

PHILOSOPHY OF PHYSICS EDUCATION & PHIL

FİZİK EĞİTİMİ VE FELSEFESİ

İÇERİK

1. **Usage of Physics Thought Experiments in Problem Solving Process**
Elif Ince, Yavuz Acar, Senem Temur

2. **Foucault Sarkacı**
Oktay Yılmaz, Çılga Misli

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Usage of Physics Thought Experiments in Problem Solving Process

Problem Çözme Sürecinde Fizik Düşünce Deneylerinin Kullanılması

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Abstract

The purpose of this study is to present undergraduate students' physics thought experiments in problem solving process and their achievements. In this context, it was requested to undergraduate students who have taken General Physics I and General Physics II to develop thought experiments in order to solve daily life problems. At the next stage, students' thought experiments were classified according to common issues in cooperative groups and were asked to try to solve the problems by using thought experiments' process from each group. As a result of this study; students' thought experiments related to daily life were developed and problem solving processes have been presented in detailed.

Keywords: Physics Education, Science Education, Thought Experiments, Problem Solving Skills

Özet

Bu çalışmanın amacı, üniversite öğrencilerinin işbirlikli gruplarda fizik düşünce deneyleri geliştirme yöntemini problem çözme süreçlerinde uygulamasının sunulmasıdır. Bu bağlamda, Genel Fizik I ve Genel Fizik II derslerini almış öğrencilere günlük hayatla ilişkili ve öğrenmek istedikleri konuların neler oldukları soruldu. Sonraki aşamada ise ortak konu seçen öğrencilere göre işbirlikli gruplar oluşturulmuş ve bilmek istedikleri bu konulara yönelik günlük hayat problemleri, problem çözme basamaklarına göre çözmeleri ve düşünce deneyleri geliştirmeleri istenmiştir. Bu çalışmanın sonucunda; öğrencilerin günlük yaşam problemlerine yönelik geliştirdikleri düşünce deneyleri ve problem çözme süreçleri detaylı olarak sunulmuştur.

Anahtar Kelimeler: Fizik Eğitimi, Fen Bilgisi Eğitimi, Düşünce Deneyleri, Problem Çözme Becerileri

Introduction

Thought experiments are effective form in both teaching of physics and science and are performed in the mind. As known, during the scientific revolutions of the 17th and of the 20th century, thought experiments were used by famous scientists such as Galileo, Newton and Einstein. In physics education, thought experiments have had important role since they were used by leading scientists for the formulation of new theories, the representation of views, the variation of the existing theories which were designed and performed mentally by the scientists while investigating a new topic. In physics community, Galileo's falling bodies (Galileo, 1638), Newton's bucket and cannon (Newton, 1729), Einstein's elevator (Einstein, 1938), Maxwell's demon (Maxwell, 1871), Heisenberg's γ-ray microscope (Heisenberg, 1930), Schrödinger's cat (Schrödinger, 1935), the E.P.R experiment (Einstein, Podolsky & Rosen, 1935) are very popular thought experiments in this respect (Velentzas, Halkia & Skordoulis, 2007).

Scientific studies defined that thought experiments have huge impact to student learning of

scientific concepts (Helm, Gilbert & Watts, 1985; Matthews, 1994; Gilbert & Reiner, 2000b). Gilbert and Reiner have shown that students configure imagines for problem solving, if they are encouraged to develop their own thought experiments, they can create new facts, new explanations, and alternative solves (Matthews, 1994). Klassen stated that it is necessary for students to deal with the learning materials and occasions actively to understand (Klassen, 2006). While the thought experiments help students for developing the hypothesis and predictions which lead to scientific knowledge, it is also a kind of crucial way for scientific teaching to make them imagine things do not exist in daily life and developing their creativity (Velentzas, Halkia & Skordoulis, 2007; Velentzas & Halkia, 2011). In accordance with the findings of (Gilbert & Reiner, 2000b); thought experiments process engages the students' mind, and reveals what a student believes. In another study, Reiner indicated that students provide access to implicit knowledge while problem solving discussions were in the format of thought experiments (Reiner, 1998).

Thought experiments implementation has significant role in physics. Especially the usage of thought experiments in modern physics teaching attracted the attention of researchers in science teaching to apply (Kösem & Özdemir, 2013). But the usage of it requires students' imagination and prediction about situations that do not take place in everyday life and reaching results on the basis of existing or new hypotheses. Students may imagine the situation without help about concepts or processes in everyday life. In this context, thought experiments help them to use their imagination, develop their critical thinking, make hypotheses and exchange ideas (Matthews, 1994). It can be seen that thought experiment implementation has become a bridge students' everyday experience and the new concepts which have to be taught for students.

Thought experiments are usually determined a basic component by problem solving, hypothesis testing and constructing imaginary situations. If we examine the details of these components; we reach to similar founding of Reiner and Brown such as; proposing a problem or hypothesis; forming an imaginary situation, designing and setting an experiment as mentally using background knowledge, producing experiment as logic, drawing or reaching a result (Reiner, 1998; Brown, 1991).

Learning through problem solving is based on Dewey's six-step problem solving method (Dewey, 1933). Problem solving process include a number of efforts to eliminate the difficulties, is an effective way of learning and personal development skills. Problem solving process begins with awareness, desire and self-confidence. Anderson (1980) stated that, problem solving process includes cognitive processes and it is an important way of structuring information in our minds.

In our study, we used collaborative groups in learning process. Collaborative learning is one of active learning approaches and it provides academic achievement, critical thinking skills, meaningful learning, higher level attention and capacity (Cooper et all., 1991).

The purpose of this study is to investigate of physics thought experiments' effects on students' logical problem-solving skills and to present students' problem-solving performance in collaborative groups.

Materials and Methods

In this context, it was requested to undergraduate students who have taken General Physics I and General Physics II to develop thought experiments in order to solve daily life problems. At the next stage, students' thought experiments were classified according to

common issues in cooperative groups and were asked to try to solve the problems by using thought experiments' process from each group. As a result of this study; students' thought experiments related to daily life were developed and problem solving processes have been presented in detail.

The participants of the study consist of 50 undergraduate students attending Istanbul University Education Faculty, Science Education Department at the first grade who received General Physics I and General Physics II courses with book contains topics of Beichner (2002).

At the first step of this study; students were asked: "which problem do you know about world, daily life or universe?" And then students started to research the problem which they wanted to know how to solve the subject they choose. One week later students came into the course with their subjects. Then, the groups were determined according to their common subjects. Each group includes 7 or 8 students. Before the instructions, an orientation was given to the students about problem solving processes and thought experiments and rubric evaluation procedures for two weeks and detailed with examples were presented.

The subjects related to *Anti-Matter, Big Bang, Sound Waves, Dark Matter and Dark Energy, Universe, Life in Space, Time Travel*. Students started to develop their thought experiments to solve the problem which was determined by them according to problem solving strategies. The procedure took 7 weeks and they produced their thought experiments with concrete models. Each week, students were directed by researchers. Students' problem solving methods were evaluated with the agreed rubric by the instructors, an independent coder and the peers. Rubrics were commonly used at implementation of process evaluation (Jackson and Larkin 2002) and provides students awareness about learning goal and self-assess their work and better understanding about learning targets (Stoll, 2003). Problem solving is a teaching method which should be considered with result and process. In this content The analytical assessment rating scales provide the most objective way of this process (Moskal, 2000). T-test statistics and analysis of variance procedures were also used to analyze the reliability and validity of the assessments made. The results revealed that the developed rubric was used consistently by the instructor and peers and significant correlations 0.002 were found among the scores. The inter-coder reliabilities were 0.87. It was concluded that the developed rubric was able to highlight the aspects of the problem solutions and helped increase students' achievement (Appendix 1).

At the second step, students were asked: "what kind of impacts of this activity do you feel you in terms of problem solving, relating physics with daily life, and reasoning, positive or negative attitude towards physics, self-confidence, self-evaluation, and success in group studies?". The answers of each group were also presented in detailed.

Findings

Group Anti-Matter

Determination of Problem

What is anti-matter? How does anti-matter create? Does anti-matter exist? If anti-matter exists, is it present in this universe? If it is existing in the parallel universe, then why? How does it differ from the Matter? When did anti-matter exist?

Defining and Limiting the Problem

When anti-matter and matter will merge, energy will be revealed; so it should stay away from the Matter. So, we have limited our problem with the question of Where-is anti-Matter?

Data Gathering about the Problem

There are several opinions about the problem. Some scientists argue that a parallel universe exists and the particles of anti-matter are present in there. We know that anti-matter was formed at the Big Bang, and its existence is proved. Because, today, anti-matter particles were created in the laboratory at CERN, and they were observed for a very short while. With our group friends, we have developed hypotheses about where the anti-matter particles can occur and tried to find evidences.

Building the Hypothesis

Anti-matter exists and it is in this universe. After the big bang, matter and anti-matter have interacted with and destroyed each other; but as a result of rapid extension of universe and the impact of gravity, matter remained in the visible universe. Anti-matter remained as a layer in the universe.

Testing the Hypotheses

Let us give an example about the existence of anti-matter. Anti-matters interact with each other than energy is exposed. If they had interacted when Big Bang happened, energy would be exposed and the universe would not exist. If that thing which separated them from each other did not exist, then the universe would not be created. When we look at the structure of these particles, we see that one of them is determined and the other one is not. The gravity that occurs at Big Bang would pull the matter. But, as the anti-particles are undetermined; matter and the anti-particles are distanced from one another.

We have tested the hypothesis with the experiment we made. We have considered an inflated balloon as the state of universe before it existed, in other words, before Big Bang. We have put particles (lentil etc.) representing the matter and the anti-matter into the balloon. As the gravity will not have any effect on the anti-matter, we have placed those particles on the top of balloon. Then, we have popped the balloon by a needle; and if we consider it as the Big Band; we have seen that the matter fell on the ground with the effect of gravity as the anti-matters did not fall due to their undetermined structures and went to unknown places; so we had a chance to test our hypothesis.

Reaching Conclusion and Making Evaluation

As a result, it is possible that anti-matter could exist in this universe as we have claimed in our hypothesis. To state this with an experiment; we place a balloon inside a semi-circle. The balloon represents that matter and anti-matter were together before the Big Bang, which is before the existence of universe. Universe will exist with the puncture of balloon. So, Big Bang will occur with the help of needle; and we have observed how the matter and anti-particles have moved away from each other. With the help of gravity, determined matters and undetermined anti particles have moved away from each other.

