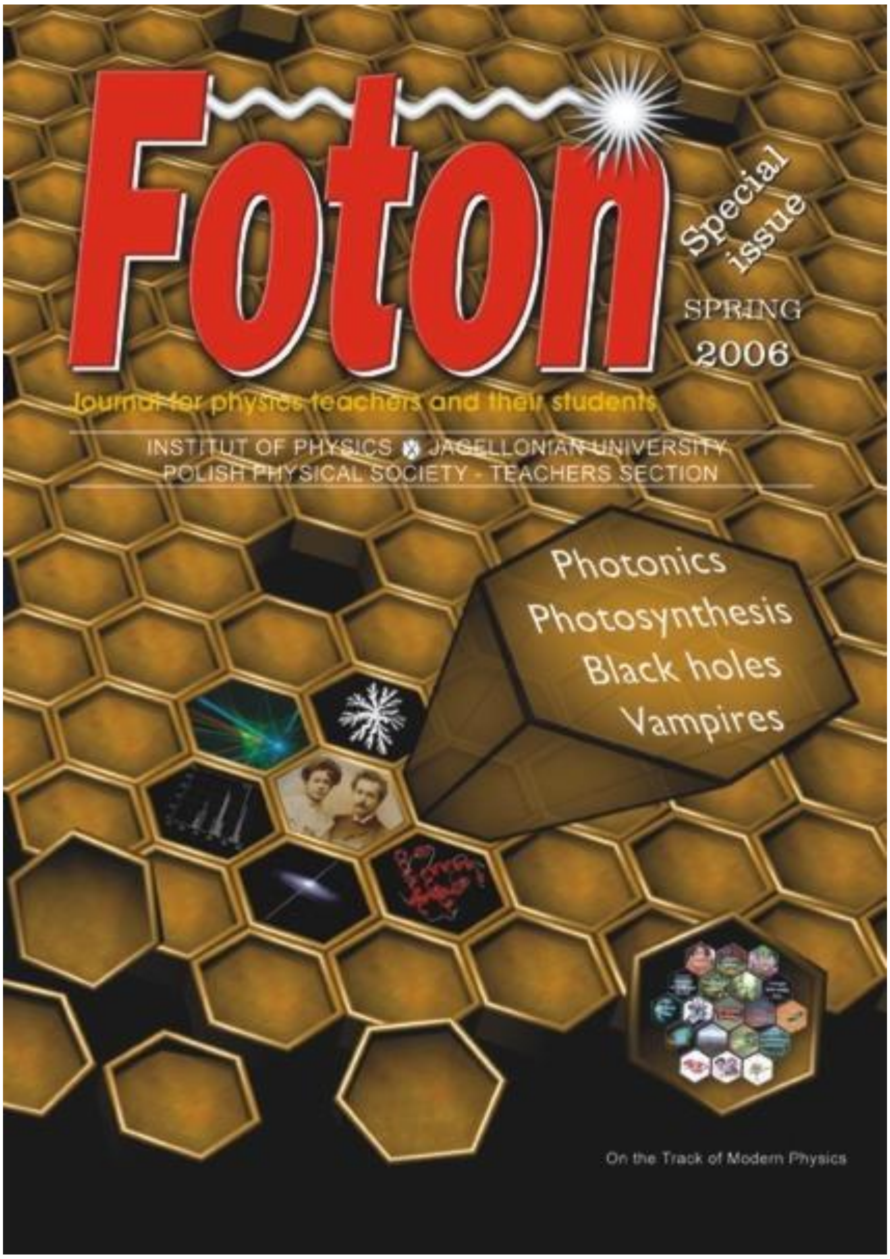


Foton

Special issue

SPRING
2006

Journal for physics teachers and their students

INSTITUT OF PHYSICS JAGELLONIAN UNIVERSITY
POLISH PHYSICAL SOCIETY - TEACHERS SECTION

Photonics
Photosynthesis
Black holes
Vampires

On the Track of Modern Physics

Editorial

You have in your hands a special issue of *Foton* (*Photon*), the journal for Polish physics teachers and their students, edited at the Marian Smoluchowski Institute of Physics of the Jagellonian University. Władysław Natanson, one of the best Polish physicists devoted deeply to physics education, wrote more than one hundred years ago that the most dangerous enemy of good teaching is boredom.

Foton's editorial team is working hard to help teachers to convince their students that physics is not boring and abstract, it is not far away from everyday life; on the contrary – it is present everywhere, even in the most unexpected phenomena. We are fully conscious that this is not an easy task, if we are not going to cheat a bit and simplify too much. But one has to try, and try again.

We know that each student is different. They differ not only in their talents, intellectual abilities, ambitions, but also in their interests. We care for our future scientists (future theoreticians maybe) challenging them by posing more advanced abstract problems (e.g. the article on Borsuk-Ulam theorem, or the article on dendrites and on Brownian motions). We present short articles considering the power of physical methods in archeology and medicine. We also show simple and very intriguing small problems far removed from the old school routine (The Lion Cub Competition). We hope to show a "human face" to all those who pretend not to understand physics, or worse still, who pretend to hate physics.

Our goals, as *Foton's* editors, overlap with the European Project "Physics is Fun"; so we have supported the project by taking part in it.

We hope that you find *Foton* interesting. We invite you to collaborate, by writing for us, or by exchanging articles (as we did recently with *The Physics Teacher*).

Zofia Gołąb-Meyer

Contents

On the track of Modern Physics

Grzegorz Karwasz
Pomeranian Pedagogical Academy in Słupsk

At one of the airports I got into a recent special issue of “Scientific American” entitled “The frontiers of Physics”. One glance and I fell into serious doubts: the theory of strings still has not been confirmed experimentally, the relativity theory can be erroneous, Higg’s particles are probably five, but before putting into operation the hadron accelerator in CERN we will not know this. How should I tell it to students, not being funny?

I was coming back from a congress in Japan on plasma technologies. 400 young Japanese were listening to the lectures, mainly by Europeans and Americans. The majority of students hardly speak English, just enough to be understood, but were eagerly learning new techniques of silicon deposition in cheap electrical discharges under atmospheric pressure. Silicon, grown in the form of nanocrystals, containing not more than a few thousand atoms, has surprising features. As far as normal silicon, that for producing transistors, is metallically grey, the new form is shining in all colours. In detail: it shows photoluminescence in a visible range. A full surprise, if not a revolution. A cheap photovoltaic cell will absorb light in the whole solar spectral range. Bye-bye petrol!

