertia law) when additional weight is removed. We need only chronometer for measuring time. We can draw next graph by using our measurements with Atwood machine:



Graph 4.10 Velocity-time graph for motion with uniform acceleration and motion with constant velocity

5. »Hands-on« Experiments

Here we will explain two »Hands-on« Experiments and how they will be connected with scientific method.

Memorizing facts and information is not the most important skill in today's world. Facts change, and information is readily available - what's needed is an understanding of how to get and make sense of the mass of data. Because of that we should teach students to think and discover to gain skills to relate ideas. Simple (“Hands on”) experiments are very convenient for teaching physics. They get students interested and can easily be done without expensive equipments. Student will get more applicable knowledge and they will be able to relate contents from physics with their life experience. Those experiments can be done with students from the youngest age. Simple experiments about accelerated motion can be Brachistochronous fall and Falling objects.

5.1. Falling objects

We can do one simple experiment similar to Galileo's falling bodies experiment. In this experiment when we use scientific method.

Aim of experiment: This experiment should allow students to investigate accelerated motion, by investigation based on scientific method, on example of free fall and it is very simple and inexpensive for realizing.

Class (students' age in Libyan schools): This experiment is convenient for teaching theme about accelerated motion (free fall) that is in curriculum specified for 6th grade of Elementary School in Libya. Students have knowledge about motion with constant velocity, they know terms: velocity, speed, time, distance.

Problem:

- At what distances weights should be attached so the sound of their free falling on ground will be evenly spaced?

Possible hypothesis:

- The weights should be attached to the string at equal distances.
- The weights should be attached to the string at decreasing separation distances from ground.
- The weights should be attached to the string at increasing separation distances from ground.

Materials: strong string, fishing line or dental floss (about 3 meters long) and a set of 5-6 small weights which can be attached to that string (nuts from large screws).

In what follows the weight of the string is assumed to be negligible, compared to that of the weights.

Procedure: We attach the weights to the string at gradually increasing separation distances. Then hold up the end of the string on the side where the separations are largest (perhaps while standing on a chair, but careful) and let it hang down, with the bottom weight just resting on the floor.



Figure 5.1 Experiment Falling objects

We will call that "weight 0" and number the other weights consecutively from the bottom as "weight 1," "weight 2" and so forth. Then when let go we will hear "clack-clack-clack..." the sounds of the impacts of the weights on the floor. If top and bottom weights are separated by a distance of 1.25 meters, the duration of the fall will be 1/2 second, and with 5 weights as drawn, your ear should distinguish 1/4 of that interval. A longer string of course extends the fall time.

Explanation of experiment: The clacks replace the sounds of balls jumping over the wires in Galileo's experiment. They should sound evenly spaced: if they do not, adjust their distances (see further below) until they do (it may help having two separate experimenters, one dropping the string, the other listening to the clacks). Then measure the distance of each weight from "weight 0". When the clacks sound evenly spaced, the impact of each is separated from its neighbor by the same time interval, which we shall denote T . Weight 1 hits the floor time t after you release the string, weight 2 after time $2t$, weight 3 after time

3t and so forth. If the distance covered by an object falling from rest is proportional to the time squared (the formula is $\frac{1}{2}gt^2$), then the distances of the weight from the end should be proportional to $t^2, (2t)^2 = 4t^2, (3t)^2 = 9t^2$ and so forth, that is, they should have ratios 1:4:9:16... That can be checked: the distances of weights 1, 2, 3, 4... divided by the squares of these numbers, that is by 1, 4, 9, 16..., should all give the same value.

In attaching the weights, you loop the string around twice around each nut, or pair of nuts--that is, if you thread the string from side "A" to side "B", take its end back to side "A" and thread it again, and again. With fishermen's weights, threading once should be enough. That way, if you want to move the weight, all you need to do is loosen the loop, then haul in string from one side and let it out on the other. Loosening the loop may be helped by a very thick needle, or a thin nail.

You should do the same thing but with equidistance nuts, to hear that than the time between "clack"s (sounds) is getting shorter.

In this experiment when we use scientific method we have:

Results:

By performing this experiment child will find out:

- When weights are attached to the string at equidistance is heard that the time between "clack"s (sounds) is getting shorter.
- The sound of their free falling of weights on ground will be evenly spaced when the weights are attached to the string at gradually increasing separation distances from ground.