Anti-matters are at the unknown places of this universe and gravity does not affect them due to their undetermined structures. So they will not interact with the matter and cause an explosion.

Groups Thoughts about This Activity

The obscurity of universe and the anti-matter that we do not know where they are have attracted our attention. We have chosen this subject to learn whether anti-matter really existed or not; and if it exists, where it is located.

This activity has been very useful in terms of developing reasoning and thinking. This activity has helped us to develop ideas, question those and to refute those arguments which had logical errors. We had several ideas until we reached this hypothesis; but we have questioned it and realized that we contradict with ourselves. We argued with other friends about the assignment, so our interaction with them increased. We understood each other. This activity has helped us to understand that we had to pass certain phases for problem solving. We have learned that by using imagination, we can reach to some data in unknown issues within the physics. Group study has helped us to diversify our activity via thinking with several minds instead of one. This activity has helped us to question the concept of anti-matter within the daily life. It helped us to look at the world of which we are observant, from the window of physics. Our attitude towards physics had a positive advance with the help of this activity.

Group Big Bang

Determination of Problem

How was the order of universe established? How was the balance in the planets created? What happened during the dark phase?

Defining and Limiting the Problem

How did the sensitive balance of the planets in the solar system and the special condition of the world occur? Then, we have limited our problem to the question of what happened during the big phase of Big Bang. While limiting the problem, we have preferred to focus on the period after the dark phase and decided to conduct research on the explosion of Supernova stars.

Data Gathering about the Problem

At this stage, we have gathered information from several sources about our problem and established a file. For our problem, we had to learn what Big Bang, Supernova and extension of universe is.

Big Bang: 13,8 billion years ago an explosion occurred at zero volume, endless intensity and a very high temperature; and as a result of this, particles and energy were dispersed and planets were created.

Supernova: when the small or big star consumes He, they turn into a big, a very big star and all its energy constitutes of iron. Iron is a very determined matter and energy can never be obtained from it. In this case, the nucleus of iron collapses. Iron atoms are transformed into protons and neutrons; neutrinos carry the excessive energy out and a neutron start is created,

neutron blasts outwards and a Supernova occurs. In short, Supernova is the collapse and blast of a giant star's nucleus, resulting with the spread of energy.

Expansion of Universe: Many scientists have objected the expansion of universe and also conducted research on this issue. Albert Einstein found in the relativity theory that the universe was not stable and he was surprised; but, as stable universe model was very popular back then, he added a cosmic stable to his equations, then he realized that he was wrong and accepted his mistake. In fact, Edwin Hubble has proved the expansion of universe. When Hubble looked at the sky in 1929 with his telescope, he determined that stars fade away and they have a light, this light is reddish and he gets very excited and this means that as lights become red this means that stars are getting away from us, but more importantly planets are getting away from each other and from us. This distance indicates that universe is expanding.

Building the Hypothesis

After the Big Bang, universe has passed through a dark phase of 400 million years and this dark phase was ended with the help of Supernovas. When Supernovas exploded, particles were spread in a regular and planned way.

Testing the Hypotheses

As a result of Big Bang, there is a dark phase of 400 million years. This dark phase which lasted for 400 million years had Supernovas; then the universe was created. So we have appeared as the result of supernova explosions at this dark phase. Supernova is the collapse of a star's nucleus and its outward explosion and energy is dispersed outwards. At the Big Bang, at 0 volume, in the endless intensity and high temperature an explosion occurs and the universe is created. In the experiment, the chess figures represented the Supernova with their combined and integrated version and each one them represent the planet to be created and from that moment on those particles find a way to become a part of orbit. We make this happen by moving the magnets.

Another one, at the Dark Age after Big Bang atoms catch each other and they create Supernova stars. Here, chess figures represent atoms and we establish a Supernova by integrating those.

Reaching Conclusion and Making Evaluation

In this model, we wanted to show that before the dark phase, supernova stars were at a single center. And, after the dark phase, there was a big explosion and Supernova stars were disintegrated, followed specific orbits and created the planets and this perfect balance. The explosion is not random, and it occurs with a specific order and plan.

Groups Thoughts about This Activity

We have done this thought experiment, because there were several opinions on Big Bang. We wondered how it occurred. Then we started to think what happened at dark phase. Because, there is a dark phase of 400 million years after the Big Bang. As a result of our experiment, we showed that planets were created from the Supernova stars and they have remained in their orbits in a perfect order.

With this activity, we have learned the steps of problem solving. We have realized it better that physics explains us the beginning and creation of the universe. With this activity,

we have both learned the subjects in physics and we had a chance to downgrade this issue to the daily life. We have understood that physics is not only rules. We had a chance to evaluate ourselves within the group friends. We have established a hypothesis in the activity and tried to test it. Step-by-step implementation of the problem solving stages, and creating a product have increased our self-confidence.

Group Sound Waves

Determination of Problem

Do the sound waves disappear?

Defining and Limiting the Problem

Is it possible to bring back or hear again the voice stemming from a source of voice? Do sound waves keep spreading forever? We have evaluated our problem within this framework.

Data Gathering about the Problem

Our problem was "Do the sound waves disappear?" For this, we have asked questions such as "What is sound?", "How is sound created?", "How does sound spread?" "What are the conditions that effect the spread of sound waves?" and gathered data about these questions.

Sound is the wave spread as mechanical vibrations is a flexible environment. The environment should be solid, liquid or gas in order for sound to spread. Sound can only be spread in material environment. They cannot spread in the free space like the electromagnetic waves. The linear vibrations of atoms or molecules in the material environment and they creates sound vibrations.

Any change of shape or concussion created in a flexible environment and its spread from one point to another is called the movement of wave. The concussion created by the vibration energy stemming from a sound source, its change of form is called sound wave.

Sound spreads with waves and sound waves are samples of mechanical waves. In order for sound waves to spread, in the environment where sound wave stems from its source, there should be particles (molecules and atoms) that create the material. Therefore, sound waves can spread in solid, liquid and gas but not in the free space.

Building the Hypothesis

Our hypotheses are; Sound is lost because it moves forward vibrating. Sound waves do not disappear, because sound is a form of energy. Sound waves disappear, because energy transforms.

Testing the Hypotheses

If we consider each hypotheses as the group;

If we consider the hypothesis which says that sound waves do not disappear because sound is a form of energy; we see that as energy does not disappear, sound does not disappear either. When we look from another perspective; let us assume we are baking a cake by using eggs, flour and sugar. After baking this cake, we cannot take an egg out of the cake. Yes, energy does not disappear but the transformation of voice is enough to bring it back.

If we consider the hypothesis which says that sound waves do not disappear because sound advances as waves; the reason why sound does not disappear is related with its characteristics of spreading with waves. If the sound spreads as waves and if its volume decreases at each wave, it will become weaker but it is never zero. The limit in the mathematics tells us that we cannot reach to zero by dividing a number; because each number has its half.

If there was an endless sea and we threw a stone in the middle of it, these waves would continue forever. It would not be visible by eyes, but never end. The missing point in this hypothesis is that it neglected the obligation of the sound to spread in material environment. Sound could not continue forever, because there were other environments which are not material. Considering from this point only indicates the lack of hypothesis in concepts of "environment" and "energy". Although a consistent hypothesis was built, as there is space close to the perfect, the transmission of sound waves would not be very easy.

If we consider the hypothesis that sound disappears because it spreads in the form of vibrations: If the sound is spread by vibrations, it loses its energy gradually and it is no longer heard. We did not see any missing point in the hypotheses as a group. We will use it in the results section.

If we consider the hypotheses that say sound disappears because it is energy: If the sound is energy and if it transforms into heat or similar energies, then after a while all the energy is transformed and sound disappears. According to the second law of thermodynamics, material constantly flows into a state of disorder. In this case, it is not possible to bring the detracted or transformed sound energy back to its original form. The experiment for the hypothesis presented: Let us put an alarm clock inside a glass jar of which the air is taken out and that does not send the sound outwards. After the alarm clock rings, if we measured the temperature in the jar; we would have proven the transformation of sound into heat energy. We did not see any missing point in the hypotheses as a group. We will use it in the results section.

Reaching Conclusion and Making Evaluation

As a result, we said that sound waves disappear. We have founded this with the second law of thermodynamics. As time moves on, universe goes into chaos. So, sound spreads as waves and it becomes more disordered by time. We cannot bring the sound back to its original form. Sound waves disappear, but their energy does not. It transforms into other energies in the universe and continues with its existence. Our thought experiment we developed through these hypotheses:

Two glass bottles nested; the first glass bottle does not have any material and energy exchange with the environment. Second glass bottle provides the sound to be transmitted outside. When the alarm clock in the second glass bottle rings, if the sound it spreads causes a change of thermometer in the First bottle; this is a proof that sound transforms into heat.

The experiment we have done in the classroom about our hypothesis: Our experiment happens in a class. The person who does the experiment knocks on the table and aks his friends to tell him how many times he knocked on the table. Then he sends a friend outside the classroom and knocks on the table. He learns from his friend outside how many times he knocked on the table. His friend gives the wrong answer, because as sound waves are energy;

a part of it is lost until the place it exists. This is why he did not know how many times he knocked on the table. According to the result of thought experiment we have done, sound waves are lost. The reason of this is that sound is an energy.

Groups Thoughts about This Activity

Because "sound" is a very interesting subject and the studies on sound are still going on. There were many points unknown about sound. The disappearance of sound was one of those. Therefore, we wanted to make a thought experiment on this subject.

This thought experiment has showed us that we have to approach in a more systematic way to the problems we will face in the daily life. Besides, we have also learned how a reasonable answer can be found for any existing problems. My perspective for physics has developed positively. Also, the group study we have done with our friends has contributed the increase of our success. It helped us to citizen and listen to each other, to defend our views and to express ourselves better.

Group Dark Matter and Dark Energy

Determination of Problem

As problem, we handled the issues such as dark matter, dark energy and the expansion of universe.

Defining and Limiting the Problem

Universe is continuously expanding. Is the dark matter which causes this the dark energy?

