The International Commission on Physics Education
I.U.P.A.P
(International Union of Pure and Applied Physics)

girep
Groupe International de recherche sur l' Enseignement de la Physique

Gerhard Mercator Universität Gesamthochschule Duisburg

Fachbereich 10
Physik - Technologie

Sektion Didaktik der Physik

ICPE-GIREP International Conference

Hands on-Experiments in Physics Education

Duisburg - Germany
August 23 - 28, 1998

Editors

Gernot Born, Horst Harreis, Herbert Litschke, Norbert Treitz

THE PHYSICS OF ANCIENT AND MODERN GREEK FOLK TOYS

G. Kalkanis *

University of Athens, Greece

The scientific methodology (properly adopted) is widely used also as a didactic methodology.

The consisting steps of this methodology may be described, in a rough way, as:

- trigger of research / trigger of teaching / trigger of students interest
- making hypothesis / questioning the problem
- experimentation
- making theory / conclusions
- continuous testing to confirm or defeat the theory / problem transfer in everyday phenomena

Following this methodology, the ingenious, imaginative and creative teacher (who has to trigger teaching / learning of a wide range of scientific topics) needs to extract triggering ideas from a great variation of sources

Furthermore, combining the need to trigger students' interest with the need to carry on the didactic process in an enthusiastic and active environment, the teacher can not ignore the possibility of playing with toys, either in situ or in the laboratory.

Mind-on work is gradually improved whenever is properly triggered and is enhanced by hand-on work and fun. That is true for young students, but not only for them (!)

There are many games / toys (especially in Greek tradition) from which teaching physics ideas and principles may benefit extensively.

We attempt, here to select such games / toys from the Greek (folk) tradition, noticing that our main interest is not a detailed study of the physics itself but, rather, mainly the way the physics ideas and principles behind these games may be pointed out, extracted and used effectively in physics teaching / learning.

But let's clarify first what we mean by games / toys.

In Greek antiquity activities which aimed at physical or mental exercise, at developing a certain degree of skillfulness and/or cleverness or, simply, at amusement - personal or/and in groups - were called παιχνίδια (the word has its origin to the verb παίζω = to play, which, in its turn, stems from the word παιδί = child).

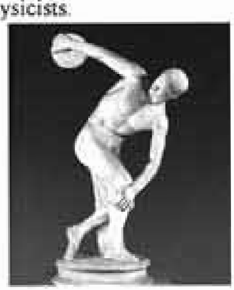
* with the contribution of O. Gikopoulou, K. Dendrinos, P. Tsakonas, M. Patrinopoulos, D. Imvrioti, I. Fergadiotou

support / encourage (or promote) both then and nowadays this type of life.

In our attempt to present some of the Greek ancient and modern folk παιχνίδια, we will, hopefully, point out the physics principles which are hidden behind, urging also physics teachers to enhance teaching / learning with relevant references, practice and experimentation / playing.

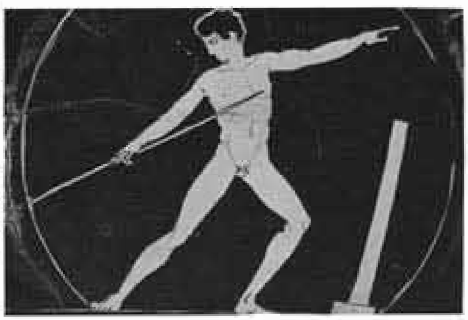
Two typical characters of the ancient times will help us. An Athenian, named Ευπρόλαλος (=the ease and early speaker) and a Lacedemonian (or Spartan), named Δυσκοίλογος (=the not easy speaker).

These cartoons (created by the author) have already been used to "trigger" teaching / learning of several physics subjects in an amusing way, through the pages of the magazine "Φυσικός Κόσμος" a publication of the Association of Greek Physicists.



Undoubtedly, δίσκος (discus) and its throwing, is a very common toy and popular activity / playing in Greek ancient times, as well as one of the first and basic athletic events / games through centuries. This activity, besides offering joy, fun and physical exercise to the players, offered / offers the opportunity for pointing out and teaching / learning / practicing / experimenting of some very important physics aspects.

- the shape of the discus and the correct starting position of the player for the longest possible flight,
- the need of the player to whirl (rotate) his body in order to gain angular momentum as great as possible
- the release of discus at the right point of its circular path (depending on the desired destination), with the maximum linear momentum / velocity (speed)
- the optimum angle of the discus' main axis and the tangent to its path, in connection with the forces (weight, aerodynamic force), in order to profit from the Bernoulli effect for the longest in distance
- longer in flight time
- the need of an initial spin about its main axis which insure the stability during flight of its axis
- the influence of the wind direction and speed



Similarly, the ακόντιο (javelin) and its throwing, also an ancient toy / plaything / activity (either as distance throwing or target throwing) and a basic part of modern athletic events, raises some very important physical questions:

- the weight, the shape and the construction of javelin (if its weight is standard, hollow javelin of nowadays has larger surface which leads to increased flight capability)
- initial conditions of throwing vs. distance of the flight
  - standing player (as in ancient times)
  - running player (as in modern times)

In some of these activities the players were using αθύρματα (= playthings, toys), also called παιχνίδια.