Conclusion:

- The distance covered by an object falling from rest is proportional to the time squared so the distances of the weights from the end should be proportional to $t^2, (2t)^2 = 4t^2, (3t)^2 = 9t^2$ and so forth, that is, they should have ratios 1:4:9:16:... to hear evenly spaced "clack"s.

Concepts that are developing: free fall, accelerated motion, acceleration, distance

5.2. Brachistochronous fall

This apparatus demonstrates the observable effects of a physical principle discovered by Galileo on November 29, 1602, and communicated by him to Guidobaldo del Monte that day. Using geometrical methods, Galileo proved that a body takes less time to fall along the arc of a circumference than along the corresponding chord-even though the latter is a shorter path. Galileo, who viewed the arc as an infinite set of inclined planes, did not realize that the brachistochrone of a body falling between two points is the arc of a cycloid and not the arc of a circle. The mathematical demonstration of the brachistochronous property of the cycloid was provided by Jacques Bernoulli in 1697.

The device consists of a wooden frame with a cycloidal channel. A straight channel also pivots on the frame, and its inclination can be adjusted by means of pegs fixed in holes with brass rings under the cycloid. Dropping two balls simultaneously down the two

channels, we observe that the ball falling down the arc of the cycloid reaches bottom well before the ball traveling down the inclined plane.



Figure 5.2 Apparatus for demonstration of brachistochronous fall

This experimental apparatus which we can find in Museum Galileo was built by Francesco Spighi. We can find video of it on next link:

<http://catalogue.museogalileo.it/multimedia/BrachistochronousFall.html>

Aim of experiment: This experiment demonstrates that a body takes less time to fall along the arc of a circumference than along the corresponding chord-even though the latter is a shorter path. That surprising experiment result can get students interested and while explaining it they learn about motion...

Class (students' age in Libyan schools): This experiment is convenient for teaching theme about accelerated motion that is in curriculum specified for 2nd grade of High School in Libya. Students have knowledge about motion with constant velocity, accelerated motion, they know terms: velocity, speed, time, distance, acceleration.

Problem:

- Will ball exceed straight or curved path in shorter time period?

Possible hypothesis:

- The ball will exceed straight path in shorter time period.
- The ball will exceed curved path in shorter time period.

Materials: 2 equal marbles, flexible thin plastic for making paths (two elastic bands)

Procedure: We make two paths – one straight and one curved (brachistochrone) and we let marbles at the same time to roll down those two paths. We watch which marble will reach the end of the path in a shorter time.

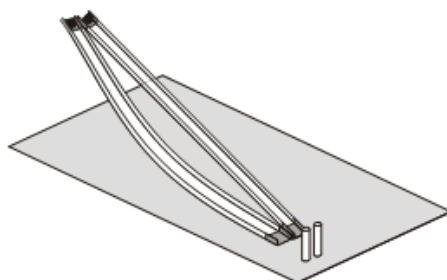


Figure 5.3 Experiment Brachistochronous fall

Explanation of experiment:

The speed of the balls depends on the height from which they start, as well as the shape (inclination) of their paths. Since the balls are made of the same material, start from the same height, and move on the same type of support, the difference in speed is caused by the difference in the band inclination. If the inclination is greater, the weight component in the direction of the path is bigger and the speed is higher. Because of that the ball sliding on the loose support (curved path) is faster.

In schools we can use next approximation to show why less time is needed for brachistochronous fall:

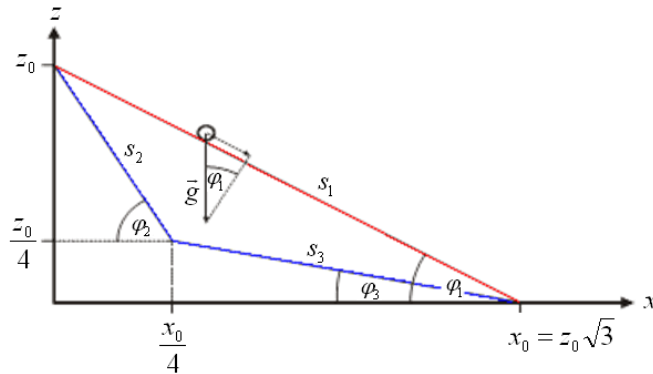


Figure 5.4 Approximate calculation of brachistochronous fall

We will show approximation for $\alpha_1 = 30^\circ$. We can see that:

$$\begin{aligned}
 s_1^2 &= z_0^2 + (z_0\sqrt{3})^2 \\
 s_2^2 &= \left(\frac{3}{4}z_0\right)^2 + \left(\frac{1}{4}z_0\sqrt{3}\right)^2 \\
 s_3^2 &= \left(\frac{1}{4}z_0\right)^2 + \left(\frac{3}{4}z_0\sqrt{3}\right)^2
 \end{aligned}
 \tag{5.1}$$