Trento is famous for skiing, beautiful mountains and apple trees. The latter grow on highlands, mature late but are wonderful. My colleagues from Trento put small apples into glass containers with nitrogen and then study their smell with lasers. Yes, their smell! In this way scientists check which apples are to be removed in order for the remaining to mature splendidly. The technique is called “photo-acoustic spectroscopy”. Why does “Scientific American” not write about such subjects?

These questions are at the basis of the projects “Physics is Fun”, founded by the European Union. School physics is difficult and for this becomes dull, if not understood properly. Speaking on 11 dimensions of space, possible but not verifiable, does not attract interest. Let’s try to find problems interesting, but “touchable”, with some possible applications.

The exhibition which travels between Paris and Słupsk describes open, complex problems of Modern Physics and it even allows one to touch quarks. Because what can not be touched by the senses, Aristoteles called “meta-physics”.

The programme “Physics is Fun” is run by (in order of tasks):

– Pomeranian Pedagogical Academy in Słupsk
– Trento University, Italy
– Jagellonian University (*Foton*)
– Ecole Centrale in Paris
– Music editor "Soliton", Sopot
– Multimedia editor "Ambernet", Warsaw
– Editor "Dudka-Design", Milan

The tasks include go-around exhibitions "Toys and Physics" and "On the track of Modern Physics" and two CDs on these subjects. The exhibitions were shown in September 2005 at GIREP conference in Lubljana, at XXXVIII Polish Physicists Convention, in October at the congress "Multimedia Tools of Teaching Physics" in Berlin, in December during open days in "Ecole Centrale", in February 2006 in Trento and are planned in May 2006 in Gdańsk.

The form is to make modern physics possibly simple, which does not mean simple.

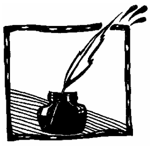
We try rather to stimulate the imagination of visitors, unexpected connections and analogies. We show quarks not only as small balls but also as small wolves, proton and neutron as grey steel cubes and as colourful Brazilian parrots from balsa, and to show the curvature of time-space we use kitchen funnels.

The contents of exhibitions are new aspects, open questions, serious doubts and not only "standard" truths. The didactical aim is to show the methodology of scientific discovery: we can learn more from Einstein's errors than from his true statements.

Temporary internet versions of exhibition are at the addresses:
http://modern.pap.edu.pl
http://www.karwasz.it/modern/index-pl
http://lab.pap.edu.pl/%7Ezs/wystawy/droga
http://www.science.unitn.it/~karwasz
and also
http://zabawki.pap.edu.pl

We invite all visitors!

/from *Foton* 92/



How do we know what we see is a black hole?

Bogusz Kinasiewicz

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> A black hole is perhaps the most fantastic of all conceptions of the human mind.
> *Igor Novikov*

1. Introduction

Nowadays, at the beginning of XXI century, we can see more than our ancestors tens of years ago. This is due mainly to the dynamical development of technology. Before the invention of the telescope people observed stars and other celestial bodies by the "naked" eye. We perceive only a small fraction of what comes to us in the form of electromagnetic waves. There are different waves around us. The human eye is sensitive only to a narrow range of electromagnetic spectrum – the so called optical range $\left(\lambda_{opt} \in (4\cdot 10^{-7},\ 8\cdot 10^{-7})\,[\mathrm{m}]\right)$.

Even now, equipped with modern telescopes which investigate our Universe in the full range of electromagnetic spectrum from the Earth or its orbit, we still do not see everything.

Nobody has seen a black hole and I am sure that nobody will do so. Not long ago nobody had any observational proof for the existence of such objects in nature, which were investigated by using theoretical physics long ago.

The concept of a body so massive that not even light could escape it was put forward by John Michel in a 1783 paper submitted to the Royal Society. However, this idea was forgotten. People reconsidered it when Albert Einstein (1915) better understood gravity than Izaak Newton (1687).

Today we have convincing observational proofs for the existence of several dozen black holes and we suppose that their number is very large [1]. One can observe black holes only in an indirect way. They interact with the environment through the gravitational field. And the idea is to observe the environment and then guess what the reason for this behavior is. Before we think how to "see" a black hole, let's say something more about these amazing objects. In our Universe one can find two kinds of black holes:

Stellar black holes – the final step in the evolution of massive stars.

Supermassive black holes are believed to exist in the centers of most galaxies, including our own Milky Way. This type of black hole contains millions to billions of solar masses. It is supposed that they are "born" in the gravitational collapse of matter in the nuclei of forming galaxies.

It is worth noting the possibility of the existence of the so-called micro black holes (with the size smaller than an atomic nucleus and mass lower then mass of a star). Some people believe that one can observe a micro black hole as a product of the certain reactions in the LHC[1] accelerator.

Let's say again, the black hole is an area of space-time from which it is impossible to send any information (we neglect here quantum effects like Hawking radiation) or a particle outside where intercommunication usually exists. The boundary of a black hole is called the **event horizon**. The possibility of the existence of black holes in nature has been predicted by the General Theory of Relativity.

The first strict solution of equations of this theory (Einstein equations) was found by Karl Schwarzschild. He analyzed the gravitational field of a static, isotropic object of a big mass. For a nonrotating black hole of a mass M, the radius of an event horizon is given by a formula derived by Schwarzschild:

$$R_S = \frac{2GM}{c^2} = 2{,}95\ (M/M_\odot)\ [\mathrm{km}]$$

where $M_\odot$ – the mass of the Sun.

2. The binary star systems – the calculations of the component masses

Stars very often exist in systems composed of at least two stars[2]. They interact gravitationally with each other and in effect they move around the center of gravity. If we know orbital periods and radial velocities and additionally we know the inclination of the orbit with respect to the observer, then using Kepler's laws, we can calculate their masses. However, when there are only the lines of one component in the spectrum of the binary, we can calculate the so-called mass function:

$$f(M) \equiv \frac{\sin^3 i}{(1+M_2/M_1)^2} M_1 = \frac{P_{orb} K_2^3}{2\pi G} \qquad (1)$$

where: M_1 and M_2 are the masses of the compact primary and the secondary, respectively,

P_{orb} – orbital period of the secondary component,

K_2 – semi-amplitude of the secondary's line-of-sight velocity,

i – inclination angle of the binary orbit

If, in addition, we know the mass of the second component, then using the mass function we can calculate the mass of the first component. Let us investigate

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[1] LHC is the contraction of *Large Hadron Collider* – the accelerator in CERN in Geneva.

