THE MONTE CARLO TECHNIQUES AS A TOOL IN PHYSICS EDUCATION - APPLICATIONS TO MICROCOSMOS PROCESSES

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Monte Carlo (MC) Methods, in general, can be described as statistical methods involving sequences of random numbers to perform various calculations. MC Techniques employ MC methods - which is to say random numbers formulated on MC methods according to specific distributions - in order to simulate by the computer certain stochastic processes. MC techniques have been long recognised as a power tool and widely used techniques by the researchers in almost every field, from economics to nuclear physics to regulating the flow of traffic. We believe that MC techniques may also help in Physics (/ Science) Education. More specifically, we believe that they may play an increasingly important role in this field, since the availability nowadays of more and more powerful computers in the classroom allows the teachers / students to study realistic systems and be convinced that the real world is not as relentlessly deterministic, as they might expect from newtonian mechanics.

Realistic systems are usually very complex, consisting of a large number of parts or/and processes and are affected by a large number of parameters, in a probabilistic and uncertain way. In addition, most of the physical realistic systems are either not easily or even not at all reproducible in common educational laboratories or not observable in nature, as for example those of MicroWorld / MicroKosmos. To study (teach / learn) them, which means to find, confirm, interpret, understand their properties and time evolution, we have to : a. model them, which is to say to distinguish their parts or/and subprocesses and analyse them step by step, b. simulate them by the computer, using such techniques as Monte Carlo techniques and c. ,equally important, visualise by animation (whenever feasible) the way the systems behave according to the simulation.

Concerning the modelling and simulation parts of this procedure, the statistical estimates of the outcoming results can be : i. compared to the results of the real experiments (if it is possible to establish equivalence) allowing the tuning of the parameters and even judging model's accuracy (a process which can gradually enhance teaching with research methodology), ii. extrapolated to extreme regions of parameters values, allowing predictions of the system behaviour under unusual conditions. Concerning visualisation / animation, we believe that it is an equally important part : i. for giving a glimpse to the details of complex realistic systems operation, ii. for its pedagogical virtues. Therefore it is a highly recommended characteristic of any MC program, whenever it is feasible. The necessity of this part is obvious when simulating physical processes which are not observable, as for example those taking place in MicroKosmos. However, very often they are visualised either through static pictures, video or computer animation, based actually on the physicist's or programmer's imagination.

MC simulation / animation programs do not simply visualise - in a hypothetical and artistic manner - physical random processes but indeed they "recreate" them, giving the most accurate approach and perceptibility of the complex reality based on the models in use, even those of the greatest complexity. So, teachers and students have the chance to open inside a classroom a window to non-observable parts and phenomena of our world and follow step by step their structures and processes. We believe that this characteristic of Monte Carlo simulation / animation programs is one of the characteristic which "legitimate" the use of computers in Physics Education.

Applications

Some applications (/ contributions to the workshop) of using MC techniques for educational purposes, in the form of computer routines / programmes of different types, are presented [1-7]. They are all dealing with microkosmos phenomena but each of them is highlighting a different option in presenting these phenomena. Such options are : diagrams, visualization / animation or/and hardware computer driven displays. The open code of one of the presented program is encouraging teachers / students to make modifications, whilst, an attempt of judging in classroom this kind of techniques / programs is, also, presented.

Elementary particles (quarks, electrons), as well as, baryons (protons, nucleons) and nuclei movements, are presented according to Heisenberg's principle of uncertainty. So, instead of well positioned spheres in well defined tracks, points are flashed to areas of high probability, according to relevant distributions. By accumulation, successive positions form shaded areas / clouds (eg. of an electron, fig. 1). The movements of molecules in solids, liquids and gases (fig. 2a,b,c), are presented, simulated / animated with the use of random numbers. This application / routines [1] are presented as an example to some techniques which are recommended in order to optimize the use of MC methods.