Some of these activities were performed (by individuals or small groups) in a competitive way. They were also called παιχνίδια. In the case they were performed under specific rules, in the frame of festivities and celebrations or in the form of periodic events and gatherings, they were / are called (also) αγώνες (= games).

We consider here all athletic / sport events or games either using equipment or playthings or toys, also and primarily as παιχνίδια, i.e. every spontaneous activity (with or without playthings / toys) which offers physical and/or mental exercise, improves skillfulness or cleverness or, simply, offers fun / amusement to individual persons or groups.

Hopefully, παιχνίδια may also play a major role in physics education.

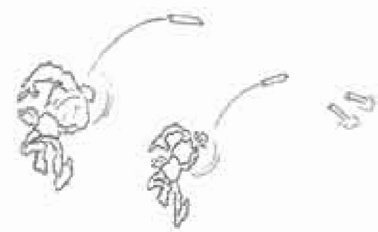
The pedagogist of the Greek antiquity had early recognized (and established as a didactic approach) the correlation between physical or hand-on action/playing and mental work/learning.

All activities which we call παιχνίδια (either using playthings / toys or not) were introduced / studied through old writings or tradition in school classes and then were practiced in gymnasia or palestrae. Teaching / learning and practicing however was extended during athletic games, in festivities in country fields at rest time in the streets of the neighborhood, at house yards, at home.

Most of these activities / toys / παιχνίδια are still in practice in Greece where the Mediterranean climate, the friendly environment and the sociability of the people

- whirling player (a discus style abandoned, although very effective for longer flight, abandoned for safety reasons)

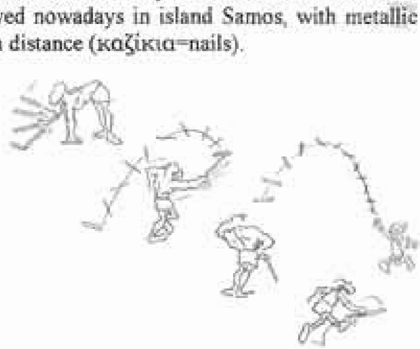
- the influence of the position of its center of mass / weight / gravity.
- the effect of the location / position of its center of aerodynamic force
- the demand of javelin point first landing
- the (arbitrary) javelin's spin during flight (as high as 25 revolutions per second) which tends to stabilize it in flight
- the javelin's oscillation about its length (frequency of about 25 Hz) which detrimental to the flight and therefore need to be minimized by the thrower.



Another παιχνίδι of the ancient times which is characterized as a plaything / toy throwing, through not adopted by the athletics organizers, was κυνδαλισμός or πασσαλισμός.

Wooden sticks / beanpoles with an end sharpened (κύνδαλα or πάσσαλοι) were thrown from a distance to be struck into moistened, soft soil or sand.

With repetitive throws the players were trying to hit previously stuck (κύνδαλα / πασσάλους) sticks and to knock them deeper into the soil / sand (although the rules and detailed description of the toy is missing) The phrase "πάσσαλος πασσάλω εκρούετω" (=stick knocking other sticks) became famous by the ancient Greek authors (Πολυδεύκης). The toy / game is still played nowadays in island Samos, with metallic long nails thrown to be stuck into sand from a distance (καζίκια=nails).



A version of this toy / plan or game is very popular and common in almost all parts of modern Greece, though it is called in each place by different names (xiliki, tsiliki,...)

It is consisted of two different in length, cylindrical, wooden sticks. The longer (approximately 0.50 m) is sharpened to the two ends, the shorter (approximately 0.25m) is sharpened to both ends. The two sticks have the same diameter (approximately 0.03 m). A player, holding the longer stake, hits vertically the shorter one, which is laying horizontally on the ground. The later jumps if it is hit on one of the sharpened ends. During its flight, the player tries to hit it again and throw it as further as possible. Other players try to catch it on the air.

Slightly different versions are encountered all around Greece.

In any case this toy / game hides a great variety of physics topics and offers the opportunity to be taught / examined / experimented / learned during the self-construction and playing.