[2] It is estimated that about 60% of stars are members of multiple stellar systems.

the two types of binaries in which the spectral lines of the first component are absent:

1. light visible companion – heavy invisible
2. heavy visible companion – light invisible

In the first type of systems we can assume $M_2 << M_1$. Then from (1):

$$M_1 \sin^3 i = \frac{P_{orb} K_2^3}{2\pi G} = \text{const} \tag{2}$$

In addition, assuming $i = \frac{\pi}{2}$ we obtain the minimal value of the mass of the first component. The second type of binaries is more difficult to analyze. The visible companion is heavy therefore the determination of its mass has a bigger measuring error, which amplifies the inaccuracy in the calculation of the mass of the invisible component.

2.1. Soft X-ray Transient

Many excellent black hole candidates have been discovered in a class of objects called X-ray binaries. These are double stars in which a compact primary star, either a neutron star or a black hole, accretes mass from a normal secondary companion star (see Section **3**.). The accretion process induces X-ray, ultraviolet and optical radiation.

A particular class of X-ray binaries, called soft X-ray transients or SXTs for short, has turned out to be especially helpful in the hunt for black holes. In these binaries, the mass accretion rate varies with time.

Most of the time, an SXT is in a very low luminosity state with $L_{acc} \approx (10^{-6} \div 10^{-8}) L_{Edd}$.

Eddington luminosity is the largest luminosity that can pass through a layer of gas in hydrostatic equilibrium, assuming spherical symmetry. If the luminosity of a star exceeds the Eddington luminosity of a layer on the stellar surface, the gas layer is ejected from the star. This limit is obtained by equating the radiation pressure with gravitational forces.

$L_{Edd} = 1{,}3 \times 10^{38}\, M/M_{\odot} \left[\frac{\text{erg}}{\text{s}}\right]$ where: M is the mass of the accreting star.

Sometimes the system goes into an accretion outburst and becomes very bright, achieving luminosity almost equal to Eddington luminosity. After the outburst, the luminosity slowly declines over a period of several months.

Observations indicate that a typical black hole mass in SXT falls in the range 5 $M_{\odot}$ to 15 $M_{\odot}$.

2.2. Is the determination of the mass a sufficient proof?

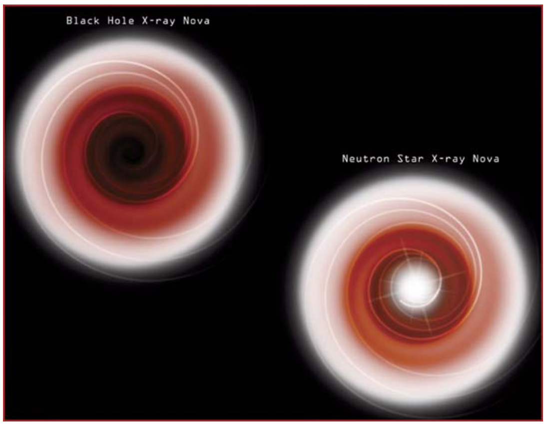
Astronomers have certainly discovered many compact stars that are too massive to be neutron stars. *Can we therefore claim victory in the search for black holes*? In the opinion of many astrophysicists, it would be premature.

It is true that a compact star with $M > 3\,M_\odot$ cannot be a neutron star and must therefore be a black hole. However, we should look for independent evidence that could confirm it. Let's think what is the most characteristic property of a black hole. It is the event horizon that makes the black hole so special. It makes a black hole so unique in the Universe. That is why we should verify whether black hole candidates posses event horizons.

How to acquire such evidence? In brief, we need an observed phenomenon (or lack of it) that is a unique signature of an event horizon. Ideally, we should compare black hole candidates to a control sample of objects, say neutron stars, that are known to have surfaces. We should show that some observable characteristic is distinctly different in the two classes of objects, and that the difference is consistent with the notion that one class (black hole candidates) has event horizons and the other class (neutron stars) has surfaces. Moreover, the difference should not have any other plausible explanation.

X-ray binaries are particularly good for such investigations since some X-ray binaries contain black hole candidates and some contain neutron stars.

Ramesh Narayan with his collaborators [3] have compared black hole and neutron star X-ray binaries and showed that quiescent black hole SXTs are very much dimmer than quiescent neutron star SXTs (see the picture below[3]).



This large luminosity difference is a natural consequence if black hole candidates have event horizons.

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[3] http://imagine.gsfc.nasa.gov

3. Accretion of gas onto compact objects

The process by which compact stars gravitationally capture the ambient matter is called accretion. However, this process doesn't necessarily involve conversion of gravitational energy into radiation. For example the accretion of a non-interacting particle increases only the mass of the central object and doesn't lead to radiation.

In real situations, both neutron stars and black holes are surrounded by clouds of gas. The problem of the accretion of gas onto a spherically symmetric body in the Newtonian theory of gravitation was investigated by Bondi (1952). He considered the adiabatic process of a gas satisfying the equation of state $p = K\rho^{\gamma}$. Bondi's considerations were later generalized to the relativistic case.

Spherically symmetric accretion is an inefficient converter of rest-mass energy into radiation. Allowing the motion of the gas cloud relative to the centre makes no substantial difference. If the velocity of the motion of a neutron star or a black hole is greater than the speed of sound in the gas, a shock wave will develop in front of the star. It will be a weak shock, and the efficiency of the transformation of the particle kinetic energy into radiation will be very low [2]. It became necessary to find a different, more efficient model of accretion. Attention was drawn to close binary systems. In such a system the matter flowing through the Lagrange point will be captured by the black hole. The process of accretion will differ from that occuring in the spherical symmetric case. The falling matter will have non-zero angular momentum. It will form a disc, gradually lose its angular momentum owing to dissipative processes, and approach the horizon, to be eventually drawn in by the black hole.

Lagrangian point – place where the gravitational force of a first body exactly balance the gravitational force of the second body.

When gas accretes on the surface of a neutron star, it is compressed by the strong surface gravity of the star, becomes denser and hotter, until the conditions are sufficient for igniting thermonuclear reactions leading to a burst of X-ray emission.

4. X-ray bursts

Bursts of X-ray emission from X-ray binaries were first discovered by Jonathan Grindlay (1976) and were immediately identified with thermonuclear explosions on the surface of a neutron star. These explosions are known as Type I bursts (to be distinguished from Type II bursts, which are not thermonuclear in origin).