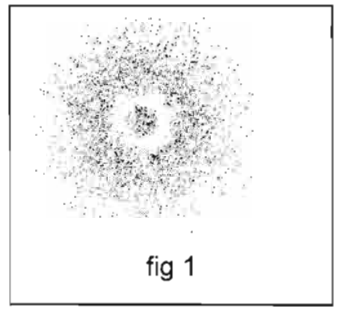

fig 1

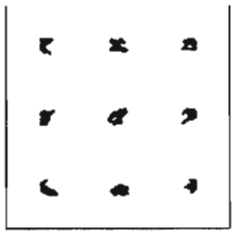

fig 2a

fig 2b

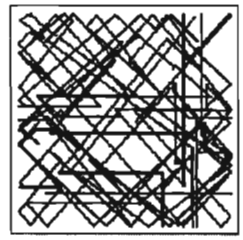

fig 2c

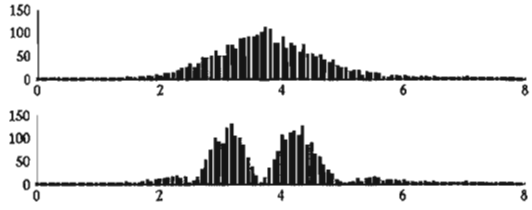

fig 4

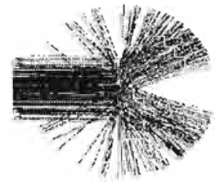

fig 3

An imaginary journey into the interior of the matter may be triggered by an experiment on matter's structure. Since in schools, experimentation of this kind is minimized due to the lack of laboratory instruments, a scattering experiment, for example, may be simulated / animated, giving hints about the structure and interactions of microkosmos. This structure and interactions / movements may be visualized / animated according to the assumptions. A program, which simulates / animates Rutherford's scattering experiments (fig 3) and narrates an imaginary journey into the interior of the atom, is presented [2].

The wave-particle duality comes up in a way that wipes out the impression / misconception of the students that "quantum mechanics is just doing physics with propabilities". The presented program [3] simulates a scattering experiment of a particle beam on a double potential barrier, doing apparent the feature of resonance by an energy distribution diagram (fig. 4, Classical and Quantum Reflection ~ Energy in eV), which implies the wave particle duality.

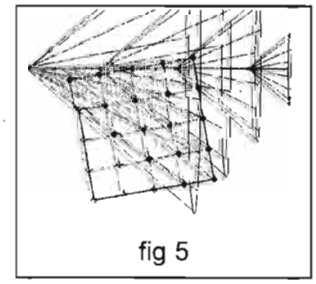

fig 5

Very energetic particles penetrate the atmospheric air in a high rate continuously, but this everyday phenomenon and their consequenses is not included of most of high school currriculums,

because of the lack of direct observation or experimentation. The presented program [4] simulates such particles (cosmic rays muons) and the emitted protons (Cherenkov light) , using random numbers and MC Techniques. The particle's trajectories and the Cherenkov photons are displayed on the screen (fig. 5). The last are also detected on a computer driven hardware display, made of light emitting diodes, simulating an array of photodetecting. The MC Techniques are used again to decide if electromagnetic absorption processes and photodetectors efficiency allow the detection.

Macroscopic phenomena of metals are related to their microscopic sctructure and movements. Using random numbers obeying to relevant distributions of particles number, position, velocity, scattering etc, allows us to simulate / visualize / animate this structure and movements, (fig. 6), and relate them to the emerged macroscopic phenomena (such as the metal connectivity ~ temperature...) The presented program [5], makes optionally use of a thermo-sensor, connected to the PC's gameport for continuous temperature readings of a heated metal. This allows, also, the tunning of the initial values and distributions to experimental data. The software code is fairly simple and accessible, so that creative teachers may adapt and tailor it to fit in with their didactic approach.

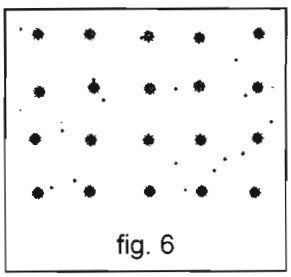

fig. 6

An interactive program, which simulates diffusion and osmotic phenomena [6], is also developed and presented in order to aid teaching of the aforementioned phenomena, while putting all the above techniques to use. It is consisted of : i. an introductory part, which stresses the character of diffusion / osmosis through the citation / simulation of a number of

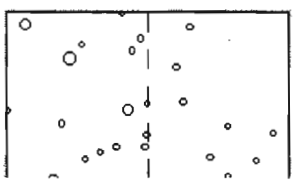

Fig 7a

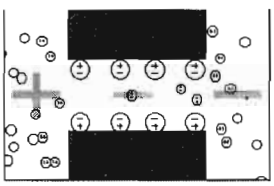

fig 7b

test cases, ii. a presentation of osmosis from a macroscopic point of view and iii. a reference on microscopic theories, the validity of which is tested through study / simulation of their mechanisms and animation of microscopic mechanisms (fig. 7a, b).

Finally, a study of teaching effectiveness of an educational MC computer program simulating buoyancy is presented [7]. The search aimed at : i. the evaluation of an educational program, specially designed to teach buoyancy, using MC Techniques, in the lower Secondary Education and ii. an estimation of the effectiveness and feasibility of such a computer program in the classrooms of Greek schools in the time limitations imposed by the Greek curriculum. Findings are discussed and suggestions are proposed.