* the optimum length of the short stick tunes its moment of inertia and, consequently, its rotation frequency, during its flight (high frequency makes the second hitting harder, low frequency makes catching by the other player easier…)
* the length of the sharpened ends of the short stick has to be optimized, also: (a short one does not allow always a kick which leads to a jump, which means that the torque is not adequate, a long one may be proved inadequate for jumping
* kicking of the short stick by the long one must occur at the middle (in order for the momentum to be transferred as linear, which leads to longer distance traveled, instead of angular momentum which of course makes the life of the other player, who tries to catch the stick in the air, more difficult…

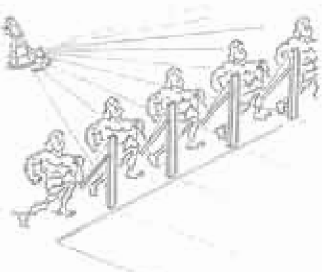
Toys / games with balls were also played in ancient times (either by a single player, two players, or groups of players…). Toys / games with ball are also played in modern times.

To our astonishment, most of them are quite similar:

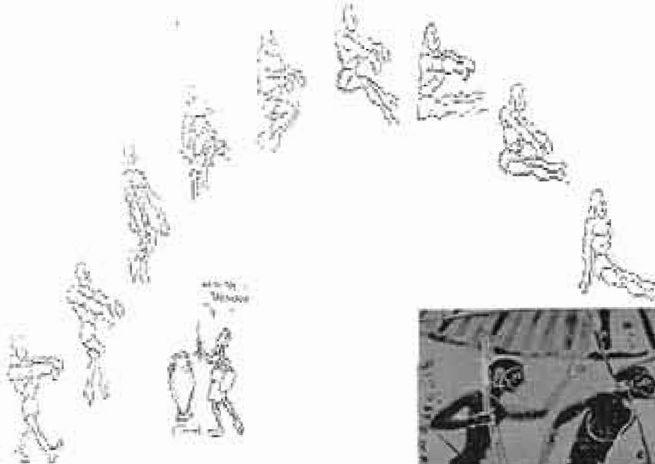
* Juggling
* Balancing
* Sphaeromachiae (Sphaere = sphere, ball, machi=battle) group games which were noisy contests to get hold of the ball. Among the most popular ones are included such games as harpaston (=grasped, robbed), the handball rugby, hockey, etc.

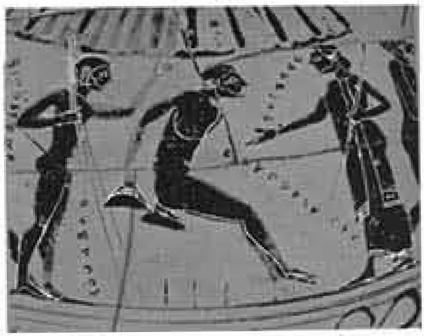
The rules are not clear today, but we can imagine some of the physics hidden behind these games.

From the physics point of view, we can say very little about παιγνίδια which are based on running or racing. However, from the physics or technology point of view, it is interesting to know how in the ancient athletic games the referees (κριτές) insured the synchronous (by all runners) starting (starting at the same time). They had invented and constructed - according to some findings in a stadium of Corinthos (where the games called Isthmia were held) - a quite simple system. The starter removed bars which were in front of the athletes using a bunch of strings (!).



Άλματα (jumps) were also very common play as well as basic game in athletic events in ancient times. One particular type of jumping (which is not officially in practice nowadays) gives us some evidence that those people had a very deep (though empirical) sense of some physics principles. That is ἅλμα με βάρη (jumping with weights). The player / athlete (standing or running) jumped, carrying with his hands, two weights (made of stone, iron or copper). Initially, he had his hands extended horizontally in front of him. When he was on the highest point of his jump, he threw the weights behind him, in order to get an extra thrust (based on the principle of the conservation of momentum) which would gain him some extra horizontal distance traveled.





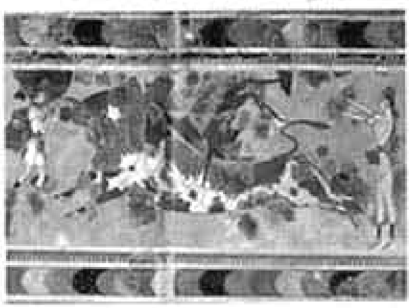
Άλματα (jumps) are also giving a lot of fun (when one uses some special equipment / toys), whilst they offer a good empirical sense of physics quantities and processes under unusual conditions.

In ancient times, during festivities, players / competitors were standing or jumping on a greasy shield or a goatskin (full of wine), experiencing at the same time a world without friction. The wine was the award given to the competitor who managed to stay on for the longest time. So jumping on goatskins is also played nowadays in Greece, although the ice fields (where a non-friction world is better simulated), have gradually replaced jumping on grease goatskins.