In a typical Type I burst, the luminosity of the neutron star increases to nearly the Eddington limit. The time interval between two bursts is usually several hours to perhaps a day or two.

Type I bursts are very common and have been seen in many neutron star X-ray binaries. However, it is a remarkable fact that no black hole candidate in any X-ray binary has ever had a Type I burst. In some sense, this is obvious. A Type I burst requires a surface where matter is compressed and heated until a thermonuclear instability is triggered.

A black hole has no surface; matter simply falls in through the event horizon and disappears. Therefore, a black hole cannot have Type I bursts.

Since black hole candidates are indeed observed not to have bursts, does it then prove that they have event horizons? The answer is, unfortunately, No!

An object that has a Type I burst must have a surface and therefore cannot be a black hole. This statement is uncontroversial. However, an object that does not have Type I bursts does not necessarily lack a surface and therefore is not necessarily a black hole. For instance, most X-ray pulsars do not exhibit bursts and they certainly have surfaces.

5. Why do black hole candidates not emit Type I bursts?

What else [3], apart from the event horizon, could cause the lack of bursts?

Could rapid rotation somehow eliminate bursts? Rotation has the effect of introducing a variation in the effective surface gravitational acceleration **g** as a function of latitude. However, even a maximally rotating compact star has only a factor of **2** variation in **g** between the equator and the pole. Such a modest variation does not have a serious effect on the burst instability.

Could black hole candidates have very strong magnetic fields and thereby avoid bursts? Then we should observe the X radiation beam modulated at the rotation period of the star, from the magnetic field (this is, in fact, the explanation for the modulations seen in X-ray pulsars). If black hole candidates have strong magnetic fields, they ought to exhibit X-ray pulsations. None of these objects have ever shown coherent pulsations.

5.1. Science fiction: "exotic stars"

Conventional physics tells us that black hole candidates cannot be normal compact stars such as white dwarfs or neutron stars. It is therefore reasonable to suppose that, if they are not black holes, then they must be exotic stars of some kind. Could they be exotic in such a manner as to prevent Type I bursts when they accrete gas? The nature of matter deep in the core of a neutron star is unknown.

Could black hole candidates have cores made of some very exotic material, and could this prevent bursts? No, because bursts are very much a surface phenomenon (with the density of about $10^6\,\mathrm{g\,cm^{-3}}$).

The unusual kinds of matter that are invoked for neutron star interiors typically occur at very high pressure, when the density exceeds the nuclear density $(>10^{15}\,\mathrm{g\,cm^{-3}})$. Such changes in the interior have no effect on bursts at the surface.

Is there any form of exotic matter that instantly converts infalling baryonic matter into exotic matter even at densities below $< 10^6\,\mathrm{g\,cm^{-3}}$? If a star were to be made of such material, there would be no bursts since there would be no nuclei on the surface to undergo thermonuclear burning. No such matter is presently known.

Finally, the black hole candidate may consist of some kind of dark matter that does not interact with baryonic gas other than via gravity (just like the dark matter in the universe). Then such a compact object would be completely porous to ordinary matter. Infalling gas would fall freely through the dark matter and gather at the center. Would such an object have Type I bursts? To answer this question, we need to do some calculations it.

5.1.1. Would-be black holes (Gravastars)

In 2001 Emil Mottola and Paweł Mazur proposed the model which describes objects consisting of very dense and rigid matter. The space-time outside them is described by the Schwarzschild solution. Their interior is filled with matter which satisfies the following equation of state $p = -\rho$ (de Sitter phase). Their rigid surface is located close to the Schwarzchild radius:

$$R_* = R_S + 2\lambda_P$$

where λ_P is the Planck length.

$\lambda_P = 1{,}6 \times 10^{-33}\,\mathrm{cm}$ the smallest length in classical physics – hypothetical threshold, below which there are only quantum fluctuations.

This means that gravastars do not have horizon and singularity, which are the characteristics of a black hole. Nevertheless there is no observational method to distinguish them from black holes. Currently we have no means to tell whether these exotic objects exist in our Universe.

6. Gravitational waves

Does any phenomenon exist to uniquely identify the black holes?

Classically speaking a black hole does not radiate and it interacts with ambient matter only via gravitational field. Therefore searching for gravitational waves seems to be a natural way of detecting black holes [4]. It turns out that a black hole produces universal signals. Disturbing black hole space-time geometry may result in the appearance of an oscillating, damped radiation – the so-called quasi-normal modes. Their periods of oscillations and damping coefficients carry unique information about global black hole characteristics: mass, charge and angular momentum, which would allow one to identify the source of the gravitational field. So the appearance of quasi-normal modes would allow for unique identification of black holes. However, similar effect would be associated with gravastars. Therefore the observer wouldn’t be able to decide as to whether he or she “sees” a black hole or its would-be “sister”.

7. Conclusions

The lack of Type I bursts in black hole candidates is an important clue to the nature of these compact stars. If these objects possess surfaces, they should exhibit widespread burst activity. Why do we not see Type I bursts in black hole candidates? The most plausible explanation [3] for the lack of bursts in black hole candidates is that the objects simply have no surface (existence of an event horizon) which is a characteristic property of black holes.

Detection of gravitational waves should uniquely solve the problem whether black hole candidates are really black holes.

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The picture from the French comic book about black holes (there are also English and German translations) Jean-Pierre Petit, *Les aventures d’Anselme Lanturlu: La trou noir*, Editions Belin, 1980–1981.

/from *Foton* 84/

Neutrino – a particle of the 21st century?

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At the turn of the 20th century, neutrino was certainly one of the most intensely investigated physical objects. On the list of Nobel prizes for physicists in the last twenty years, there are three prizes for work on neutrinos: in 1988 to Leon Lederman, Melvin Schwartz and Jack Steinberger for their experiment proving the existence of two kinds of neutrinos (performed a quarter of century earlier), in 1995 to Frederick Reines for the "experimental discovery of neutrino" (prize delayed by half a century!) and in 2002 to Raymond Davis and Masatoshi Koshiba for the investigations of neutrinos coming from the Sun and other "cosmic" sources. In the Science Citation Index of ISI one may check that ten years ago about 500 papers devoted to neutrino research were published yearly, and in 2005 there were more than 1400 such papers! Some of the papers published in the last decade in this field collected more than two thousand citations. How can one explain such an increase of interest in the particles which are not the components of the "ordinary" matter surrounding us and interact with matter so weakly, that they do not seem to influence it?