References / Contributions

[1] P. Tsakonas, E.Apostolakis, I.Koulas, A.Lazaridis, N.Mamalougos, G.Kalkanis : «Techniques for using MONTE CARLO methods on microkosmos movements»

[2] P.S.Dimitriadis, L.B.Papatsimpa, A.Lazaridis, G.Kalkanis : «A teaching model of MicroKosmos Structure and Interactions, based on MONTE CARLO Simulation and Visualisation / Animation - From Rutherford's experiment to an Inside View»

[3] N.V.Sarlis, S.S.Sklavounos, L.Spiliotopoulos, G.Kalkanis : «Teaching Quantum Mechanics - Reflection and Tunneling -, using MONTE CARLO Techniques»

[4] M.M.Sarris, G.Kalkanis : «Simulating Moving Particles and Animation / Display their Detection for Educational Purposes»

[5] E.Kyriaki, K.Dendrinos, G.Kalkanis : «Metal(lo)-Microkosmos phenomena, using elements of MONTE CARLO Techniques»

[6] P.Tsakonas, G.Kalkanis : «Teaching Diffusion and Osmotic phenomena through MONTE CARLO Simulation / Animation»

[7] K.Halkia, P.Tsakonas, G.Kalkanis : «A study of teaching effectiveness of an educational MONTE CARLO computer program simulating buoyancy»

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TECHNIQUES FOR USING MONTE CARLO METHODS ON MICROKOSMOS MOVEMENTS

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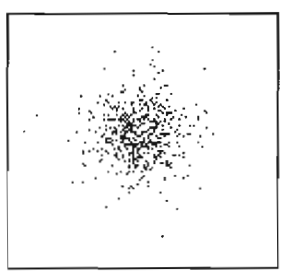
Experimental random processes, for which it is quite natural to employ random numbers, are widely formulated on Monte Carlo methods and simulated by computer programs, either to predict their results, or to check the feasibility of the design of the experiment apparatus, or to compare the outcome of the experiment to theoretical predictions. In order to apply these methods and to use relevant software in physics education in an efficient and perceptible way, the software may incorporate, as well, visualization / animation routines based on random numbers in parallel with a didactic approach.

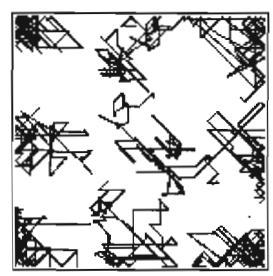
Applications to microkosmos phenomena / systems, which consist of a large number of particles in a perpetual movement - in a propabilistic and uncertain way -, demand special techniques. Calculations on such systems and visualization / animation of their processes, especially of the motion(s) of the particles, are very demanding in memory and time. Due to time crunching and memory requirements, in connection with didactic time: limitations, it is advisible: a) to make calculations on highly populated samples, reducing the population for the visualization / animation, b) to include options for precalculated and on-line demonstrations, c) to pre-calculate samples / arrays of random numbers following specific distributions and d) to use simple patterns for the visualization / animation, patterns which are created / erased on the computer screen by simple - and fast - computer operations.

Applications

Artistic repsresentations often tend to present microkosmos particles as confined by a spherical surface resembling some kind of membrane, which leads to the misconception that they behave like macroscopic bodies, having well defined boundaries. Moreover, these "spheres" are usually pointed to specific positions or/and following specific tracks.

In contrast, what is proposed here is a more proper and accurate way of visualising / animating these particles. The fact that quarks, protons, neutrons (as well as the nucleus itself) and electrons are in perpetual motion is taken into account. This motion can be thought of as a kind of whirl inside more complex formations in an uncertain way, in accordance to Heisenberg Principle. So, instead of designing them as solid spheres, we flash them as points in positions which belong to areas where it is more likely for them to be found. The proper distribution of random numbers, produced by the computer is used for the modeling of the probability of the particle position. By accumulation, successive positions form shaded areas / clouds, with a density related to the distribution used. Random numbers are manipulated to form samples of numbers following the selected distribution(s), stored in array(s) in order to accelerate animation.





Another application concerns simulation / animation of the different phases of materials (solid-liquid-gas). The aim is to present on the computer screen a picture familiar from any physics book: molecules inside the volume of a solid, liquid or gas. The advantage of the approach presented here is that the molecules' movements are simulated / animated by the computer using random numbers. The Monte Carlo techniques are used for the definition of the molecules' speed and positions according to specific distributions. The range of intermolecular forces are defined as solid spherical areas. Intermolecular interactions are modeled as elastic collisions. Modified values of the spheres' radius account for the variations in molecules' behaviour among different phases.