Data Gathering about the Problem

In the universe, dark matter has 23 % and dark energy has 73 % of space. We can only see 4 %. There are theories by scientists claiming that dark energy tries to expand the universe. Still, dark matter and dark energy did not reach to a conclusion. The experiments at CERN still try to prove that dark matter and dark energy exist. Dark energy and dark matter are not the same thing. So what were the characteristics of dark matter? So we have started to search for answers to this question. In our research, mass-gravity theories' calculations were correct for the solar system but the results were wrong for other systems. Instead of ignoring, we have developed new ideas.

Building the Hypothesis

We have stated our hypothesis as "Dark matter and dark energy exist and they affect the expansion of universe."

Testing the Hypotheses

If the dark energy has a distributing effect, then there should be another matter that effects reversely, having a collective effect. This should be the dark matter. In our study of thought experiment, we have combined the issues of dark matter, dark energy and expansion of universe; thereby creating a thought experiment. In our thought experiment, we have surrounded the straws and the inflection point of the straws represented the expansion of

universe. In the same time, the flexible balloon has represented the dark matter for the expansion of universe. We have added stars to the ends of windmill. When the fan turned the windmill, stars have hit this dark matter, but they have never disappeared, never leaving the universe. We have created an experiment mechanism and materialized our thoughts.

Reaching Conclusion and Making Evaluation

In the mechanism of our thought experiment, we have fixed the straws to the balloon and put a fan into the middle, windmill turned and as it hit the straws, the straws were opened and universe expanded; but the slow stretching of the balloon has slowed this; which is the dark matter. So, as we have said, dark matter slows down the expansion of universe.

Groups Thoughts about This Activity

The reason we wanted to develop a thought experiment on this issue was that we heard the experiments done on dark matter before. The issues such as expansion of universe, impact of dark matter and dark energy were issues I was very curious about. We wanted to have an idea, and this experience was an opportunity for us.

We started to be more optimistic that the problems can be solved, and we left our prejudices aside. We have realized that many things in life and universe were related with laws of physics or physical matters. We had a chance to relate physics with the life we are in and tried to find reasonable solutions. We had more positive perceptions on physics lesson and started to like it more. We started to believe that even the simplest hypotheses can be realized, thereby our self-confidence was increased. Group study has strengthened our friendship and provided us a chance to conduct more research and to focus on thought experiment. Producing and presenting a thought experiment has increased our self-confidence.

Group Universe

Determination of Problem

The problem is the inadequacy in the measurement of interstellar distances and lack of information. Information on starts and planets only consist of assumptions and mathematical theories. If the theory named Big Bang is real, then the energy distribution would be same everywhere as the system is geoidal or ellipse. Space would be distributed everywhere same and equal. But what we observe is that stars are at different phases and in different forms.

If the universe was constructed from a single point, why don't we see that point? Where do the black holes and white holes' lead? Is it possible to cross between universes through the wormhole? Can we pass to other dimensions by black holes and by using Einstein-Rosen Bridge?

Defining and Limiting the Problem

When we conducted research on Einstein-Rosen bridge, we have realized that we needed to have information on black holes as well. We have focused on these two issues and continued with our work.

Data Gathering about the Problem

Black Hole is a vast cosmic object in the astrophysics; which has a very strong gravity force that captures all types of material entities and radiances. It can also be said that black

hole is an object that exists with the collection of certain quantity of materials in the space at a certain point. It has been defined with the general relativity theory of Einstein.

Wormhole, also known as Einstein-Rosen bridge was introduced by Nathan Rosen and Albert Einstein. Wormhole is in fact a theoretical topographical characteristics of time/space shortcut. It is generally said for the connection between the white holes and black holes. A wormhole has at least two ends connected to a mouth. If the wormhole is transmittable, then the matter can pass from one end to the other within the wormhole.

Building the Hypothesis

What happens when the energy of all starts are consumed? It is assumed that there are 9 dimensions that we do not know. What created these dimensions and the pocket universes?

Which factor determines whether the collapsed star becomes a black or a white hole?

We say that stars are fading away. What if the stars are not moving away, but we do; and what if we realize only now the distances?

We know that the first rocks on the Earth do not exist now. Then, how can we measure the age of Earth?

Energy is not created out of nothing. Then, what triggered Big Bang? When the Universe was so small as a pinhead, what caused its explosion?

Testing the Hypotheses

According to our thought experiment, Universe occurred after the Big Bang. When the seas were formed on the planets in our galaxy, a loss of time was experienced due to moving away from the center of universe. As time passed faster at the center of the universe, time was lost as the distance increased. As a result of this, in the planets which are close to the Sun, the glaciers melted; but this did not happen in distant planets. Maybe there was life on Mars before. The studies indicate that there are waterways on Mars. According to our other hypothesis, universe has entered into a black hole we call as Cosmos after the Big Bang. In other words, as our universe travels in time, it also creates its own time. The black holes occur with the fall of stars are the gates opening to nothingness. Any matter that passes through a black hole loses its characteristic. The 9 dimensions that we do not know happen at the place we call nothingness. At that point, we can see the start and end of time. By using the white holes that balance these black holes, the matter can again be established. By passing through this hole, any matter can be transformed.

Reaching Conclusion and Making Evaluation

As a result, everything in the universe is within a cycle. Just like existence and annihilation; the universe which disappeared by Big Collapse can be re-established by Big Bang. We are the travelers of time inside the Cosmos bridge; and as we reach to nothingness by black holes, we can also travel in-between locations with the help of our hypothesis.

Groups Thoughts about This Activity

We have wondered whether passing space and time and going to a new dimension is possible, which helps us to see the beginning or end of the universe.

This activity has showed me that there are so many things I do not know about the universe. It helped us to question the unknown. We made brainstorming with other group members and solved some of these questions. We can say that this activity has helped us to be practical on problem solving. Learning the existence of our universe with its realities has helped us to see how important physics is in our life. Our skills of questioning and reasoning have increased in terms of problem determination and limitation. The studies within the group have developed our feeling of trust.

Group Life in Space

Determination of Problem

Is there life in space? Can life be created in the space afterwards? Can we explore new places where life exists in the future?

Defining and Limiting the Problem

The existence of life in space is a very popular question. We wondered whether there was life in space or not; so we have determined these problems. We could have written more problems, but these two problems attracted more interest; so we have limited our study with them.

Data Gathering about the Problem

One of the most important questions of mankind is whether there are other life forms in the space or not. It is very hard to provide a clear answer for this question. Until today, no life form could be found except for Earth. But, the part of space we could look and see is not even one in a trillion. When we consider the fact that there are 200-400 billion stars in Milky Way Galaxy only; and that there are billions of galaxies in the space, then we can understand that we only see a small area.

The discoveries in recent years have helped us to understand the contents of distant galaxies. The discovery of planets out of the solar system has also accelerated. The existence of necessary conditions for life were determined in many corners of the space. According to the assumptions, there are billions of Earth-alike-planets in Milky Way. The formation of necessary conditions in these planets will naturally result with the existence of life.

American astronomers have stated that a planet with the perfect conditions for life was discovered. USA National Science Institution has stated that the planet named with Gliese 581g code name, which is outside the solar system, is neither too distant nor too close to its star. The statement continued saying that it is neither too cold nor too warm to prevent the life conditions or water; and that it is similar with the Earth.

NASA has launched the SETI project in 1979 in order to search for Extra Terrestrial life. This project is a positive step to send radio signals into the space, and to receive and decode signals from other planets and to understand more about the extra-terrestrial civilizations.

John Grotzinger; one of the crew in Mars exploration vehicle Curiosity, has stated that trails of primitive life form were seen on the surface of Red Planet. It has been stated that many tests should be conducted for the accuracy of results. Scientists in the Curiosity team have stated that they determined complex chemical structures on the soil of Red Planet and that they have also reached the trails of organic components they were looking for.

Richard Hoover, a scientist at NASA stated that very little "space bugs" were found inside the meteors that fell on Earth. Astrobiologist Hoover has detected microscopic fossils inside the oldest meteors that fell on Earth, which were very similar with the bacteria photosynthesizing in the existence of oxygen.

Building the Hypothesis

Universe expands by time, and new galaxies and planets are generated as result of this expansion. Different life forms exist in these galaxies and planets. There are planets which have completed their life before, with life forms existed within them. Mars has a life form. This life form is different than the life form on Earth. A new planet might exist at the orbit of Earth and it could be similar with Earth.

Testing the Hypotheses

We know that universe expands by time. We think that new galaxies and planets were formed as a result of this expansion. For instance, a planet similar with Earth was discovered, which is named Gliese 581g. We claim that as universe expands, other planets might also exist.

And the Earth will end when its time comes. There might be other planets similar to Earth, with the life form inside them completed.

We know that elements of chloride, sulfur and carbon and water were seen on Mars. As animals, we breathe with oxygen. We have adopted with the conditions on Earth. The organisms in Mars might be breathing by chloride and maybe they have adopted with the conditions on Mars. It is hard for us to live in Mars, but maybe it is not hard for other organisms.

If there was another planet on the orbit of Earth, we would definitely realize it through the radio signals sent to space from Earth. So we have refuted our hypothesis.

Reaching Conclusion and Making Evaluation

In conclusion, we think that we are not alone in the universe and that there is life on another planet. As universe expands, new galaxies and planets are being formed. As the Earth was formed once. We base our view on a planet similar with Earth was discovered, which is named Gliese 581g. The small bacteria inside the meteor that fell on Earth show us that there might be life in the universe, and that there are other living organisms in the space in different life forms.

Groups Thoughts about This Activity

Life in space was an issue on which we had interest. As no certain evidences can be found, and no exact claims can be made; we started to focus on this issue. For this reason, we wanted to conduct a research on this issue and to learn more about our universe.

This activity has helped us to gain skills such as questioning and problem solving. We had a chance to relate physics with daily life and questioned things. It helped us to increase our self-confidence; it taught us which stages to follow in self-evaluation. As a group, we have obtained knowledge on phases and thought experiment. We have achieved to distinguish the scientific knowledge. Our own ideas have become more concrete with the thought experiment.

Group Time Travel

Determination of Problem

At the determination of problem stage, we have shared the questions that came to our minds with each other. These were;

Is time travel possible?

Does time have a specific flow?

Is it possible to travel in time by beam?

Can we exceed the speed of light?

If parallel universes exist, can we travel there?

Is the mass of photon zero?

How does the mass of photon effect time?

Does photon affect reach the speed of light?

Will the concept of time disappear if we can reach the speed of light?

Does speed of light have any impact on time travel?

Is time relative?

Does speed and matter have impact on time?