One should admit that the history of neutrino research is unusual. It is probably the only particle, for which we know "the birth date" with the accuracy of one day. On December 4, 1930 Wolfgang Pauli, the great German physicist (also a Nobel prize winner, but for work unrelated to neutrinos) sent to his colleagues gathered on the meeting of a local physical society the famous letter, addressing them jokingly as "honorable radioactive Ladies and Gentlemen". In this letter Pauli proposed the explanation of anomalies observed in the investigations of beta decay by the existence of a new "invisible" neutral particle, which originates in the decay beside the electron (the latter registered by the detectors). The name proposed by Pauli for the new particle was "neutron"; two years later another great physicist, Italian Enrico Fermi suggested to give this name to the neutral partner of proton, newly discovered by Chadwick, and to call the "Pauli particle" by Italian diminutive "neutrino", since the data suggested for this particle a value of mass much smaller than for proton (and electron).

Neutrino was supposed to be electrically neutral, therefore one expected that its detection should be much more difficult than the detection of electron; this explained the "invisibility" of neutrino. In fact, Pauli suggested that the probability of interaction of neutrino with matter would be not much smaller than the corresponding probability for photons with similar energies (e.g. ten times smaller). Soon, however, other eminent physicists, Bethe and Peierls estimated that this probability is smaller by many orders of magnitude. Not just Earth, but even the Sun is no obstacle for neutrinos – the probability of interaction during the passage through Sun for a single neutrino with energy typical for beta decay is much smaller than one. After this estimate was made, Pauli announced that he offers a box of champagne to the first physicist, who registers an interaction of neutrino.

The wager seemed perfectly safe, but the interactions of neutrinos with matter were in fact observed in Pauli's lifetime. It is easy to explain the rare mistake of the physicist known for his uncanny intuition: Pauli could not foresee the discovery of nuclear fission by neutrons, and the following discovery of the chain reaction of fissions, when each act of fission leads to the emergence of a few "new" neutrons, leading to the next fissions. Such a process occurs in a nuclear bomb, and (in controlled form) in a nuclear reactor. The enormous number of free neutrons and neutron-rich nuclei originating in this process and decaying via beta decay produces the flux of neutrinos millions times stronger than any sources known in 1930. Even if the probability of interaction in our detector is of the order of one trillionth for a single neutrino, we shall certainly register some interactions, if many trillions of neutrinos pass through our apparatus!

In fact, such an experiment is very difficult, since the reactor is of course the powerful source of many kinds of radiation, and it is difficult to discern the neutrino interaction from all other possible processes. It requires very sophisticated experimental methods, which we shall not discuss here; an interested reader may find the details in many textbooks and popular essays. Frederick Reines, mentioned above, conducted such investigations with his collaborator, Clyde Cowan Jr. (who, unfortunately, did not live long enough to get the Nobel Prize) for quite a few years in the 1950's. They had to transfer their equipment from Hanford to a new, more powerful reactor in Savannah River, before they succeeded. The discoverers notified Pauli, but never got even the congratulations, not to mention the champagne which was drunk by Pauli and his collaborators...

In the meantime it was discovered that the nature provided us with a commonly available source of neutrinos, offering the flux comparable to those produced in the nuclear reactors. This source is our Sun, which draws the energy from the nuclear reactions running in its interior. The number of neutrinos born during these processes is so enormous, that even on Earth, at the distance of 150 million kilometers, their detection is possible. Every second more than 60 billion neutrinos from the Sun pass through each square centimeter of Earth surface (or the surface of our bodies). Fortunately, few of them interact during our lifetime.

The registration of neutrinos from the Sun is, however, not easy. Raymond Davis, mentioned above, constructed in 1950's a detector, whose main element was a big tank filled with carbon tetrachloride (a cheap cleaning fluid) and placed it in an old mine Homestake in the US. Neutrinos penetrated through the surface of Earth and several kilometers of rock (which absorbs most of other kinds of cosmic radiation) and interacted with chlorine nuclei inside the tank, converting them into radioactive argon nuclei. Every few weeks the tank was flushed with gas, which “collected” argon, and then the decays of argon nuclei were registered, measuring the number of neutrino interactions. The result was surprising: for almost fifty years one systematically registered only a half of the number of interactions predicted by the theory! It seemed that there are only two possible explanations: either the detector was “losing” events, or the Sun was emitting less neutrinos than it should.

Finally, however, both the analysis of experiment and the theory describing the Sun were verified to be correct. The effect responsible for the observed “deficit” was different: the neutrinos born in Sun were transformed on their way to Earth into different kind of neutrinos, for which the detector was “blind”.

The existence of two different kinds of neutrinos was proven in 1962 by the experiment of Schwartz and collaborators mentioned already above, and the third kind of neutrinos was discovered in the next decade (and directly registered only in the XXI century). The neutrinos of two new kinds could not interact in the way employed in the Davis experiment, which explained the observed deficit. The consecutive experiments confirmed that neutrinos transform on their way from the Sun, and the similar effect appears also for the neutrinos born in the Earth atmosphere from the decay of particles created by cosmic rays. The key experiments for the “atmospheric” neutrinos were “Kamiokande” and “Superkamiokande”, initiated by Masatoshi Koshiba, another Nobel Prize winner, in the old Kamioka mine in Japan. The interactions of neutrinos in the underground tank (containing 50 thousand tons of ultra pure water) were registered by the Cherenkov radiation emitted by electrons and muons created in the interaction.