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G. Kalkanis, «The Monte Carlo Techniques as a tool in Physics Education - Applications to MicroKosmos processes», Workshop in 1996 GIREP-ICPE Conference: «New Ways of Teaching Physics», Ljubljana, Slovenia, August 1996.

A TEACHING MODEL OF MICROCOSMOS STRUCTURE AND INTERACTIONS, BASED ON MONTE CARLO SIMULATION AND VISUALISATION / ANIMATION - from Rutherford's experiment to an inside view

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The students have a difficulty in comprehending the structure and the properties of the Mikrokosmos. We believe that an efficient and feasible procedure to attempt to substitute the lack of direct observation and experimentation, as well as, to gain some insight of the interior of microkosmos, is simulation / visualisation computer programs. According to our proposition, an experiment is simulated by the computer, giving hints about structure and interactions of microkosmos, and then, presenting the structure and movements of microkosmos are visualised / animated, using random numbers in the frame of Monte Carlo methods / techniques, according to the relevant theoretical assumptions. Our approach concerns university or/and lower level students, to whom the structure of matter as well as the interactions in microkosmos are introduced.

The program presented, starting from simulating Rutherford's experiment and following Rutherford's path, narrates with elegance an imaginary journey into the interior of matter. In a scientific level, scattering experiments are carried out in order to derive information relevant to regarding the properties of the forces of interaction projectile - target or search into the internal structure of target. These experiments have broadened significantly our minds reference to modern physics and generally are proved to be so important as the throwing of diverse balls from the tower of Pizza by Galileus. Nevertheless the realisation of such experiments in the school laboratory and the consequent analysis of their data by the students appears technically impossible.

However, in our days, the lack of laboratory instruments can be compensated by computers used by high school students to obtain a simulation of some scattering experiments. Having these aims in mind we've created a program that simulates Rutherford's experiment written in Visual Basic. The program narrates with elegance an imaginary journey into the interior of matter. The student, thanks to his progressive diminishing / proportional enlargement of the objects, penetrates gradually the interior of a sand grain and after having passed successively from the lattice then from the molecule reaches at least the atom.

With the application of Monte Carlo methods, the movements of the molecules of lattice are

represented as well as movement of electron having as a direct result the collapse of atom because of the transmission of electromagnetic radiation.

The program offers the student a chance to observe closely the scattering of á-particles, by using different sources and targets chosen interactively. Thanks to the display of scale on the screen, he / she realizes the penetration of á-particles to the interior of the atom. Based on his/her observation of particles deflecting in large angles, in addition to his/her previous experience regarding the elastic collision of microscopic spheres, he / she is able to under-stand the way in which the projectile interacts with the target as well as the existence of a nucleus with mass significantly bigger that the one of an á-particle. He / she is also able to measure the minimum distance between projectile and target, which also constitutes the upper limit of nucleus radius, while he/she has the chance to elaborate on his / her measure-ments in order to see how this minimum distance relates to projectile energy and to element used as target. In this way, the student is given a chance not only to observe but also to elaborate on data, as it happens during a real experiment. Having in mind these results, the student finally establishes Rutherford's atom model, having a glimpse inside the atom.

Reference

G. Kalkanis : «The Monte Carlo Techniques as a tool in Physics Education - Applications to MicroKosmos processes», workshop in 1996 GIREP-ICPE Conference: «New Ways of Teaching Physics», Ljubljana, Slovenia, August 1996.

TEACHING QUANTUM MECHANICS - REFLECTION AND TUNNELING - USING MONTE CARLO TECHNIQUES

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When students in the last classes of senior highschool or freshmen of the University are introduced to the concepts of Quantum Mechanics(QM), they learn that according to theory, the electron in the hydrogen atom could be described by a cloud that denotes the probability of its observation at a given site around the proton. Moreover, most of the time this the only thing that is discussed in their first lesson in QM and for students that aren't Physics or Chemistry majors this is the only thing they have to know about QM.

Having these in mind, we decided to write a computer program [**] according to MC simulation techniques [1] that would assist the discussion in class of the most important feature of the Quantum theory, that is, the wave property of particles in connection with that "first" lesson in QM. This way, the first impression of the students that "QM is just doing Physics with probabilities" will wipe out in view of the startling results that the wave-particle duality implies. For this reason, we selected the simplest case where the wave-particle duality comes up, and this is nothing but the case of one-dimensional scattering in a double barrier potential.