Jumping with the legs inside sacks (made out of wool or cotton) is / was a game very popular and common in modern and ancient times. This game offers an extraordinarily good sense of the way the center of gravity has to be placed at the correct position each time a jump is completed. For the experience of an exaggerated sense, the players compete for the longest or the shortest duration of run.

A special jump, an acrobatic jump over a bull, was practiced at festivities in Greece during Minoan times.

This jump possibly was operated with the cooperation of the bull, helping the jumper with a sudden raise of its horns / head (on time with the extension of the jumper's legs). It offered a good sense of the initial momentum needed, the body rotation, landing.



Αυτόματα = automata, self moving machines. In ancient times such mysterious devices looked like a part of superstition, but the were mainly toys. First of all we consider Siphon as a simple automaton. The Pythagorean Cup for example was also called Δίκαια Κούπα, which means drinking cup of fairness.

Aristotle mentions self moving tripods. According to tradition, Daedalus made self-moving statues, of which Plato writes that "unless fastened, they would of themselves run away". This makes Socrates use as a figure of speech to illustrate the importance of not only acquiring but of holding on fast to scientific truth, that it may not fly away from us.

A contemporary of Plato, the Pythagorean philosopher, mathematician, cosmographer and mechanician, Archintas of Tarentum (to whom the inventions of the screw and the crane are accredited), is said to have constructed a wooden pigeon that could fly about. According to Aulus Gellius "it was nicely balanced by weights and put in motion by hidden and inclosed air".

Of all the early inventors, the most remarkable genius was Hero of Alexandria. He lived at about 150 BC.

In his unusual book Epeiritalia (a great storehouse of ingenuity) divides his experiments into those which are primarily scientific and those that are intended to give to their owners some of the more delectable refinement of playing with toys.

To the former belong (among others)

- the first siphon (in both its typical forms),
- the syringe,
- the steam engine

• ...

The earliest example of Hero's work in toy-making was a bird which (by means of a stream work) was made to pipe or sing...

The list of toys (αθύρματα), played in ancient as well as in modern times in Greece is quite long. Selecting those which may offer some physics achievements, we refer to:

- The metallic or wooden ring (having a 0.25 to 1.0 m of diameter) which was / is rotated on the ground by the hand or with the help of a metallic or wooden stick. The empirical way the player increases or decreases its angular momentum (and its angular / linear velocity) or changes the direction of its motion, the correlation of the ring's mass and diameter to the stability of its rotation / angular momentum, ... bear a direct reference to the relevant physics concepts.

- The well known γιο-γιο was / is also offering the opportunity of studying some physics concepts: angular momentum conservation, initial conditions, friction, the effect of the moment of inertia, etc.

- The κούνια (swing), very popular and widely used in ancient and modern times was / is a very handy toy, helping also to change and study a number of parameters / physical quantities, i.e. length of the ropes, friction on the points of support, potential and kinetic energy conservation, resonance, etc.
- Toys with wheels
- Toys with ropes
- ...

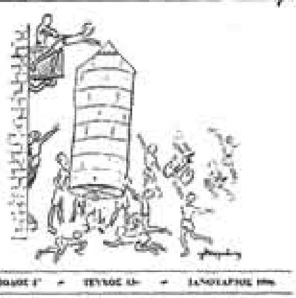
Most of the games / toys played in ancient and modern times in Greece (and elsewhere as well) are based, mainly, on the laws of mechanics.

However, we must not forget that some electric and magnetic phenomena had been observed in Greek antiquity, although only in a very primitive level. Ηλεκτρον (amber) was already known as having some properties of attraction after rubbing it with specific materials (preferably clothes of wool). Magnetite, a mineral found also at large quantities in the region of continental Greece called Magnesia, was known as able to attract light metallic pieces. It seems more than possible that pieces of electron and / or magnetite were used as toys.

In a country like Greece, with a great number of small or larger streams, bringing amounts of water down from mountains, or sea waters surrounding practically the whole country, it would be strange if the water weren't a means of playing games.