May-2002 Neutrino2002 @ Munich

History of Super- Kamiokande

- 1996.4 Start data taking (SK- I)

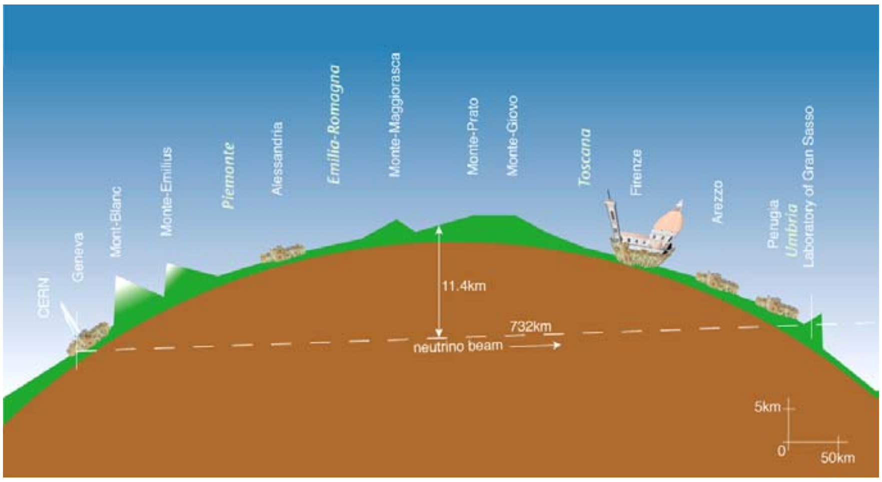
Water Cherenkov detector

- 1000 m underground
- 50,000 ton (22,500 ton fid.)
- 11,146 20 inch PMTs
- 1,885 anti-counter PMTs

- 2001.7 Stop data taking for detector upgrade
- 2001.11 Accident (6777 inner PMTs, 1100 outer PMTs were destroyed)
  partial reconstruction of the detector
- 2002.10 resume data taking (SK- II)

The effect of transformation, the so-called neutrino oscillations, is a quantum effect, and its analysis requires the use of advanced mathematical methods. It is very important that oscillations can occur only for particles with non-zero mass. Till now, no experiments allowed to measure the neutrino masses; only the upper bounds were found. These bound were set so low at the end of 20th century that neutrinos were found to be more than hundred thousand times "lighter" than electrons, the particles with smallest measured mass. It seemed natural to assume that neutrinos have zero mass. Now we learned it is not true! This requires significant modifications of the standing model of elementary interactions, so-called standard model.

The neutrino oscillations are so fascinating that physicists decided to investigate them in the neutrino beam which is better controlled than that of neutrinos from the Sun or from Earth atmosphere. The neutrinos were sent to the Superkamiokande detector from KEK accelerator centre, few hundred kilometers away. Let us note that such a beam does not require any beam pipe – the Earth, as already mentioned, is practically transparent for neutrinos. The first results from this experiment called "K2K" confirm the earlier data for oscillations. We hope that the next experiment, where the neutrino beam from the CERN laboratory near Geneva will be sent under Alps to the underground Gran Sasso laboratory, 700 km away, will yield more accurate data on oscillations, which would help to determine the neutrino masses and to explain theoretically their values.



The facts presented above do not exhaust the rich list of reasons, why the neutrino physics is so attractive. The neutrino oscillations were investigated in

Japan by another experiment, in which the neutrinos from all the reactors within the thousand kilometer range were registered. It is easy to imagine that a similar experiment may serve as a "reactor remote control" once the oscillation theory is well established. The in situ missions of inspectors will no longer be necessary to check if some rogue country obeys IAEA rules. Recently, a project on the verge of science fiction ideas was presented: a powerful neutrino beam may destroy illegal stores of nuclear weapons from arbitrary distance.

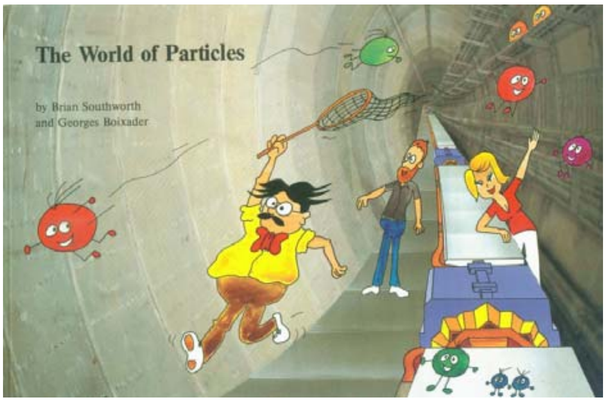
Another application of the same detector was a recent experiment in which the net radioactivity of the Earth interior was measured. The results suggest that the standing models of our planet should be modified: it seems that the radioactive decays were more relevant for the Earth history than generally believed. Great hopes are set on the future investigations of cosmic neutrinos, which may provide a "tomography picture" of the Earth interior, which they penetrate as easily as X-rays penetrate our bodies.

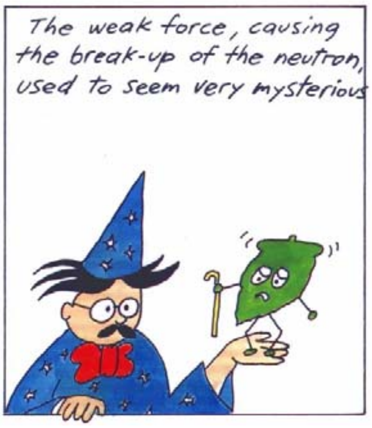
We expect also that the role neutrino research has played in the understanding of processes occurring in the Sun (and the registration of neutrinos from a Supernova explosion, which occured in 1987) were just the first steps of a new branch of science: neutrino astrophysics. The investigation of neutrinos from the Sun was so valuable because neutrinos created in the centre of Sun emerge "intact" on the Sun surface after only a few seconds, whereas photons interact so often, that they need thousands of years to pass this way. Our knowledge of the processes occurring in more "exotic" astrophysical objects (e.g. in the galactic nuclei) is based solely on the electromagnetic radiation, and thus very indirect and distorted. If we learn how to register neutrinos from such sources, we shall certainly learn many new facts and phenomena.

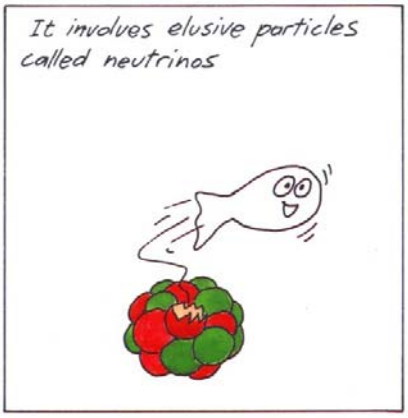
Many physicists believe that the 21st century will be the "neutrino century", when these particles will cease to be just an object of basic research, and will serve as new valuable tools of applied science and technology. It seems fit to mention here that our eminent writer Stanisław Lem used neutrino physics as a base of two of his novels. In "The Master's voice" the cosmic "older brothers" use the neutrino beam to code the message which men strive to decode, and in "Solaris" the "thinking ocean" constructs from neutrinos the stable systems, which imitate the people reconstructed from human thoughts. The first idea is feasible (although unlikely to occur exactly along the lines presented in the novel), the second one seems to contradict the known physics – but who can predict the future...