The program, Q (Quantum reflection and tunneling), simulates an experiment where a beam of particles is scattered by a double barrier potential and the energy of the outgoing particles is measured in two ideal detectors in the opposite sides of the potential. The incident beam has a variable wavevector profile that can be selected out of the three most common distributions in nature: Gaussian, Lorentzian and uniform. The student can select the wavevector mean value k_{in} of the beam as well as a measure of its variance $\ddot{a}k$. The program uses appropriate random number generators [2] (RNG) that assign to every incident particle a wavevector according to the selected distribution. The particle is then "scattered" by the double barrier potential. The decision of whether the particle is transmitted or reflected is taken by comparing the result of a uniform RNG to the exact QM probability. For the case of two repulsive delta potentials, with respective coupling constants $\ddot{e}_1$, $\ddot{e}_2$ which are separated by distance $\acute{a}$, the probability of reflection is

$$R(k)=\frac{k^2m^2(\ddot{e}_1-\ddot{e}_2)^2\sin^2(k\acute{a})+[2m^2\ddot{e}_1\ddot{o}_2\sin(k\acute{a})+km(\ddot{e}_1+\ddot{e}_2)\cos(k\acute{a}\,)]^2}{\left\{m^2\ddot{e}_1\ddot{e}_2[1-\cos(2k\acute{a}\,)-k^2\right\}^2+[m^2\ddot{e}_1\ddot{e}_2\sin(2k\acute{a}\,)+km(\ddot{e}_1+\ddot{e}_2)]^2}$$

where m is the mass of the incident particle, $\hbar=c=1$. According to the results of this comparison, the program returns the recordings of the two detectors after all the particles of the beam have been scattered. The well known feature of resonance [3] comes up for appropriate values of k_{in}. This wave property of QM can be compared with the results from a similar MC where now the reflection probability is given by

$$R_{classical}(k)=\frac{(q_1-q_2)^2}{1-q_1q_2} \quad \text{where} \quad q_i=\frac{m^2\ddot{e}_i^2}{k^2+m^2\ddot{e}_i^2}\text{v}$$

This "classical" probability corresponds to the case that the beam is made up of "Newtonian" point particles that follow classical paths but have a probability q_i to be reflected by the i-th potential barrier. This model is very close to what a student that believes that "QM is doing Physics with probabilities" would think. The comparison between the two different results will clearly manifest the wave-particle duality of QM and help students to avoid misconceptions about the Quantum theory. The QM results can also be used for a classroom presentation of the quantum resonance tunneling in semiconductors [4], the effect of the double potential barrier as an energy filter [5] etc.

References

[*] supported by a Scholarship of the National Scholarship Foundation of Greece, IKY.

[**] available at: ftp://atlas.uoa.gr/pub/philos/educat/qzip.exe .

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SIMULATING MOVING PARTICLES AND ANIMATE / DISPLAY THEIR DETECTION FOR EDUCATIONAL PURPOSES

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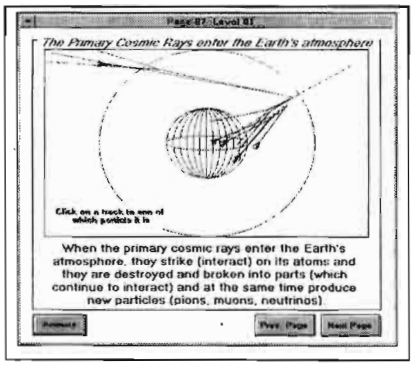
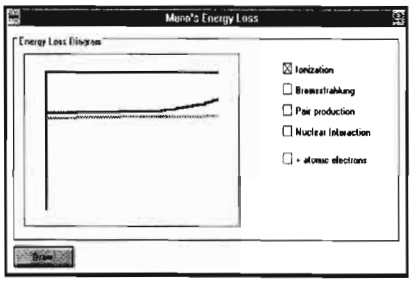
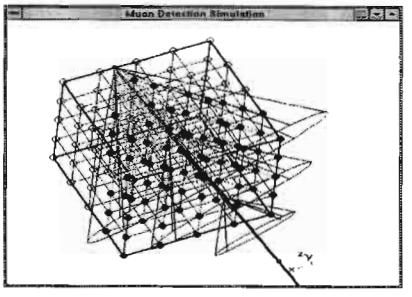
For the study of the particles that penetrate the Earth's atmosphere, three educational purposes are intended: a) To give as many and detailed information about Cosmic Rays both from physical and mathematical aspect, though figures, drawings, formulas and diagrams, b) To "see" an "event", i.e. the detection of such a particle using a Cerenkov counter which is an array of photodetectors, c) To produce such an "event" modifying the particle's characteristics (momentum, e.t.c.), the medium and the detector's characteristics (geometry, attenuation length, efficiency, e.t.c.). For the first purpose we developed the "Database" module. Our decision to have the same database for all levels of education forced us to divide it to pages and levels (horizontal and vertical structure). The user can change page or level using the hypertext

technique. For the accomplishment of these purposes, apart from the above mentioned pages and levels, three simulation software have been so far developed.