Is the past recorded somewhere?

Can we only travel back or forward in time; or can we travel to both directions?

Does the mass gravity affect time?

Is time the fourth dimension?

Is time a flat direction or is it twisted?

Will the matter shrink and disappear at the speed of light?

What is the function of wormholes?

Defining and Limiting the Problem

We have defined our general problems and have created a common problem as a result of these. The common point of our problems was time travel. We have determined the possible factors effective in time travel. We have reviewed our own knowledge before conducting a research. We have determined our main problems. Main Problems:

Can we reach the speed of light and do time travel? What might be the results of time travel? How can we travel in time?

Data Gathering about the Problem

In beginning of our study, we have examined photon structure. We have seen that photon is an energy package, that its mass is considered as zero and it is related with the structure of wave and particle of the light. We read several studies, news and articles. According to our researches we have seen that time is slower in the space. We focused on white and black holes. We have learned that white hole cannot be entered. We thought that Einstein-Rosen bridge, in other words, the wormholes might help us. We have conducted studies on the possibility of parallel universes. We have accepted the existence of parallel universes in our thought experiment.

Photon: It is the main unit and main particle of the light. The mass of photon is zero.

Speed of Light: Light is a form of energy that provides us vision. Light travels with 300 thousand kilometers per second. Light consists of photons.

Time: It is the most sensitive measured criteria in physics. Many scientists have opinions on time.

Parallel Universe: This is a theory. It is also called as the theory of multiple universes. According to this theory, our universe is not alone and that there is a parallel universe.

White hole, Black hole, Wormhole: Black hole intensity is very high. It takes all the objects around. Black hole symmetrical is the white hole. White hole does not hold any object; it throws them away. Wormhole is the connection point between the white hole and black hole.

Building the Hypotheses

As the group, we have three hypotheses. These are:

If the mass of photon was not zero, then the light would not go through linear but slopped due to gravity and the shades of objects would look different.

Black hole is very intense; therefore, it pulls up everything inside. The symmetrical of this, white hole, does not allow anything inside and throws them out. A wormhole is created at the point where these two meet. So, a travel can be made between the universe and the future universe.

By assuming that a different universe will be created each time, so the number of universes is endless. If we travel to the future, it is not determined which universe we will go at.

Testing the Hypotheses

We have conducted three experiments in accordance with our hypotheses. We have tested the hypotheses with our experiments.

First Experiment: We have used a black cloth, a white cloth, a ball and a cupboard roll. White cloth represented the white hole, black cloth represented the black hole, cupboard roll represented the wormhole and the ball represented an object with its mass and burden as zero. The ball (object) thrown from the black hole has passed through the wormhole and reached to white hole and thereby passed to any universe. In order to make time travel and travel between universes, speed of light is required.

Second Experiment: We used 1 cupboard and 6-7 straws. We have made a labyrinth from the cupboard and the straw. This labyrinth represented the parallel universes occurred in each decision. We have showed that the object going out of white hole could go to any universe.

Reaching Conclusion and Making Evaluation

As a result of these experiments; if we can find an object with zero mass and burden, we have discovered that speed of light can be reached and travel in parallel universes might be possible. Our thought experiment is positive and our thoughts are reasonable; but we have decided that time travel is not possible with our recent technology. Even if it was possible, it would be contradictory with the biological watch of living organisms.

Groups Thoughts about This Activity

Issues such as universe, time travel and parallel universes have always gained our interest. We wanted to combine the issues which we all have thought before and to find out where we can reach at. So we have used the issues such as speed of light, time and parallel universe and we have done our experiment.

With this activity, we have learned the steps of problem solving. We have learned how these stages will be evaluated and written. We have seen that physics is not only a science and that we see it in our daily lives. We have conducted many studies during the experiment and we questioned them, also learned reasoning. We had positive opinions on physics, because we have conducted research on an issue we wanted to find out more about and meanwhile we have learned and understood physics. Groups study was fun. We have observed the positive sides of group study and exchange of ideas with this experiment. In this activity, we have seen that physics can be fun.

Table 1. Groups' Thought Experiments Scores for Each Problem Solving Steps as Logically and Topics.

Groups' Thought Experiments Topics	Determination of Problem	Defining and Limiting the Problem	Data Gathering about the Problem	Building the Hypotheses	Testing the Hypotheses	Reaching Conclusion and Making Evaluation	Total Score
Anti-Matter	5	5	5	5	5	5	30
Big Bang	3	4	3	3	5	3	21
Sound Waves	3	4	4	5	5	3	24
Dark Matter and Dark Energy	5	5	5	5	5	5	30
Universe	4	4	5	5	4	4	28
Life in Space	5	5	5	5	5	5	30
Time Travel	3	4	5	3	5	5	25

Problem solving strategies were scored by researchers as 5 points for proposing a problem or hypothesis (problem question); 5 points for forming an imaginary situation(problem borders and relates), 5 points for designing and setting an experiment as mentally using background knowledge (sources and knowledge usage), 5 points for producing experiment as logic (comparing the hypothesis' result with the other results, 5 points for drawing or reaching a result (produced own products about thought experiments). Each group was scored according to their own thought experiments as determined problems by themselves. It was shown groups' thought experiments scores for each problem solving steps and topics (Table 1).

As shown in Table 1; the minimum and maximum scores of collaborative groups are computed as 21 and 30, respectively. It is clear that; students have high scores on problem solving process using by physics thought experiments. In addition, it is interesting that; many

students wonder structure of the universe topics instead of physics laws around them related to daily life.

Conclusion

Rubric describes achievement levels and performance of students and it has importance to reach targeted achievement and performance. It defines student' performance in a constructive learning and self-evaluation process (Hafner and Hafner 2003).

When examined students' opinions, it was seen that this activity has helped them to understand phases for problem solving, develop their imagination, understand physics explains about daily life, improve self-confidence, know many more things about physics. The results of this study showed that implementation of thought experiments in problem solving process has high impact on students' achievements. It can be said that students were able to think deeply, imagine situations beyond their everyday life experiences and try to use their scientific knowledge (Kösem & Özdemir, 2014). Thought experiment implementation method helped students both to overcome borders in understanding the laws of physics and to modify their ideas related to physics topics, especially on universe.

It's also observed in Kosem and Ozdemir's (2013) academic research; thought experiments have a high potential in effective learning and comprehend information, it would also benefit to comprehend the various problems in science teaching. As another, Karakuyu and Tortop's 20 high school students' research, the results show that the thought experiments are positively effective in students' logical thinking skills in problem solving process and cognitive comprehension level (Karakuyu, & Tortop, 2009).

Thought experiments could give us true information because they are highly beneficial both in pedagogic and intuitional by providing true insight (Brown, 2006). Thought experiments are not only thought but also they are communication and education tools, because they contribute to convert scientific knowledge to school and public knowledge (Velentzas et al., 2007).

There are limited studies on implementation of students' physics thought experiments in problem solving process. Therefore, it is believed that this study will contribute to the physics education literature. In the light of the results, it is suggested that thought experiments implementation should be used in problem solving process widely in physics instruction.

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Problem Çözme Sürecinde Fizik Düşünce Deneylerinin Kullanılması

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Bu çalışmanın amacı, üniversite öğrencilerinin fizik düşünce deneylerini problem çözme süreçlerinde kullanımlarının sunulmasıdır. Düşünce deneyleri, özellikle fizik eğitiminde öğrencilerin; hayal güçlerini arttırıcı ve sorgulayarak üst düzey düşünme becerilerini geliştirici bir etkiye sahiptir.

Çalışmanın örneklemini bir Devlet Üniversitesinde öğrenim gören 50 adet ikinci sınıf Fen Bilgisi öğretmen adayı oluşturmaktadır.

Bu çalışmada öğrencilere öncelikle; günlük hayatla ilişkili ve merak ettikleri konuların neler oldukları sorulmuştur. Sonraki aşamada ise ortak konu seçen öğrencilere göre 7 ya da 8' er kişilik gruplar oluşturulmuştur. Bu konular; büyük patlama, ses dalgaları, görelilik teoremi, karanlık madde ve karanlık enerji, evren-uzay, zaman yolculuğu şeklindedir. Öğrencilerden, bilmek istedikleri bu konulara yönelik problemleri, *"problemin belirlenmesi, problemin sınırlarının belirlenmesi, probleme yönelik bilgi toplama, problem çözümüne yönelik düşünce deneylerini kullanarak hipotez geliştirme, hipotezi test etme, sonuca ulaşma ve somut birere model oluşturma"* basamaklarına göre problemlerini çözerlerken düşünce deneyleri geliştirmeleri istenmiştir. Problem çözme süreçleri öğretim üyelerinin rehberliği eşliğinde yedi hafta sürmüş ve öğrenciler, geliştirdikleri düşünce deneylerini somut modellerle sunmuşlardır. Öğrencilerin, problem çözme basamaklarındaki performansları ve yazılı dokümanları 1 ile 5 puan arasında araştırıcılar tarafından puanlanmıştır. Buna göre gruplar en az 21, en çok 30 puan almışlardır.

Bu çalışmada; öğrencilerin öğrenmek istediği konuların genellikle uzay ve zamanla ilgili olduğu görülmüştür. Bunun sebebinin ders sırasında öğrencilerin hayal etmede zorlandıkları bu konuları tam olarak hayal edemekdikleri ve bu sebeple merak ettikleri düşünülmektedir. Öğrenci gruplarına bu çalışma sayesinde ne tür kazanımları olduğu sorusu da sorulmuştur ve öğrenciler genellikle; düşünme, araştırma, birlikte akıl yürütme gibi özellikleri çoklukla kullandıklarını ve bilgiye ulaşma ile somut model üretme aşamalarında kendilerine olan güvenlerinin arttığını belirtmişlerdir.

Bu çalışmada, öğrencilerin günlük yaşam hakkında bilmek istedikleri konular, bu konulara yönelik geliştirdikleri düşünce deneyleri, düşünce deneylerini problem çözme sürecinde kullanımları detaylı olarak sunulmuştur.