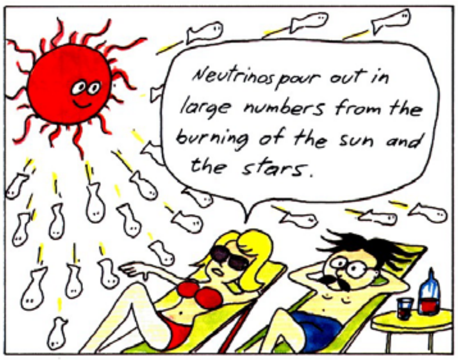
/from *Foton* 92/

About neutrinos from CERN – comic



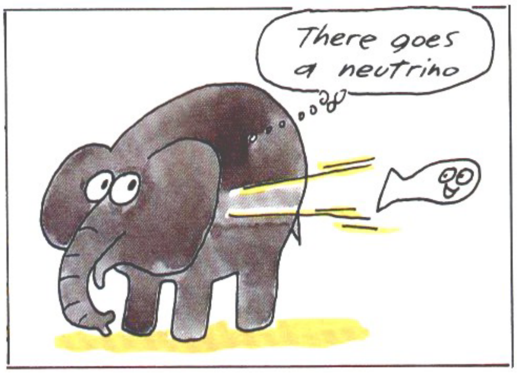







As the stars shine, neutrinos are being made and the weak force is at work


They are so averse to other particles that they can pass through the whole earth without difficulty. Thousands of them are passing through you now


There goes a neutrino

Go photonics, go!

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What is light? – what a question, everyone knows that. Is this really the case? Try asking several different people and you get as many answers as the number of people you asked. Some will say light drives all life on earth, others will stress the role of light in our reception of the real world, still others will notice how light inspires poets and artists. Although each reply will be obviously correct, none will provide a full answer to the question. No wonder that light, being an eternal source of fascination for so many people, has been a long-standing challenge also for scientists. In particular, physicists have tried to explain *what is light* for a very long time. While no special knowledge is needed to use light, revealing its nature kept the best brains busy for centuries. It is enough to mention such scholars as Newton, Einstein, though also Johann Wolfgang von Goethe, who was not only the great romantic poet but also, which is less known, an outstanding scientist whose treatise "Zur Farblehre" has made a profound contribution to the history of science. The breakthrough in our understanding of light happened already in the 19th century, mainly due to the work of the theorist James Clerk Maxwell and experimentalist Heinrich Hertz. Yet, it was only recently that the puzzle of light was solved completely: the 2005 Noble Prize for Roy Glauber for his quantum theory of light has finally brought the issue to a close.

When we already understood the nature of light, it became possible to study various ways of its generation, to learn how to detect it and tailor it to our specific needs. This used to be the natural field of optics and of atomic and molecular physics. These disciplines were, and still are, actively developed in Poland. In the Jagellonian University, systematic research in this field started after World War II when massive migrations forced by the new geo-political conditions brought Professor Henryk Niewodniczański (1900–1968) from his native Vilnius to Kraków. Professor Niewodniczański contributed very much to the development of physics in Kraków and, in particular, to *atomic optics*, i.e. the optical spectroscopy of atoms. In 1962 within the Institute of Physics of the Jagellonian University he founded the Department of Atomic Optics headed by Professor Danuta Kunisz (1924–1979), a former Niewodniczański's student. This was the beginning of modern research in the field of optical and atomic physics in Kraków. Thanks to the development of lasers the field flourished in the seventies and attracted many young enthusiasts. The enthusiasm was indispensable to pursue experimental research in Poland at that time, since equipment was so scarce that nothing could be accomplished without a great deal of optimism and devotion. Despite these difficulties, unlike our colleagues in other East-European countries, we were fortunate enough to be able to travel and cooperate with the best groups in the world. Many of the scientific and personal contacts of that time have lasted until now.

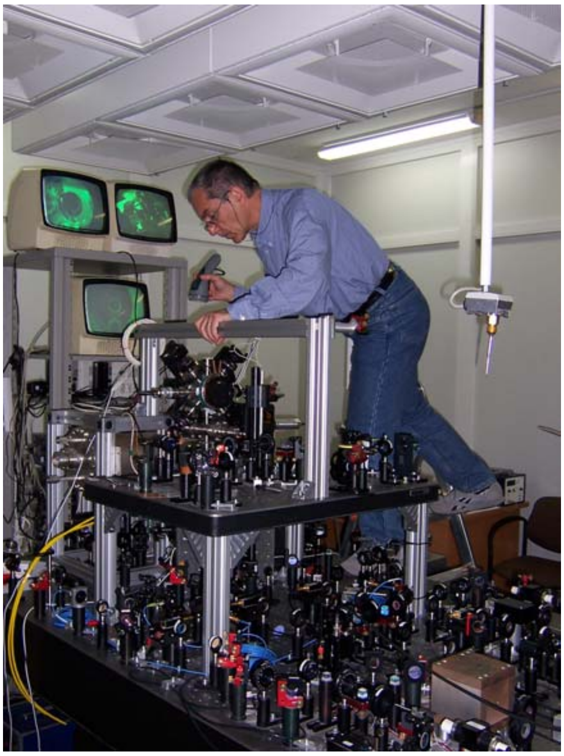
Lasers are very remarkable light sources. Laser light is entirely man-made, and practically does not exist naturally in the universe (though stimulated emission and laser action does occur in some astronomical systems). It has really unique features: coherence, high intensity, high degree of collimation and it can be generated at a very well defined color (monochromaticity) that can be finely tuned to induce resonant interaction with any atom. Such features, on the one hand, allow one to precisely study various aspects of interaction of matter with strong electromagnetic fields and, on the other hand, to modify atomic/molecular properties, control chemical reactions, exert mechanical forces on atoms, molecules and living objects and can be used to manipulate their movements. Thanks to these extraordinary features new disciplines emerged, like quantum and nonlinear optics or the new-born and rapidly expanding photonics. The term *photonics* is not well defined. Attempts to provide an accurate definition fail due to the fast evolution and constant expansion of the field. In general, it can be understood as the creation, transmission and transformation of information via photons, just as it is done by electrons in the case of *electronics*.