According to formulae (5.1):

$$\begin{aligned}
 s_1 &= 2z_0 \\
 s_2 &= \frac{\sqrt{3}}{2}z_0 \\
 s_3 &= \frac{\sqrt{7}}{2}z_0
 \end{aligned}
 \tag{5.2}$$

Based on The Second Newton's law:

$$a = g\sin\alpha \tag{5.3}$$

we have:

$$\begin{aligned}
 a_1 &= \frac{g}{2} \\
 a_2 &= \frac{g\sqrt{3}}{2} \\
 a_3 &= \frac{g}{2\sqrt{7}}
 \end{aligned}
 \tag{5.4}$$

For accelerated motion we know that:

$$v = v_0 \pm at \quad (5.5)$$

$$s = v_0t \pm \frac{at^2}{2} \quad (5.6)$$

$$v = \sqrt{v_0^2 \pm 2as} \quad (5.7)$$

In our example according to written equations we get:

$$t_1 = 2\sqrt{2}\sqrt{\frac{z_0}{g}} \approx 2,83\sqrt{\frac{z_0}{g}} \quad (5.8)$$

$$t_2 = \sqrt{2}\sqrt{\frac{z_0}{g}} \quad (5.9)$$

$$t_3 = (\sqrt{56} - \sqrt{42})\sqrt{\frac{z_0}{g}} \quad (5.10)$$

Adding the equations (5.9) and (5.10) we get:

$$t_2 + t_3 = (\sqrt{2} + \sqrt{56} - \sqrt{42})\sqrt{\frac{z_0}{g}} \approx 2,42\sqrt{\frac{z_0}{g}} \quad (5.11)$$

Now, we can conclude that since $t_1 > t_2 + t_3$ marble rolling down the blue path (s_2+s_3) will be faster, so the curved path is quicker.

In this experiment when we use scientific method we have:

Results:

By performing this experiment child will find out:

- The ball which is sliding on the loose support (curved path) gets to the end in shorter time period.

Conclusion:

- The ball sliding on the loose support (curved path) is faster.

Explanation how we can show that in school by use of calculus is given above.

Concepts that are developing: path, brachistochrone, speed, acceleration, time, graphs

6. Conclusion

Like all other sciences, physics is based on experimental observations and quantitative measurements. The main objective of physics is to find the limited number of fundamental laws that govern natural phenomena and to use them to develop theories that can predict the results of future experiments. The fundamental laws used in developing theories are expressed in the language of mathematics, the tool that provides a bridge between theory and experiment.

When a discrepancy between theory and experiment arises, new theories must be formulated to remove the discrepancy. However, thanks to Galilei, practical application and testing of ideas leads way to new breakthroughs in all fields of science not only physics. Galileo was one of the first that used experiments for studying nature phenomena (after Archimedes there were many years of silence in science) and thanks to that he has shown that Aristotle wasn't right. He can be thanked for introduction of scientific method in physics.

We should allow students to do the same in laboratory work – to study phenomena by observations in schools. There is no doubt that the importance of introducing scientific methods into the teaching process is enormous. Also we should use as many as possible simple experiments because of their easily performance and availability and the possibility of use of scientific method by theirs implementation in teaching process.

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Short biography

Zouhor Zekri was born on the 1st of August 1986 in Surman, in Libya. Finished Primary school and High school in Surman. Studied at Faculty of Science at University of Zawia and started studying master of physics (teaching physics) at Faculty of Sciences at University of Novi Sad, in Serbia, in 2010.



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Suggestion for formation and development of the concepts of Accelerated motion in the teaching process is given in this work. In order to understand better concepts of Accelerated motion besides theoretical explanation the implementation of scientific method and simple experiments ("Hands on") into the educational process is shown.

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U ovom radu prikazana je ideja kako se mogu formirati i razvijati pojmovi prilikom obrade Ubrzanog kretanja u nastavi. U cilju boljeg razumevanja pojmova u vezi sa ubrzanim kretanjem, pored teorijskog objašnjenja prikazana je implementacija naučnog metoda i jednostavnih ogleda u proces obrazovanja.

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član:

Dr Maja Stojanović, docent

član:

Dr Dušanka Obadović, redovni prof.