Appendix 1
The Rubric Scale for the Assessment of Problem Solutions Using by Physics Thought Experiments

	0	1	2	3	4	5
Problem question	There is no evidence determinate of the problem	The problem determination is incorrectly, irrelevant or inadequate	There is quite a lack of problem determination	There are some shortcomings in the process of determination the problem	There are very little lack of problem determination	The problem was determined correctly
Problem borders and relates	There is no evidence to determine the boundaries of the problem	The problem boundaries determined inaccurately or insufficient	There is quite a lack of problem boundaries determination	There are some shortcomings in the process of determination the problem boundaries	There are very little lack of problem boundaries determination	The problem boundaries were determined correctly
Gathering Information about the Problem (sources and knowledge)	There is no information or knowledge about problem solving	Investigated information is inadequate or irrelevant for the problem solving	There is quite a lack of gathering information about the problem	There are some shortcomings in the process of gathering information about the problem	There are very little lack of gathering information about the problem	Gathering information about the problem were correctly
Constructing Hypothesis	There is no hypothesis related with thought experiments to solve the problem	The number of hypotheses related with thought experiments to solve the problem is one	The number of hypotheses related with thought experiments to solve the problem are two	The number of hypotheses related with thought experiments to solve the problem are three	The number of hypotheses related with thought experiments to solve the problem are four	The number of hypotheses related with thought experiments to solve the problem are five or more than five
Testing the Hypotheses	There is no ideas for the outcome and comparing of each hypothesis and evaluation the results thought	The number ideas for the outcome and comparing of each hypothesis and evaluation the results thought experiments is	The number ideas for the outcome and comparing of each hypothesis and evaluation the results thought experiments are	The number ideas for the outcome and comparing of each hypothesis and evaluation the results thought experiments are	The number ideas for the outcome and comparing of each hypothesis and evaluation the results thought experiments are	The number ideas for the outcome and comparing of each hypothesis and evaluation the results

	experiments	one	two	three	four	thought experiments five or more than five
Reaching to Conclusion and evaluation (drawing or reaching a result, producing model about own thought experiments)	There is no conclusion or producing models about own thought experiments	Reaching to conclusion and producing model inadequate or irrelevant for the problem solving	There is quite a lack of reaching to conclusion and producing model	There are some shortcomings in the process of reaching to conclusion and producing model	There are very little lack of reaching to conclusion and producing model	Reaching to conclusion and producing model were correctly

Foucault Sarkacı

Foucault's Pendulum

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Özet

Jean Bernard Léon Foucault (1819-1868)birçok mekanik ve optik aletlerin keşfi ile tanınan Fransız bir fizikçidir. Hava ortamında yayılan ışığın hızının su ortamındakinden büyük olduğunu ölçmüştür. Aynı zamanda modern fotoğraf tekniğini geliştirerek Güneş ve yıldızların fotoğraflarını çekmiştir (bu, o zamanlar teknolojik güç gösterisi anlamına gelir).Çekimlerden daha iyi sonuç almak için sarkaç güdümlü kurmalı bir cihaz yaptı ve bu cihazla çalışırken; sarkacı, dünyanın kendi ekseni etrafındaki günlük dönüşünü göstermek için kullanabileceğini fark etti.Paris'te bulunan Panthéon adındaki büyük kilise binasının kubbesine bir sarkaç astı ve ilk defa 1851 yılında sarkacın salınım düzleminin yavaşça döndüğünü gözlemleyerek Dünya'nın kendi çevresinde döndüğünü ve dünyanın eylemsiz bir sistem olduğunu kanıtladı. Artık dünyanın dönüşü, teleskoba ve uzun gökyüzü gözlemlerine gerek kalmadan, direk algılanabilir şekilde görünür hale gelmiştir.Penceresiz odada bile dünyanın dönüşü kanıtlanabilir ve hassas ölçümle odanın enlem açısı hesaplanabilir. Bu nedenle Foucault, sarkaç için "doğrudan gözlere" konuşur diye bahsetmiştir. Üstelik sarkacın temel aldığı ilkeyijiroskobu geliştirmek için de kullanmıştır. Keşfin yapıldığı 1851 yılından günümüze, Foucault sarkaçları dünyanın dört bir yanında boy göstermektedir ve her yüz yılda bir Foucault sarkacı yılı için kutlamalar yapılır. Üstelik Umberto Eco'nunFoucault Sarkacı isimlimeşhur romanında konu edilmiştir.Ayrıca 2002 yılında Robert P. Crease'in "Tüm Zamanların En Güzel Bilimsel Deneyleri Nelerdir?" isimli anketine göre Foucault sarkacı,bilimde en güzel ilk on deneyinarasındayer almaktadır (Crease,2003). Bu çalışmada Foucault sarkacının çalışma prensibi, sarkacın denklemleri ve başlangıç koşullarını içeren çözümleri, Foucault'nun elde ettiği sayısal verilerle, sade ve anlaşılır bir şekilde sunulmaktadır.

Anahtar Kelimeler:Dönen sistemler, hayali kuvvetler, Foucault sarkacı, presesyon periyodu, enlem açısı.

Abstract

Jean Bernard Leon Foucault (1819-1868) is a famous french physicist who has discovered many mechanical and optical devices. He measured speed of light and showed that the it was greather in air than in water. He also improved the modern photograph technique and he took some of the earliest photographs of sun and stars(technical tour de force at the time). To get a better result from the shootings, he developed a pendulum controlled winder device and while working on this device he realized that he could use this pendulum to show the world's daily spin around its own axis. Foucault hanged a pendulum in 1851 under the greath dome of the Pantheon in Paris and its oscillation plane is observed to rotate slowly with time. The Foucault pendulum demonstrates that the earth is a rotating noninertial frame and the earth's rotation seems to become visible with Foucault's pendulum. People thinks it is not necessary to observe the skyA person in a windowless room could prove that the room was rotating and, by careful measurement, even determine latitude of the room. Foucault 'feels' that it is speaking to him directly in his eyes.Foucault applied the same principle on which the pendulum had been based to develope the gyroscope. The year 1851 was the Year of the Pendulum and Foucault pendulums propagated all over the world. It was the subject of famous Umberto Eco's novel. In 2002, in the magazine Physics World, Robert P. Crease asked physicists to nominate the most beautiful experiment of all time, Foucault's pendulum is among the first ten experiment according to that inquiry (Crease, 2003). In this study, the principle of Foucault's pendulum, its equations and solutions with initial conditions and using his original data at that time is presented in simple and understandable way.

Key words: Rotating frame, fictitious fources, Foucault pendulum, precession period, latitude.

Giriş

Jean Bernard Léon Foucault (1819-1868) Paris'te bulunan görkemli Panthéon kilisesinin kubbesine bir sarkaç astı ve sarkacın salındığı düzleminin döndüğünü gözlemleyerek ilk defa 1851 yılında Dünya'nın kendi çevresinde döndüğünü kanıtladı.

1850 yıllarında Dünya'nın döndüğü biliniyor olsa da, bu gerçek astronomi gözlemlerine dayanıyordu. Teleskobu olmayanların ya da kullanmayı bilmeyenlerin Dünya'nın döndüğünü bizzat görme imkanı yoktu (Crease, 2003).Kuzey'den bakıldığında yerküre saat yönünün tersinde döndüğü için uzaydaki gök cisimler de saat yönünde hareket ediyor gibi görünür. Bu yerkürenin dönme hareketinin kanıtı olarakgörülebilir, fakat bu tür olaylar eski Yunan filozofların gösterdiği gibi sabit yerkürenin etrafında gök kürenin dönmesi halinde de gözlenebilir.

Foucault sarkacıyla kapalı bir ortamda bile Dünyanın dönüşü görülebilir ve Foucault'nun hoşlandığı ifadeyle "doğrudan gözlere" konuşur. Halbuki Descartes yorumuna göre, hiçbir şey doğrudan gözlere konuşmaz. Foucault, ideal ve geometrik olarak düşlediği şeyi görebileceğine kendini ikna etmişti. Salınan sarkacın arka planında uzak yıldızların olduğu durumu geometrik bir model olarak hayal edebiliyorsak, Dünya'nın döndüğünü "görebildiğimizi" düşünebiliriz. Maurice Merleau-Ponty neyin hareket halinde yada durgun olduğunu algılamanın bile, neyi ön yada arka plan saydığımıza göre değiştiğini söylemektedir (örneğin; biri durgun, diğeri hareket eden trenlerdeki yolcularda oluşan algılar). Foucault sarkacında da ya sarkaç salınım düzlemi yada Dünya dönüyor gibi bir algı oluşmaktadır. Sarkacın salınım düzleminin hareketini görmek için, sarkaç ön plan ve sarkacın içinde bulunduğu oda arka plan olarak sayılır. Dünyanın döndüğünü görmek için de daha büyük uzay veya uzaktaki yıldızları arka plana dahil etmek gerekir (Crease, 2003).

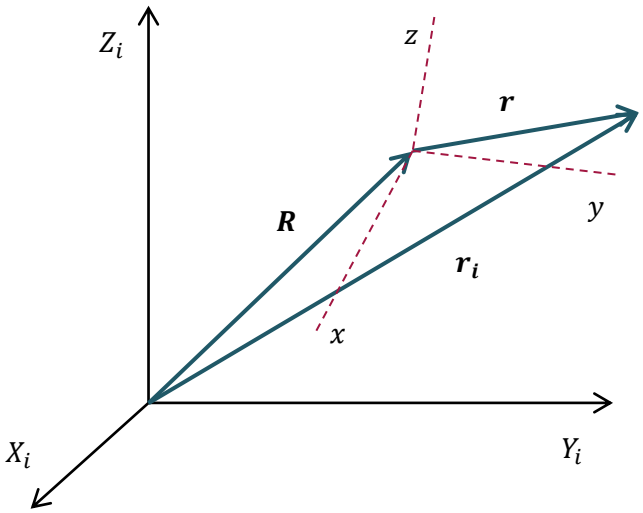
Yerkürenin döndüğü ancak dönen koordinat sistemde, Newton'nun hareket yasası yeniden ifade edilerek ve sarkaç problemi çözülerek kanıtlanabilir. İvmeli bir sistemde Newton'nun hareket yasası

$$m\ddot{\boldsymbol{r}} = m\ddot{\boldsymbol{r}}_i - 2m\boldsymbol{\Omega} \times \boldsymbol{v}_r - m\dot{\boldsymbol{\Omega}} \times \boldsymbol{r} - m\boldsymbol{\Omega} \times (\boldsymbol{\Omega} \times \boldsymbol{r}) - m\ddot{\boldsymbol{R}} \quad (1)$$