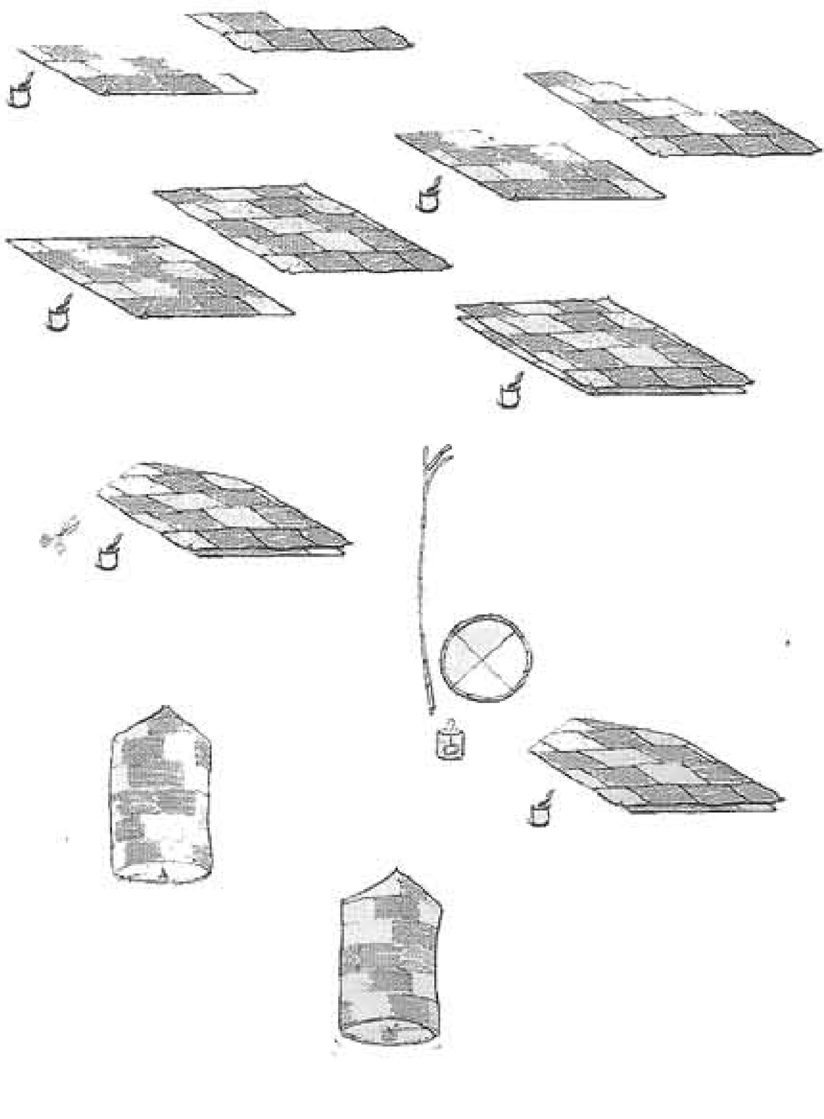
Hand-made wind-wheels (ανέμη) made of fruit (oranges etc.) and some wooden sticks, rotate for centuries in country sides during spring, when the snow is melting. The number of their wings, their length, the length of the part that goes under water and a number of other parameters are / were optimized empirically, and they could also become the subject of several physics courses.

Small wooden boats - ranging in size from some centimeters (used as toys) to real boats (able to carry children) - have also been sailing for centuries during the summer season in Greek waters. Through this process the Greeks gathered enough experience in order to be able to optimize a number of sailing techniques. Every day practice for - ancient and modern - sailors, but also a toy or game, amusement and sport, as well as a trigger and an experiment for studying the laws of hydrodynamics.



Since the Greeks spent a great part of the year in the outdoors, in the open air, learning to play with the air too, was inevitable. An example of such games is the aerostat which was constructed and then put to flight by a large team of players, who were actually prospective experimentalists. They used pieces of paper which they glued together. A light branch from a tree was formed in the form of a circle and used as an inner skeleton, in order for the paper made aerostat to maintain a cylindrical shape. Some wire was used in order two form a cross along two mutually perpendicular diameters of this circle. From the middle of the cross the players hang a piece of sponge, which they had already soaked in oil, spirit, or some other flammable liquid substance, which they would later (when the aerostat would be ready to fly), in order to heat the air inside the aerostat and lift it up in the air. It is important to note that the players were empirically aware of the fact that in order for their aerostat to be stable during its flight, they had to give it an initial rotation, while releasing it, around its vertical axis, which means that they relied on the conservation of angular momentum in order to have a successful game!

This game is one of the many that has survived even during modern times, and it was practiced in a great number of villages (including the author's home village) by players of various ages, at least until recently.



THE KYNDALON OR XILIKI IN GREEK TRADITION AS A TOY AND AN EXPERIMENT - ITS CONSTRUCTION, MODE OF OPERATION, SIMULATION, PHYSICS AND OUR TEACHING METHODOLOGY

P. Tsakonas, D. Imvrioti, M. Patrinopoulos, G. Kalkanis
University of Athens, Pedagogical Department P.E.
Science, Technology and Environment Laboratory

Abstract

The physics of the rigid body along with all the associated physical quantities, i.e. force, acceleration, moment of inertia, rotation, angular momentum etc., is presented through a very popular Greek traditional game, played even nowadays. The traditional Greek game named kyndalon (version), xiliki or tsiliki is used as a means of developing a relevant teaching methodology of this subject. This outdoors game is quite simple to construct (it takes only two pieces of wood), but requires a well established knowledge of physical phenomena, or the intuition of the experienced player which may readily be transformed into physical study through proper motivation.