1. Simulation of the entering of Primary Cosmic Rays into the Earth's atmosphere: A particle of the Primary Cosmic Rays enters the Earth's atmosphere. It reacts with the matter and it decays. The particles produced also decay and so on. The energy of the incoming particle follows a certain energy distribution using a Monte Carlo technique. Additionally, all decay channels follow the probabilities predicted by theory.
2. Study of the contribution of several processes in the energy loss of Muons: Muons as they travel in matter, loose energy due to several several electromagnetic processes: the ionization process, the muon Bremsstrahlung effect (radiation loss), electron and muon pair production and a photonuclear scattering. To understand the nature of this energy loss, one has to understand separately each interaction process. To achieve this, we can "turn on and off" interactions and watch how they contribute to the total energy loss.
3. A Monte Carlo simulation software of a Cosmic Rays Muon detection by a lattice detector consisting of photodetectors: From the billion of Cosmic Rays Muons that penetrates the Earth's atmosphere, the user can watch the detection of such one. Then this muon follows the exponential energy distribution of Cosmic Rays using a Monte Carlo technique. The muon's path is divided into small steps. At every step the muon that travels in matter looses energy due to several processes. Since the muon travels in a medium with velocity greater than the velocity of light in the medium, at every step it emits Cerenkov Radiation (photons). The number of Cerenkov photons are calculated according to theory. Also they are uniformly distributed (Monte Carlo technique) on a cone of a certain angle (Cerenkov angle) around the muon's track. This angle depends on the velocity of the muon. The photons travel in matter some of them are absorbed due to electromagnetic processes: photoelectric absorption, the Compton scattering and the pair production. These processes define an attenuation length for the medium. Using a Monte Carlo technique and the attenuation length we "decide" exactly which photons at every step will be absorbed. Some of the remaining photons hit a photodetector and they are detected taking into account a certain detector efficiency, also using a Monte Carlo technique. So, what we really see is not the muon itself but the Cerenkov photons emitted by the muons that they weren't absorbed, they had hit a photodetector and they were detected. It is obvious by the figure that they are distributed over a cone showing indirectly the path of the Cosmic Rays Muon. The "event" is more clearly presented on a prototype computer driven hardware display that can be developed by students using simple electronics. Each photodetector is presented by a L.E.D. which turns on when a photon "hit" the corresponding photodetector.





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[2] F. James, 'Monte Carlo Theory and Practice', CERN DD/80/6, Geneve 1980

(The software is available in ftp://atlas.uoa.gr/pub/philos/educat/osmosis.zip)

METAL(LO)-MICROKOSMOS PHENOMENA USING ELEMENTS OF MONTE CARLO TECHNIQUES

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Introduction

METALCL is a simulation / visualisation / animation program of the free electron model of metal (metallo, pl.metalla, in Greek) microkosmos (written in PowerBasic), using MONTE CARLO techniques. It includes:

- The use of the compiler's built-in random numbers generator
- A routine that uses random numbers, to indicate the initial position for each particle and create a 2-D random unit step
- A routine to calculate the speeds of the free electrons, according to Maxwell-Boltzmann distribution law
- A routine to calculate the speeds of the free electrons through random numbers mapped against the Maxwell-Boltzman distribution.

The program applies the physical laws of motion, for each metal particle. The macroscopic phenomena observed are obtained as an overall result of the system.

Some elements of the application

Free Electrons' motion

Initial position: `Xcur = LeftSampleTop + INT(WidthSample*RND)`
`Ycur = LeftSampleTop + INT(HeightSample*RND)`
Direction: Angle in the range `[0,2*PI]`, `DX=COS(Ang)`, `DY=SIN(Ang)`
Speed: Values according to distributed random numbers, stored in an array.

Free Electrons - Thermal effects

THEORY: The mean square velocity of the electrons is proportional to the absolute temperature: $Vrms = \sqrt{\frac{2kT}{m}}$

All systems in thermal equilibrium have a well defined distribution of velocities of the particles. Maxwell-Boltzmann distribution has been chosen to represent the electrons velocities distribution in free electron model: $\frac{dn}{dv} = 4\pi N\left(\frac{m}{2\pi kT}\right)^{3/2} v^2 e^{-mv^2/2kT}$

SIMULATION:

```
vrms = SQR(2*1.4*10^-23*T/(9*10^-31))
dndv = 4*PI*NrEl*(1.05*10^-8/T)^1.5*v^2*EXP(-3*10^-8*v^2/T)
```

For a temperature T given by the user, dndv is calculated for NrOfSpeeds around vrms.