ve

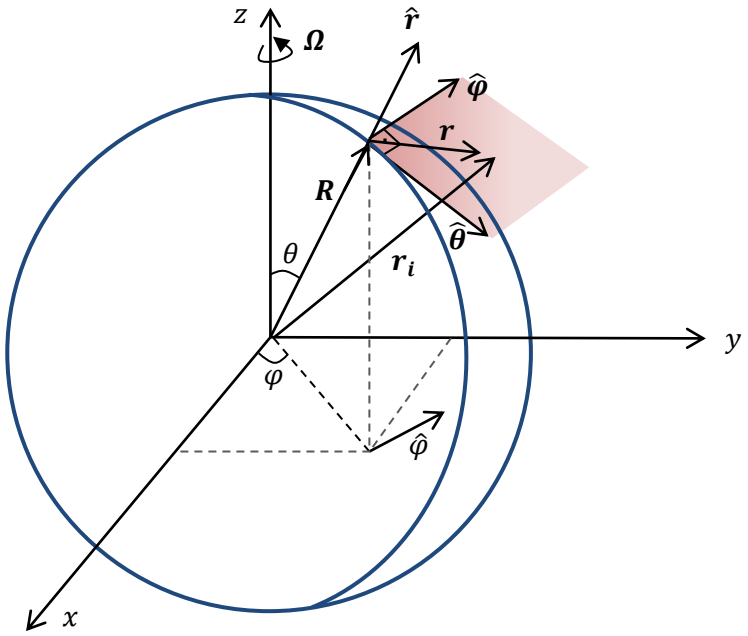
$$\boldsymbol{r}_i = \boldsymbol{R} + \boldsymbol{r} \quad (2)$$

ile verilir (Şekil 1).



Şekil 1. Eylemsiz ve eylemli referans sistemleri

Eşitlik (1) ile verilen sağdaki ilk terim eylemsiz (ivmesiz) sistemde yazılmış olan $m\ddot{\boldsymbol{r}}_{\boldsymbol{i}} = \boldsymbol{F}$ Newton'nun hareket yasasıdır. Burada, $\boldsymbol{F}$ ivmeye neden olan net kuvvettir. Sırasıyla ikinci terim Coriolis, üçüncü Euler, dördüncü merkezcil ve son terim öteleme (translational) kuvvetleridir (Barger ve Olsson, 1995).



Şekil 2. Sabit ve Dünya ile birlikte dönen koordinat sistemleri

Şekil 2'de Dünya'ya sabit olarak tutturulmuş Dünya ile birlikte dönen bir koordinat sistemine göre, Dünya'nın açısal hızı

$$\boldsymbol{\Omega} = \Omega\cos\theta\,\hat{\boldsymbol{r}} - \Omega\sin\theta\,\hat{\boldsymbol{\theta}} \tag{3}$$

vebüyüklüğü

$$\Omega = \frac{2\pi}{T} = \frac{2\pi}{24 \cdot 60 \cdot 60}\,\mathrm{rad/s} = 7.27\ 10^{-5}\,\mathrm{rad/s} \tag{4}$$

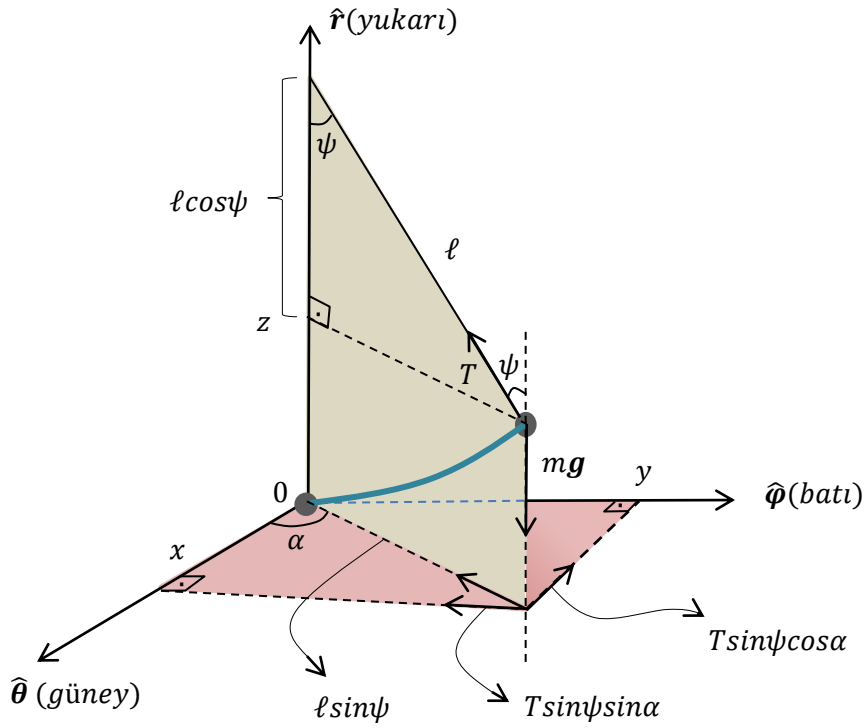
ile verilmektedir. Şekil 3'de her yönde serbestçe salınabilen m kütleli bir cismin, herhangi bir t anındaki koordinatları

$$\boldsymbol{r} = x\hat{\boldsymbol{\theta}} + y\hat{\boldsymbol{\varphi}} + z\hat{\boldsymbol{r}} \tag{5}$$

ve hızı

$$\boldsymbol{v}_r = \dot{\boldsymbol{r}} = \dot{x}\hat{\boldsymbol{\theta}} + \dot{y}\hat{\boldsymbol{\varphi}} + \dot{z}\hat{\boldsymbol{r}} \tag{6}$$

ile verilir.



Şekil 3. Foucault sarkacı ve etkiyen kuvvetler

Şekil 3'e bakılarak koordinatlar açılar cinsinden

$$x = \ell \sin\psi \cos\alpha \tag{7}$$

$$y = \ell \sin\psi \sin\alpha \tag{8}$$

$$z = \ell(1 - \cos\psi) \tag{9}$$

ve açılar da koordinatlar cinsinden

$$\sin\psi = \sqrt{x^2 + y^2}/\ell \tag{10}$$

$$\cos\psi = (\ell - z)/\ell \tag{11}$$

$$\tan\alpha = \frac{y}{x} \tag{12}$$

gibi rahatlıkla yazılabilir. (10) ve (11) ifadelerinin karelerinin toplamından

$$x^2 + y^2 + (\ell - z)^2 = \ell^2 = \text{sabit} \tag{13}$$

ve buradan

$$z = z(x, y) = \ell \mp \ell\sqrt{1 - \frac{(x^2 + y^2)}{\ell^2}} \tag{14}$$

yalnız bırakıldığında serbestlik derecesinin aslında iki olduğu görülür. Sarkacın ucundaki m kütleli metal küreye etkiyen net kuvvet

$$\boldsymbol{F} = -mg\hat{\boldsymbol{r}} + \boldsymbol{T} \tag{15}$$

ile verilir. (15) ile verilen $\boldsymbol{F}$ kuvveti Şekil 3'deki düşey düzlemin içinde kaldığı için, eylemsiz koordinat sistemine göre, salınım düzlemi zamanla değişmemektedir. Burada, teldeki gerilme kuvveti

$$\boldsymbol{T} = -T\sin\psi\cos\alpha\,\hat{\boldsymbol{\theta}} - T\sin\psi\sin\alpha\,\hat{\boldsymbol{\varphi}} + T\cos\psi\,\hat{\boldsymbol{r}} \tag{16}$$

olmak üzere metal küreye etkiyen net kuvvet

$$\boldsymbol{F} = -T\sin\psi\cos\alpha\,\hat{\boldsymbol{\theta}} - T\sin\psi\sin\alpha\,\hat{\boldsymbol{\varphi}} + (T\cos\psi - mg)\hat{\boldsymbol{r}} \tag{17}$$

ile verilir. Açıların koordinatlar cinsinden (10), (11) ve (12) ifadelerinin (17)'de yerine yazılması ile etkiyen toplam kuvvet

$$\boldsymbol{F} = -\frac{Tx}{\ell}\hat{\boldsymbol{\theta}} - \frac{Ty}{\ell}\hat{\boldsymbol{\varphi}} + \left(T - mg - \frac{Tz}{\ell}\right)\hat{\boldsymbol{r}} \tag{18}$$

şeklinde ifade edilir. (1) eşitliğindeki Coriolis kuvveti

$$\boldsymbol{F}_{cor} = -2m\boldsymbol{\Omega} \times \boldsymbol{v}_r = -2m\left[\Omega\cos\theta\,\hat{\boldsymbol{r}} - \Omega\sin\theta\,\hat{\boldsymbol{\theta}}\right] \times [\dot{x}\hat{\boldsymbol{\theta}} + \dot{y}\hat{\boldsymbol{\varphi}} + \dot{z}\hat{\boldsymbol{r}}] \tag{19}$$

vektörel çarpma işleminin ardından

$$\boldsymbol{F}_{cor} = 2m\Omega\dot{y}\cos\theta\,\hat{\boldsymbol{\theta}} - 2m\Omega(\dot{x}\cos\theta + \dot{z}\sin\theta)\hat{\boldsymbol{\varphi}} + 2m\Omega\dot{y}\sin\theta\,\hat{\boldsymbol{r}} \tag{20}$$

gibi hesaplanabilir. Dünya'nın kendi çevresindeki dönme açısal hızı Ω zamanla değişmeyen bir sabit olduğu için buradaki Euler terimi sıfırdır. Açısal hızın karesi ile orantılı olan dördüncü

$$\boldsymbol{F}_{cf} = -m\boldsymbol{\Omega} \times \boldsymbol{\Omega} \times \boldsymbol{r} \tag{21}$$

merkezcil kuvvet ile son terim

$$\boldsymbol{F}_{tr} = -m\ddot{\boldsymbol{R}} = -m\boldsymbol{\Omega} \times \boldsymbol{\Omega} \times \boldsymbol{R}_E \tag{22}$$