Specifically the materials used to construct the pieces of the toy, as well as the way they are put together, are described (and shown...). Then a reference (and practice...) is made to the way this game was / is played (number of players, aim of the game etc.), giving emphasis on a number of variations under which lie several specific physical principles.

A computer-based simulation / visualization program is also presented which enables the user to study the process of the game, to vary initial conditions, to measure physical quantities, to graph results etc. The user may also interactively play the game from the computer.

1. Introduction

The ancient Greek game named Kyndalon (or Xiliki or Tsiliki - Kyndala, Xilikia or Tsilikia in plural) is / was played not only in Greece but in a number of countries such as Albania, Poland, India etc.

2. Constructing / Playing the game

The first step to construct the game is to choose a piece of wood of cylindrical shape (a branch from a tree should do), the sides of which are then sharpened in order to create a cone-like surface. These surfaces, when properly carved and successfully hit upon, will enable the xiliki to lift high in the air while rotating. The player manages to lift the xiliki by striking either one of its sides using a second piece of wood. While xiliki is rotating, the player tries to strike a second blow, in order to send it as far as possible.

In a variation of the game, the aim is to have xiliki rotating with great frequency, so as to make it difficult for other players to catch it on the air. In this case the second strike must be applied in such a way as to increase the angular velocity caused by the first blow. This means that the force must be applied away from the middle of xiliki, so that its torque will give the desired angular acceleration.

In another variation, the idea is to hit xiliki in such a way as to send it as far as possible. In this case of course proper care must be taken in order that the second strike aims somewhere in the middle of xiliki's length, so that most of the energy transformed to it will become kinetic energy, thus resulting in the covering of the longest possible distance.

In a third variation, the player tries to make the xiliki land as near as possible to a formerly designated point which can either be a stone, a piece of wood which has been firmly fixed on the ground, or the landing point of other players' xilikia. From the second case stems the ancient Greek phrase "Πάσσαλος πασσάλω εκρούετω", which refers to a piece of wood knocking on another piece of wood, and it has, through the ages, become a Greek saying.

In most cases players calculate the distance covered by xiliki using the second piece of wood (the one they used for hitting xiliki) as a measuring instrument / unit.

A reconstruction of the game was made by a group of children working in collaboration with researchers from the Physics, Technology & Environment Laboratory of the Pedagogical Department P. E. of the Athens University. During this reconstruction, a number of xilikia were constructed in the traditional way, and several variations of the game were tried out. The whole process was filmed, and a short clip from this film was incorporated in the software developed for the simulation of the game.

3. Simulating the game

A computer-based simulation / visualization program was prepared, in order to facilitate the understanding of the physical laws governing the game.

A number of parameters, such as the sharpness of xiliki's edges, xiliki's weight, length etc., may be defined by the user through specific controls placed inside the window of the program. The user may also interactively lift the xiliki (using the mouse) and place it – or let it drop – wherever desirable.

Once the initial conditions of the game have been determined, the user may apply a force on xiliki. The program designs a vertical force vector inside the playground, the magnitude of which varies as the user clicks on the appropriate scroll bar. As in the case of xiliki itself, the user may use the mouse to move the force around the screen. Special care has been taken in order not to allow the force to be moved inside xiliki's volume, or inside the ground.

As an additional visual aid, the user may choose to have the program draw a grid on the screen, in order to facilitate the process of measuring distances.

Next, the user may initiate the simulation process, by clicking on the appropriate button. The program responds, by gradually moving the xiliki in the way determined by the two forces (i.e. its weight and the externally applied force). The simulation proceeds at a slow pace, but it may readily be accelerated by the appropriate controls included in the user interface. Along the simulation process, the program presents a qualitative / semi-quantitative visual update of the magnitude of torques in the form of horizontally oriented color bars, the length of which is determined by the torques' magnitudes. Specifically, the torque of the xiliki's weight (red bar), the torque of the externally applied force (blue bar) and the total torque (yellow bar) are presented. Along with these, the same technique is employed in order to visually represent the magnitudes of xiliki's linear velocities in the x- and y-axes.

In the beginning, and assuming that the point of application of the external force lies somewhere along one of xiliki's sharp edges (for example the left one), xiliki rotates about the left base point of its edge (Point A in fig. 1). As soon as the outermost point of xiliki (Point B in fig. 1) reaches the ground, then the center of rotation shifts. As a result the magnitudes of the torques of the forces, undergo a – most of the times – substantial change.

From that point on, xiliki's behaviour / movement depends on its angular speed, acquired during the first phase of the rotation process.