General remarks

METALCL's source code is available, so that it can be studied (and modified) by the science teacher and the students, in order to increase understanding of the model.

The program makes use of "abstract objects", which represent real-world objects (e.g. electrons). Those "virtual" objects posses properties and are controlled by user- input.

METALCL.EXE is included in the following educational packages (archives):

1. METALLO.ZIP (Greek) and METAL.ZIP (English): About metal mikrokosmos
2. METALSN.ZIP (run METALSNE.BAT for English): About metal microkosmos

The above mentioned files contain MS-DOS programs, created by E. Kyriaki, in cooperation with K. Dendrinos, and under the supervision of prof. G. Kalkanis.

Some library routines were created by P.D. van Dijk and are available for free use.

The minimum system requirements for the programs are: a 80386 PC, MS-DOS 3.3^{+}, a VGA graphics card, a colour monitor and about 1.4 Mb of free harddisk-space.

The most recent versions can be found on the following anonymous (Internet) ftp-site: atlas.uoa.gr directory: /pub/philos/educat.

TEACHING DIFFUSION AND OSMOTIC PHENOMENA THROUGH MONTE CARLO SIMULATION / ANIMATION

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The subject of educational software is addressed using diffusion and osmotic phenomena as a proper vehicle. The aim is to present seemingly unrelated phenomena, giving emphasis to the fact that a) these similarities facilitate study of physics, b) a few basic physical principles and methods may be utilized to explain a great number of phenomena, c) a computer program can be used to change the students' approach to science.

Educational Software - Reproduction / Simulation of Natural Phenomena

Educational software is one way of overcoming all the above difficulties. A properly de-signed computer program enables the user to repeateadly examine a physical phenome-non in order to make sure that all the important aspects are given proper notice. Additio-nally, it gives the opportunity of visually simulating a natural process, as if one observed the real phenomenon, while it may present numeric results or draw graphs for a more quantitative approach, when the user changes the value of one or more parameters.

If one views a computer program as an experimental tool, then a way to proceed in developing educationla software is to encode all the known mathematical and physical background of the phenomenon and leave it to the simulation process to present results.

The language of (applied) mathematics is the language of models. If the results, derived from a model, are in accordance with what is observed in nature, then the model is consi-dered to be successful, at least to the limit of experimental verification, and then we feel free to use in our minds these mathematical constructions as substitutes for what really goes on in nature. In this content, mathematical models are a means that can be used to actually reproduce nature to the best possible extent and with the best possible accuracy. The problem is that, in order to be able to profit form this method, one must already be accustomed to it, in other words, be able to

think in such an abstract level and handle ideas in a concise manner, which of course is rarely the case for students. This problem may be addresed by a special kind of visualisation which goes far beyond simple results, drawings and diagrams. The form of reproduction mentioned above can be embodied in a computer program, i.e. a mathematical model may be integrated in a visualisation algori-thm through the equations and functions that - we believe - represent the principles and laws of nature. In this way the images the computer produces (either still or moving) may be considered as a way to make abstract models more concrete and tangible. In a si-mplified approach this can be thought of as an addition to experimenta-tion, since it ena-bles one, while exploiting the ability of a computer to perform complex calculations and present results very quickly, to repeat a process as many times as one likes. On a more e-laborate level, one may become aware of the mathematical nature of the underlying mo-del and extend one's study to the point where this model is taken into account. The bi-form advantage is that one is convinced about the accuracy of the presented material, si-nce, undoubtedly, the results the computer produces are based on scientific knowledge, while one's interest is shifted from simple observation to the need of understanding the model. So one may argue that such a computer program simulates not only the natural process, for which it was built, but, also, s(t)imulates one's development from a mere ob-server to a full-featured scientist !

The Software

An interactive program [3], which simulates osmotic phenomena, was developed in order to aid teaching of the aforementioned phenomena, while putting all of the above principles to use. It is consisted of an introductory part, which stresses the character of diffusion / osmosis through the citation/simulation of a number of test cases, a presentation of os-mosis from a macroscopic point of view, and a reference on related microscopic theories, the validity of which is tested through study / simulation of their mechanisms.

References

[1] G. Kalkanis, «The Monte Carlo Techniques as a tool in Physics Education - Applications to MicroKosmos processes», workshop in 1996 GIREP-ICPE Conference: «New Ways of Teaching Physics», Ljubljana, Slovenia, August 1996.

[2] Th. N. Skolikidis, "Physical Chemistry, Vol. $I_{1,2}$, SYMMETRIA publ., Athens 1986

[3] available at: ftp://atlas.uoa.gr/pub/philos/educat/osmosis.zip .