öteleme kuvveti kıyaslandığında $r \ll R_E$ olduğu için merkezcil kuvvet terimi öteleme kuvvet teriminin yanında ihmal edilebilir ($F_{cf} \ll F_{tr}$). Böylece (22) ifadesi vektörel çarpma işleminden

$$\boldsymbol{F}_{tr} = m\Omega^2 R_E(\cos\theta\sin\theta\ \hat{\boldsymbol{\theta}} + \sin^2\theta\,\hat{\boldsymbol{r}}) \tag{23}$$

hesaplanabilir ve öteleme ivmesinin büyüklüğü

$$a_{tr} = \frac{F_{tr}}{m} = |\boldsymbol{\Omega} \times \boldsymbol{\Omega} \times \boldsymbol{R}_E| = R_E\Omega^2\sin\theta = 0.034\sin\theta\ \mathrm{m/s^2} \tag{24}$$

hesaplanabilir ve küçük bir değerdir. Böylece (18), (20) ve (23) ile verilen eşitliklerin toplamından

$$\begin{aligned}\boldsymbol{F}+\boldsymbol{F}_{cor} + \boldsymbol{F}_{tr} = &\left(-\frac{Tx}{\ell} + 2m\Omega\dot{y}\cos\theta + m\Omega^2 R_E\cos\theta\sin\theta\right)\hat{\boldsymbol{\theta}} \\ &-\left(\frac{Ty}{\ell} + 2m\Omega\dot{x}\cos\theta + 2m\Omega\dot{z}\sin\theta\right)\hat{\boldsymbol{\varphi}} \\ &+\left(T - mg - \frac{Tz}{\ell} + 2m\Omega\dot{y}\sin\theta + m\Omega^2 R_E\sin^2\theta\right)\hat{\boldsymbol{r}}\end{aligned} \tag{25}$$

elde edilir ve (1) formülü ile verilen denklemin bileşenleri

$$m\ddot{x} = -\frac{Tx}{\ell} + 2m\Omega\dot{y}\cos\theta + m\Omega^2 R_E\cos\theta\sin\theta \tag{26}$$

$$m\ddot{y} = -\frac{Ty}{\ell} - 2m\Omega\dot{x}\cos\theta - 2m\Omega\dot{z}\sin\theta \tag{27}$$

$$m\ddot{z} = T - mg - \frac{Tz}{\ell} + 2m\Omega\dot{y}\sin\theta + m\Omega^2 R_E \sin^2\theta \tag{28}$$

hesaplanmış olur. (28) denkleminden, küçük salınım $\frac{z}{\ell} \ll 1$ yaklaşımı ve $\dot{z} \cong \ddot{z} = 0$ varsayımı ile elde edilen

$$T \cong mg - 2m\Omega sin\theta\dot{y} - m\Omega^2 R_E \sin^2\theta \tag{29}$$

gerilme kuvveti (26) ve (27) denkleminde yerlerine yazılarak

$$m\ddot{x} = -m(\frac{g - \Omega^2 R_E \sin^2\theta}{\ell})x + 2m\Omega sin\theta\frac{x}{\ell}\dot{y} \tag{30}$$

$$+2m\Omega\dot{y}\cos\theta + m\Omega^2 R_E \cos\theta\sin\theta$$

$$m\ddot{y} = -m(\frac{g - \Omega^2 R_E \sin^2\theta}{\ell})y + 2m\Omega sin\theta\frac{y}{\ell}\dot{y} \tag{31}$$

$$-2m\Omega\dot{x}\cos\theta - 2m\Omega\dot{z}\sin\theta$$

eşitlikleri elde edilir ve yine benzer şekilde $\frac{x}{\ell} \ll 1$ ve $\frac{y}{\ell} \ll 1$ yaklaşımı yapılarak

$$\ddot{x} = -\omega_e^2 x + 2\Omega\cos\theta\,\dot{y} + \Omega^2 R_E \cos\theta\sin\theta \tag{32}$$

$$\ddot{y} = -\omega_e^2 y - 2\Omega\cos\theta\,\dot{x} \tag{33}$$

çiftlenimli denklemleri bulunur. $\omega_0 = \sqrt{g/\ell}$olmak üzere, burada sarkacın etkin (effective) açısal frekansı

$$\omega_e = \sqrt{g_e/\ell} \tag{34}$$

ve

$$g_e = g - R_E\Omega^2 \sin^2\theta \tag{35}$$

etkin yerçekimi ivmesidir. (32) ve (33) numaralı çiftlenimli denklemler, kompleks sayılar dahil edilerek,

$$\frac{d^2}{dt^2}(x+iy)+i2\Omega\cos\theta\frac{d}{dt}(x+iy)+\omega_e^2(x+iy)=\Omega^2R_E\cos\theta\sin\theta \tag{36}$$

gibi tek bir denklem halinde verilebilir (Arovas, 2013).

Denklemin Çözümleri

$u=x+iy$ve$u\in\mathbb{C}$ olmak üzere, (36) numaralı denklemde, zamana göre türev işlemi kısaca nokta ile gösterilecek olursa

$$\ddot{u}+i2\Omega\cos\theta\,\dot{u}+\omega_e^2u-\Omega^2R_E\cos\theta\sin\theta\ =0 \tag{37}$$

şeklinde düzenlenir ve

$$w=\omega_e^2u-\Omega^2R_E\cos\theta\sin\theta \tag{38}$$

dönüşümü ile

$$\ddot{w}+i2\Omega\cos\theta\,\dot{w}+\omega_e^2w=0 \tag{39}$$

kompleks katsayılı homojen denklem tipine dönüştürülür. Önerilen

$$w\sim e^{i\gamma t} \tag{40}$$

gibi bir çözümün (39)'da yerine yazılması ile

$$\gamma^2+2\Omega_r\gamma-\omega_e^2=0 \tag{41}$$

karakteristik denklemi elde edilir. Burada

$$\Omega_r=\Omega\cos\theta \tag{42}$$

ve

$$\omega=\sqrt{\Omega_r^2+\omega_e^2} \tag{43}$$

tanımları cinsinden (41) numaralı denklemin

$$\gamma_+=-\Omega_r+\omega \tag{44}$$

ve

$$\gamma_- = -\Omega_r - \omega \tag{45}$$

gibi iki kökü bulunur. Böylece A_+ ve $A_- \in \mathbb{C}$ keyfi kompleks katsayılar olmak üzere, genel çözüm

$$w = A_+ e^{i\gamma_+ t} + A_- e^{i\gamma_- t} \tag{46}$$

$$w = e^{-i\Omega_r t}\left(A_+ e^{i\omega t} + A_- e^{-i\omega t}\right) \tag{47}$$

ile verilir. Daha sonra (46) veya (47) eşitliğindeki A_+ve A_-kompleks sayılarının başlangıç konum (x_0, y_0) ve başlangıç hızı $(\dot{x}_0, \dot{y}_0)$ cinsinden ifadeleri hesaplanıp bulunduktan sonra (46) veya (47)'de tekrar yerine yazılarak reel ve sanal katsayıların birbirine eşitliğinden

$$\begin{aligned} x(t) = {} & \frac{\Omega^2 R_E \cos\theta \sin\theta}{\omega_e^2} + y_0 \sin(\Omega_r t)\cos(\omega t) \\ & + \left(x_0 - \frac{\Omega^2 R_E \cos\theta \sin\theta}{\omega_e^2}\right)\cos(\Omega_r t)\cos(\omega t) \\ & + \left(\frac{\dot{x_0} - \Omega_r y_0}{\omega}\right)\cos(\Omega_r t)\sin(\omega t) \\ & + \left(\frac{\dot{y_0}}{\omega} + \frac{\Omega_r x_0}{\omega} - \frac{\Omega_r \Omega^2 R_E \cos\theta \sin\theta}{\omega\omega_e^2}\right)\sin(\Omega_r t)\sin(\omega t) \end{aligned} \tag{48}$$

ve

$$\begin{aligned} y(t) = {} & y_0 \cos(\Omega_r t)\cos(\omega t) \\ & - \left(x_0 - \frac{\Omega^2 R_E \cos\theta \sin\theta}{\omega_e^2}\right)\sin(\Omega_r t)\cos(\omega t) \\ & - \left(\frac{\dot{x_0} - \Omega_r y_0}{\omega}\right)\sin(\Omega_r t)\sin(\omega t) \\ & + \left(\frac{\dot{y_0}}{\omega} + \frac{\Omega_r x_0}{\omega} - \frac{\Omega_r \Omega^2 R_E \cos\theta \sin\theta}{\omega\omega_e^2}\right)\cos(\Omega_r t)\sin(\omega t) \end{aligned} \tag{49}$$

çözümleri elde edilebilir.

Foucault Sarkacı ve Deneyi

J.B. Léon Foucault' nun Paris'teki Panthéon kilisesinin kubbesine astığı sarkacın boyu $\ell = 67$ m (220 ft) ve ucunda asılı bulunan kürenin kütlesi $m = 28$ kg (62 lbs)' dır. Bu noktada enlem açısı $\Phi = 48°\,52'\mathrm{N} = 48.87°$ $(\theta = 90° - \Phi = 41.13°)$'dir. Bu Foucault

sarkacı probleminde $\Omega_r \cong 5.5\,10^{-5}\mathrm{s}^{-1} \ll 1$ ve $\frac{\Omega^2 R_E \sin\theta}{\ell} \cong 3.3\,10^{-4}\mathrm{s}^{-2} \ll 1$ olduğu için $\omega \cong \omega_e \cong \omega_0 \cong 0.382$ rad/s ve $\frac{\Omega^2 R_E \cos\theta \sin\theta}{\omega_0^2} \cong 0.114$ m'dir. Metal kürenin harekete başlangıç parametreleri $x(0) = x_0$, $y(0) = 0$ ve $\dot{x}_0 = \dot{y}_0 = 0$ olarak belirlendiğinde,

$$x(t) = \frac{\Omega^2 R_E \cos\theta \sin\theta}{\omega_0^2} + \left(x_0 - \frac{\Omega^2 R_E \cos\theta \sin\theta}{\omega_0^2}\right)\cos(\Omega_r t)\cos(\omega_0 t) \tag{50}$$

$$y(t) = -\left(x_0 - \frac{\Omega^2 R_E \cos\theta \sin\theta}{\omega_0^2}\right)\sin(\Omega_r t)\cos(\omega_0 t) \tag{51}$$

çözümleri bulunur. (50) ve (51)'deki çözümler

$$\left(x - \frac{\Omega^2 R_E \cos\theta \sin\theta}{\omega_0^2}\right)^2 + y^2 = \left(x_0 - \frac{\Omega^2 R_E \cos\theta \sin\theta}{\omega_0^2}\right)^2 \cos^2(\omega_0 t) \tag{52}$$

gibi tek bir denklemde de verilebilir. (50), (51) veya (52)'den sarkacın ucundaki kütlenin (yada salınım düzlemi) $t = \frac{2\pi n}{\omega_0}, n \in \mathbb{N}$zaman değerlerinde merkezi $\left(\frac{\Omega^2 R_E \cos\theta \sin\theta}{\omega_0^2}, 0\right)$ noktasında yarıçapı $\left(x_0 - \frac{\Omega^2 R_E \cos\theta \sin\theta}{\omega_0^2}\right)$ olan ve Ω_r açısal hızı ile saat yönünde bir çember çizdiğini görebiliriz. Bu şu demektir: sarkaç, kuantumlanmış belli zaman aralıklarında, çembersel yörünge üzerine dizilmiş olan çivileri devirmektedir.