If this angular velocity results in a vertical component of linear velocity with large enough magnitude to lift xiliki from the ground, then the simulation continues with xiliki's elevation / flight in the air. The game ends as soon as xiliki lands on the ground. At that moment a message appears notifying the user that the game has ended.

If, on the other hand, initial values / conditions lead to an unsuccessful result (for example, xiliki does not lift, or it does not have enough speed in order to travel far), then a message appears informing the user of the problem, while suggesting a number of solutions (i.e. change the point of application of the external force, decrease xiliki's weight, decrease xiliki's length, increase sharp edge's length etc.).

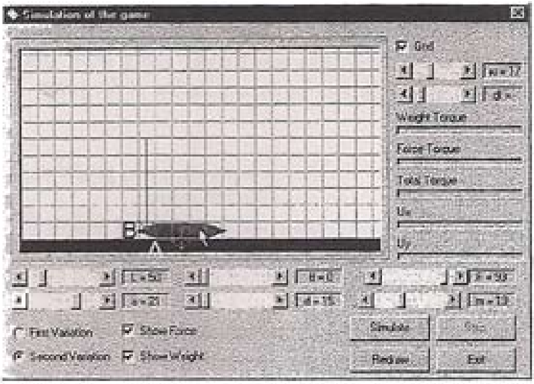


FIGURE 1. The main screen of the program

In either case the user may repeat the game, following the directions presented on the screen. Of course, variations concerning initial values are allowed, in order to make comparisons and determine the effect that such values have on the final outcome of the game.

4. Concluding remarks

A great number of physical principles must be obeyed during the playing of xiliki in order that the game have a successful result. One may safely assume that these principles are/were – at least empirically – known to the players. During playtime this set of rules was communicated to next generations of players, while undergoing several improvements, proven beneficial by the game results. This process in nothing more than actual scientific experimentation (even is a mostly simplistic and elementary form) and, when stressed upon, may be utilized as a starting point in order to develop proper experimental behavior and convert as team of players into a group of Physics students and experimentalists, occupied in procedures taking place outdoors and, what is more important, performing experiments by themselves and studying the results. Thus, the pedagogical dimension and educational value of games in the study of Physics are self-evident.

THE AEROSTATON / AEROSTAT IN GREEK TRADITION AS A TOY AND AN EXPERIMENT - ITS CONSTRUCTION, MODE OF OPERATION, SIMULATION, PHYSICS, AND OUR TEACHING APPROACH

P. Tsakonas, G. Kalkanis
University of Athens, Pedagogical Department P.E.
Science, Technology and Environment Laboratory

1. Introduction

The traditional Greek game named Αερόστατο (Aerostaton or Aerostat) was played in Greece even a few years ago. The main reason that nowadays it has become rare, is the fact that a large number of players is needed, along with an open area, where the construction and the game itself can take place easily.

2. Constructing / Playing the game

The first step to construct the game is to collect a number of paper sheets, which are then glued together in order to form the aerostat's surface. One practical rule to follow is to use light pieces of paper, yet strong enough, so that they will withstand the tensions during the game.

As soon as this surface has been formed, its top side is glued together (the process is considerably simplified by giving it a cone-like shape instead of a semi-spherical one), while the bottom side remains open.

Then pieces of straws (yet another light material) are used in order to construct a ring which will be used as a skeleton and give the aerostat its cylindrical shape. The pieces of straw are held firmly together with some wire. Wire is also used in order to form a cross inside the ring. From the center of this cross a piece of sponge is hanged. The sponge has already been soaked in oil, spirit, or some other equally flammable material, and will serve as a means of heating the air inside the aerostat, so that the latter can lift in the air.

When the construction process is complete, a number of players hold the aerostat in a vertical position using a piece of rope connected to the aerostat's top. In cases where the aerostat is of considerable size (which is quite common in Greece), these players may have to stand on trees or in the opening of a window on the first floor of a building, so that the aerostat may be filled with hot air (by lighting the soaked sponge) more easily. As soon as this has been accomplished, the aerostat has acquired enough lift so that it can float in mid air. While letting it go, players give it a spin (angular momentum) around its vertical axis, in order to make it more stable.

As an additional means of precaution, a long rope is connected to the sponge, which may be used to release the sponge from the wire cross, thus preventing a fire hazard.

3. Simulating the game

I. Introduction

Since the lifting of the aerostat is determined by physical quantities such as momentum, its conservation, forces exerted during a collision and the like, the program starts with an introductory part, where such matters are discussed. In the first screen a pair of spherical bodies are presented, with appropriate initial position and velocities in order to collide. The spheres are considered to be perfectly rigid bodies, so that their collision is elastic. The default values for the velocities are such that the collision takes place along a straight line.