A STUDY OF TEACHING EFFECTIVENESS OF AN EDUCATIONAL MONTE CARLO COMPUTER PROGRAM SIMULATING BUOYANCY

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This research aims at :

a) the evaluation of an educational program specially designed to teach buoyancy - using Monte Carlo techniques - in the lower Secondary Education, and

b) an estimation of the effectiveness and feasibility of such a computer program in the classrooms of Greek schools in the time limitations imposed by the Greek curriculum.

Methodology :

The sample consisted of 238 pupils, of ninth grade, divided in three groups. A pre-test was distributed, consisted of four qualitative problems. Then, the three groups were taught the subject, within one teaching period, (time scheduled by the Greek curriculum):

i) for the 1st / control group the traditional approach was used,

ii) for the 2nd group the teaching was primarily supported by a program simulating buoyancy from a macroscopic point of view,

iii) in the 3rd group the same program was used, but the microscopic aspect was emphasized upon through the use of additional software parts. Three days later, a post-test was distributed, equivalent to the pre-test.

Results :

1) The study of (Seffe) pre-test outcome showed that the pupils succeeded very poor results, one year after their having been taught the subject. The content - analysis of the pre-test indicated that the pupils had developed a very little knowledge and understanding. The pupils revealed many misconceptions and alternative conceptions. So, the traditional teaching of the subject proved inefficient in the long run.

2) The statistical analysis of the (Seffe) post-test indicated that the control group succeeded better results, although still very poor, than the other two groups. The two experimental groups, with the support of simulation program, failed to improve their knowledge and understanding of the subject. A remarkable point to note here is that the misconceptions the pupils revealed in the pre-test proved to be very persistent.

Conclusions

The reasons for the ineffectiveness shown may refer to :

A. Traditional teaching:

   1) The limited time given by curriculum.

   2) Teachers' ignorance about: a) their pupils' alternative conceptions, and b) alternative ways of teaching.

B. Teaching based on software:

   1) as above

   2) as above

   3) The limited time of teaching (1 period, i.e. 45 min), enforces rather hasty approach. As a result, the pupils don't have the time to assimilate the knowledge offered to them by the program.

   4) The teacher does not necessarily have a positive attitude towards teaching Physics with the support of New Technologies (NT), or the experience to handle such a program efficiently in the every-day teaching.

   5) Problems related to:

      a) the way different groups of pupils can operate simultaneously their computer programs, under their teacher's instructions,

      b) the proper teaching time sharing in NT and in conventional ways of teaching,

      c) the lack of teachers' preparation time for lab exercises as well as for simulation program exercises can prove crucial to the proper ncorporation of such programs in teaching Physics.

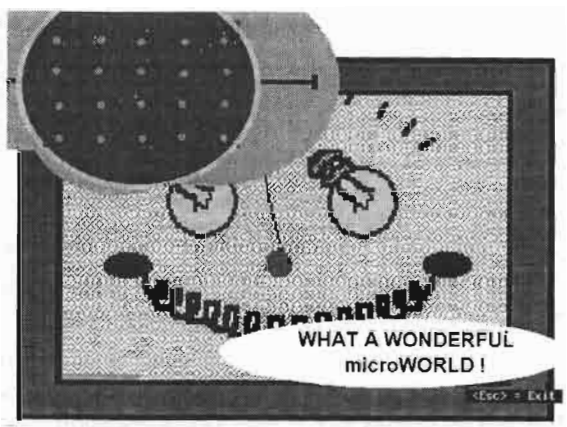
   6) The applied simulation by itself. Maybe the specific program conceals some shortcomings in the way it presents the relative information, or it simulates the relative

experiments, or / and it interacts with pupils, so a feedback is needed (for this and any simulation program).

Suggestions

The problem of the incorporation of a simulation program to the everyday Physics class has to be tested many times before it ends to its final answer. The findings of this research lead to the following suggestions, with respect to the possibilities of the embodiment of simulation programs to the everyday teaching:

1) The curriculum should be reoriented to less and different "subject matter", in order to assimilate the NT.
2) A computer program which simulates experiments must operate complementary. In that case, pupils will study this program in their home computer as a part of their routine study, or develop in groups some projects in Physics.
3) The Physics teacher must get a proper training on NT and especially on simulation programs, so they will acquire positive attitude and a "knowhow" of their use.

References

[1] G. Kalkanis, «The Monte Carlo Techniques as a tool in Physics Education - Applications to MicroKosmos rocesses», workshop in 1996 GIREP-ICPE Conference: «New Ways of Teaching Physics», Ljubljana, Slovenia, August 1996.