Güney yarımküredeki çözümleri bulmak için de (50) ve (51) ile verilen çözümlerde kısaca

$$\theta \to (\pi - \theta) \tag{53}$$

dönüşümü yaparak

$$x(t) = -\frac{\Omega^2 R_E \cos\theta \sin\theta}{\omega_0^2} + \left(x_0 + \frac{\Omega^2 R_E \cos\theta \sin\theta}{\omega_0^2}\right)\cos(\Omega_r t)\cos(\omega_0 t) \tag{54}$$

$$y(t) = \left(x_0 + \frac{\Omega^2 R_E \cos\theta \sin\theta}{\omega_0^2}\right)\sin(\Omega_r t)\cos(\omega_0 t) \tag{55}$$

çözümleri bulunabilir. Bu çözümlerden sarkacın salınım düzleminin Ω_r açısal hızı ile saat yönünün tersinde döndüğü görülür.

Sarkacın salınım düzlemi ile x ekseni arasındaki açı

$$\alpha(t) = \Omega_r t = (\Omega\cos\theta)t \tag{56}$$

şeklinde zamanla değişmektedir. Açı 2π değerini aldığında geçen süre presesyon veya foucault periyodu T_{prec} diye tanımlanırsa (56)' dan

$$T_{prec} = \frac{T}{\cos\theta} = \frac{T}{\sin\Phi} \tag{57}$$

formülü elde edilir. $\theta = 0$, kuzey kutup noktasında$T_{prec} = T$ ve $\theta = \frac{\pi}{2}$, ekvator üzerinde $T_{prec} = \frac{T}{0} = \infty$ olduğu için presesyon gözlenemez. Burada

$$\alpha(t) = \frac{2\pi}{T_{prec}} \cdot t \tag{58}$$

açısı presesyon periyodu cinsinden de verilebilir. Sarkacın açısal frekansı

$$\omega_0 = \sqrt{\frac{g}{\ell}} = 0.382 \text{ rad/s} \tag{59}$$

veya sarkacın periyodu

$$T_0 = \frac{2\pi}{\omega_0} = \frac{2\pi}{0.382} = 16.45 \text{ s} \tag{60}$$

olan sarkaç presesyon hareketi ile yerdeki ince kum tabakası üzerinde 3 m yarıçapında bir çember çizmektedir (Kittel, Knight, Ruderman, Helmholz ve Moyer, 1973). (57) numaralı formülden presesyon periyodu

$$T_{prec} = \frac{24 \text{ saat}}{0.753} = 31.87 \text{ saat} \cong 32 \text{ saat} \tag{61}$$

olarak bulunur. (58) numaralı ifadeden, bir periyot zaman sonra süpürülen açı

$$\alpha = \frac{2\pi}{31.87} \cdot \frac{16.45 \text{ s}}{60 \cdot 60 \text{ s}} \cong 9\ 10^{-4} \text{ rad} \tag{62}$$

ve bu açıya karşı gelen yayın uzunluğu da

$$s = \alpha \cdot x_0 = 9\ 10^{-4} \cdot 3 \text{ m} = 2.7\ 10^{-3} \text{m} = 2.7 \text{ mm} \tag{63}$$

olarak hesaplanır. Yine (58) numaralı ifadeden, bir saat zaman sonra süpürülen açı

$$\alpha = \frac{2\pi}{31.87 \text{ saat}} \cdot 1 \text{ saat} = 0.197 \text{ rad} = 11.3° \tag{64}$$

ve bu açıya karşı gelen yayın uzunluğu da

$$s = \alpha \cdot x_0 = 0.197 \cdot 3 \text{ m} = 0.591 \text{ m} \cong 0.6 \text{ m} \quad (65)$$

olarak bulunur.

Sonuç

Foucault sarkacı ile yapılan deneysel sonuçların teorik hesaplar ile uyumlu olduğu gözlenmiştir. Eylemsizlik ilkesi gereğince, sarkacın salındığı düşey düzlem sabit yıldızlara göre değişmez kalır. Bu nedenle Dünya saat yönünün tersinde dönüyorken, Dünya'dan bakan bir gözlemciye göre sarkaç saat yönünde dönüyor görünür. Hiç teleskoba gerek duyulmadan penceresiz kapalı bir odada bile presesyon periyodu ölçülerek sarkacın bulunduğu yerin enlem açısı ve sarkacın doğal periyodu ölçülerek Yerçekimi ivmesi daha doğru hesaplanabilir. Foucault'nun sarkacı ile birlikte, Dünya'nın dönüşü daha net görünür hale gelmiştir. Foucault sarkacı Dünya'nın döndüğünü ve dönme etkilerini gösteren önemli kanıttır.

Foucault, sarkacın temel aldığı ilkeleri, 1817'de Johann Bohnenberger'in keşfettiği mekanik alete uygulayarak aleti geliştirmiş ve bu mekanik alete jiroskop adını vermiştir.

Foucault sarkacı fizik dünyasında çabuk şöhreti yakalayan deneylerden biridir. Günümüzde Foucault sarkaçları birçok üniversitede, gözlemevinde ve bilim müzelerinde sergilenmektedir (Crease, 2003).

Kaynaklar

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Foucault's Pendulum

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Introduction

Jean Bernard Leon Foucault (1819-1868) hanged a pendulum in 1851 under the great dome of the Pantheon in Paris. Its oscillation plane is observed to rotate slowly with time and he proved that rotating of earth its own axis.Although most people in 19th century knew that the earth moved, all evidence was based on astronomical observations. People without a telescope and the knowledge of how to use it had no way to see that motion for themselves (Crease, 2003). As we have seen from Nort pole, Earth rotates in counterclockwise direction and whereas other celestial bodies in space are moving in a clockwise direction. This can be seen as evidence of the Earth's rotation, but such events are also observed in Ptolemaic system, the stars were thought to be on a celestial sphere, with the earth at its center, that rotated each day. A person in a windowless room could prove that the room was rotating and Foucault likes to say, pendulum speaks "directly to the eyes.". However, according to vision of Descartes nothing can speak directly to the eyes. Foucault has convinced himself that he could see what he imagines ideally and geometrically. If we could imagine the situation of the pendulum oscillating against the background of the distant stars as a geometric model, then we could see the Earth's rotation. French philosopher Maurice Merleau-Ponty pointed out that even visiual perceiving what is in motion and what is at rest depends on what we take as the foreground and what as the background or horizon (for example, passenger in one train which is moving relative to passenger in other train which is rest. They fell different perception, which one is moving?). Foucault's pendulum seems to offer of the experience either of the plane of pendulum turning in the gravitational field of the earth, or of the earth turning under our feet. In order to see the plane of the pendulum's oscillation move, we need to take pendulum as the foreground and the surrounding room as the background. In order to "see" the earth moving, we would have to introduce a different and much bigger background (fixed stars in space) where the earth would show itself as moving, and the plane of oscillation of the pendulum would show itself as stationary (Crease, 2003). Earth's rotation can be proved only by solving Foucault's pendulum and then re-expressed Newton's second law in terms of a coordinate system fixed on the rotating Earth than in terms of an inertial coordinate system (Barger and Olsson, 1995).

Calculations

Newton's equation of motion law in the non-inertial frame from (1) and after some calculation (Arovas, 2013), we get solutions from (51), (52) or (53). We note that pendulum bob at time $t = \frac{2\pi n}{\omega_0}, n \in \mathbb{N}$, draw the circle with centre coordinates $\left(\frac{\Omega^2 R_E \cos\theta \sin\theta}{\omega_0^2}, 0\right)$ and radius is $\left(x_0 - \frac{\Omega^2 R_E \cos\theta \sin\theta}{\omega_0^2}\right)$ is such that

$$\left(x - \frac{\Omega^2 R_E \cos\theta \sin\theta}{\omega_0^2}\right)^2 + y^2 = \left(x_0 - \frac{\Omega^2 R_E \cos\theta \sin\theta}{\omega_0^2}\right)^2 \cos^2(\omega_0 t) \qquad (52)$$

and also note that an earth-fixed observer thus sees the pendulum plane precessing slowly clockwise (in the northern hemisphere) with angular frequency Ω_r. The time required for the pendulum plane to process by 2π is

$$T_{prec} = \frac{T}{\cos\theta} = \frac{T}{\sin\Phi} \tag{57}$$

the precession periodvanishes at the equator and is maximum at the North pole, where the pendulum precesses clockwise through a complete revolution every twentyfour hours. From the viewpoint of an observer in space, the oscillation plane remains fixed, while the earth turns counterclockwise under the pendulum in the northern hemisphere (Barger and Olsson, 1995).

Conclusion

Foucault's experimental results were compared with theoretical calculations. Itwasfoundthat results are in agreement. According to the principle of inertia, vertical plane of pendulum remains unchanged compared to the fixed stars. Therefore, Earth rotates in counterclockwise direction however the pendulum rotates clockwise direction on the northern hemisphere. A person without telescope person in windowless room could prove that the room was rotating and, by careful measurement of precession period and angular frequency of pendulum, even determine latude of the room and find correctly acceleration of gravity. With Foucault's pendulum, the Earth's rotation seems to become visible.Foucault pendulum shows that significant evidence rotation and rotation effects of the Earth.In 1817 Johann Bohnenberger discovered a mechanical device and later Foucault applied the same principle on which his pendulum had been based to develope that mechanical device and gave it a name as gyroscope.Few scientific experiments met with such instantaneous fame as Foucault's pendulum in physics world.Today, Foucault pendulums exist all over the world in science museums, universities, and other institutions (Crease, 2003).