The user may change all the relevant parameters (masses, initial positions, velocities) by clicking the button "Options". Along with these, the model of the collision may also be changed, in order that either velocity alone, or both this and force be continuous functions of time. This enables the user to understand the concept of the scientific model, along with the meaning of approximation. The user may also select the type of collision (i.e. elastic, plastic), colors of bodies and colors of respective vectors (velocities, forces).

The next screen (Unit 3, Page 2, fig. 1) enables the user to study collisions in greater detail. Now the experiment is limited in one dimension. The user again may determine initial values and have the program simulate the collision. During the simulation, graphs – which may include positions, velocities and forces exerted on each body – are drawn. The user may zoom each one of these graphs by clicking on it with the left mouse button, while the right mouse button changes the proportion of the vertical and horizontal axes, in order to view the graph in greater detail.

During the simulation, the user may also use the "Pause" and "Step" buttons in order to control the simulation process. Along with these a "Delay" control (in the form of a scroll bar) is included, that determines the pace of the simulation during normal mode.

II. Macroscopic View

A reconstruction of the game was made by a group of children working in collaboration with researchers from the Physics, Technology & Environment Laboratory of the Pedagogical Department P. E. of the Athens University. During this reconstruction, an Aerostaton was constructed and flown in the traditional way described previously. The whole process was filmed, and a short clip from this film was incorporated in the software developed for the simulation of the game.

III. Microscopic View

This part of the software incorporates the microscopic simulation of the phenomenon. As shown in fig. 2, the program presents the behaviour of molecules inside the aerostat. The program also performs calculations concerning forces exerted on the aerostat's cover. As it can be seen, the values of forces on the vertical sides do not result in a zero net force. This is due to the fact that the number of molecules is not large enough. Although the user may vary the number of molecules used for the simulation, the maximum number is too small to reach statistical equilibrium, as is the real case. This limit is imposed not only by the fact that the computer can not simulate the movements of a large amount of molecules in real time, but also because if the number increases, then the illustration will become too obscure to be of any practical use. In order to compensate for this, the program calculates mean time values of forces. The result is stable and close to zero. In an analogous manner, the net vertical forces is calculated to have a steady negative (since the downward direction is considered to be the positive one) value. In order to visually represent the macroscopic movement of the aerostat, since the area where it is drawn is limited, a grid is superimposed on the aerostat, representing the frame of reference. So instead of moving the aerostat itself, the program moves the grid in the opposite direction (on the x- and y-axes). For a more qualitative view, two color bars have been included (one having vertical direction and the other horizontal), which represent the net force exerted on the body in the respective axes.

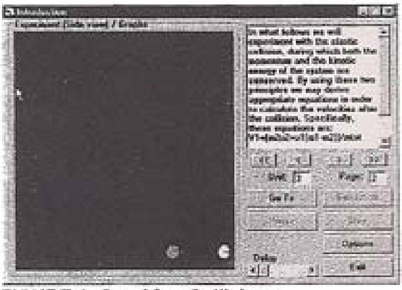


FIGURE 1. Graphing Collisions

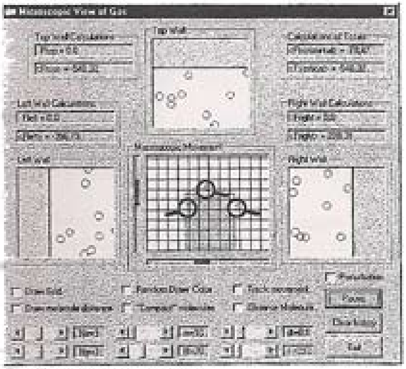


FIGURE 2. Simulation

In order to study in greater detail the effect of temperature on the lifting force of the aerostat, a scroll bar has been included through which the user may increase or decrease the temperature. In the case of decreasing, the user may notice that it takes quite a wile for the system to reach the new equilibrium state. Therefore the button "Clear history" is included, which restarts all the calculations from the beginning, thus eliminating any effect of previous states / magnitudes of forces.

4. Final remarks

The program incorporates an reusable programming object named "Particle" which permits the simulation of molecular behaviour in a number of physical conditions. This object was developed for this particular application, but a number of general characteristics have been added to it in order to make it suitable for a variety of applications, simulating materials either in the solid, the liquid or the gas phase, eithet in the presence or absence of an external force field (i.e. gravity, electrostatic field and the like).

A number of visual enhancements have also been added in order to facilitate the study of the particles. To name just a few, the user may choose to display each particle in a different color or all of them in the same color, display them as solid colored spheres or just circles, track their movement, observe a single molecule (by drawing it in a color different from the one used for the others), etc. So it is up to the teacher to employ whichever (sub)set of these characteristics in order to enhance teaching.