The rapid development of optics and photonics is caused by several factors. Firstly, the new light sources and optical methods are far cheaper than accelerators and huge research centers, yet they provide scientific results equally important for fundamental science. It suffices to mention the numerous Nobel Prizes in physics and chemistry (four prizes in the last eight years!) for research based on optical methods. Secondly, optical methods are very versatile and are frequently applied in other fields. This contact of various techniques and approaches results in new interdisciplinary research fields, like nano-photonics, bio-photonics, as well as in novel applications, e.g. in computers, laser printers, optical memories, optical fiber techniques for data transmission, precision instrumentation for measurements of all kinds, medical diagnostics and therapy, etc, etc.

The PHOTON reader can follow the activity in photonics on the example of the Kraków physicists of the Photonics Department of the Jagellonian University.

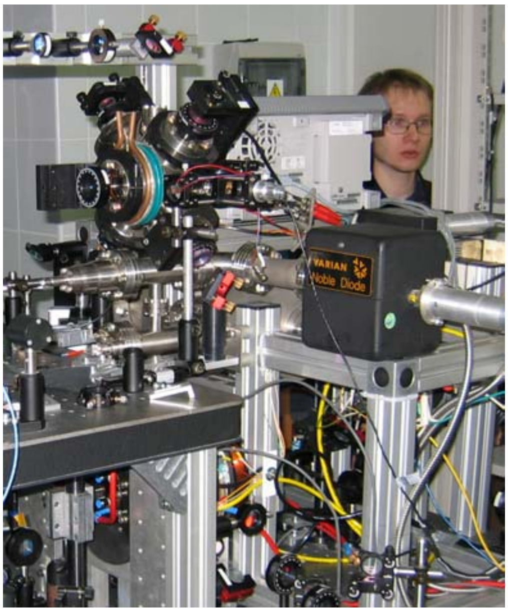
The Photonics Department of the Jagellonian University consists of several research groups. One group has many years experience in plasma diagnostics based on precision laser spectroscopy. These methods are important for the characterization and control of many technological processes, e.g. thin diamond layers. To obtain materials of desired characteristics it is necessary to have full control over plasma sources at temperatures of several thousands of degrees where many complex, not completely revealed physical processes take place. One sensitive method of studying such systems has been worked out at our Photonics Department and is successfully applied also in several foreign labs.

While the plasma diagnostics group employs lasers for the studies of extremely hot media, another group in the Photonics Department uses lasers to reach extremely low temperatures, a few microKelvins above absolute zero. In temperatures so low – much lower than those in outer space – matter exhibits some very unusual features which are extremely interesting and useful for solving many problems of contemporary physics, like superfluidity and superconductance. These features are also important for many fascinating applications such as the construction of novel computers. It is noteworthy, even to many physicists, that the ultra-low temperatures are obtained with the help of lasers which are commonly known as a source of energy and heat, rather than a cooling device.



As can be seen, low temperature research has reached a really high level...

Nonlinear magneto-optical phenomena induced by coherent laser light are the next field of research pursued in the Department. These phenomena seem to have an even wider application potential than cold matter, in particular in emerging quantum information. In quantum computers, the elementary portions of information are specifically prepared quantum states, the so called *qubits*, as opposed to standard *bits* used in contemporary computer science. The difference is very profound and reflects different logical operations that can be performed with qubits (*see the article by Szymon Pustelny on quantum computers in Foton 81*). The novel logic may in future allow a much faster operation of quantum computers. Although quantum computers are still to be constructed, a related field of quantum information, quantum cryptography, has already found its way into commercialization, proving that quantum information is not merely art for art's sake. Another important application of nonlinear magneto-optics are sensitive measurement instruments. For example, precision magnetometers whose principles are developed in the Photonic Department will be able to search for natural resources, to scan the oceans for submarines or to detect hazardous materials, be they single bacteria like anthrax or explosives. On the other hand, ultra-sensitive optical magnetometers can be used for the non-invasive monitoring of cardiac and/or brain action.



The heart and brain of the apparatus

Medical oriented research on the effects of laser light on elementary biomedical processes, the properties of various vital substances and function of organisms is developed in cooperation with different teams of medical and/or biological specialists. We are particularly interested in processes where light acts as the catalyzer of specific chemical reactions that control certain biological processes in tissues and organisms. A familiar example of such a process is *photosynthesis* which is a continuous challenge to scientists of various disciplines. A very attractive discovery to medicine, particularly important for cancer treatment, is the so called *photodynamic therapy* and *diagnostics*. It is based on administrating a special drug to the patient body. The drug has two important features. First is the ability to concentrate in tumor tissue, rather than in healthy cells, the second is that after being activated by illumination with light of an appropriate wavelength the drug triggers a chemical reaction which destroys the tumor without affecting the healthy tissue. While the basics of the photodynamic reaction are widely known, its practical application requires detailed studies combining the knowledge of physics, especially optics and photonics, with medicine.

Another kind of research developed in the Photonics Department are studies of optical and photonics materials. The unique apparatus and sophisticated methods developed for many years, primarily for fundamental research, are now very useful for such application studies. We start cooperation with some development companies and are heading towards closer contacts with hi-tech industry.

Undoubtedly, now is a good time for photonics. In Kraków this field has great traditions and excellent prospects for further development. We do hope to take advantage of both and encourage all who would like to help us to start studies in physics or material science, and then to specialize in photonics.

/from *Foton* 92/

Why is photosynthesis interesting?

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Life on the Earth is solar powered. Photosynthesis is the process by which plants use light energy to produce food molecules for all living creatures. Besides light, water and carbon dioxide from the atmosphere are required in green plants photosynthesis.

Life on our planet began about 3.5 billion years ago with the appearance of the first photosynthetic organisms, such as bacteria and primitive algae. At the beginning anaerobic photosynthesis was present, in which H_2S, for example, was used as an external source of electrons and protons. Oxygenic photosynthesis occurred about 2 billion years ago. Cyanobacteria and higher plants are able to extract electrons and protons from water. A by-product of this reaction is oxygen. The occurrence of O_2 in the atmosphere determined the direction of life evolution. Oxygen is essential in the process of respiration by which organic compounds are oxidized back to carbon dioxide and water and at the same time the energy necessary for living organisms is released.

Photosynthesis can be defined as a process utilizing sun energy and converting it into chemical energy by means of complex biophysical and biochemical reactions taking place in plant chloroplasts and in the cells of photosynthetic prokaryotes. The light driven reactions take place in the inner membranes of the chloroplasts called thylakoids (Fig. 1). Photosynthesis consists of a series of reactions starting with the splitting of water molecules into molecular oxygen, protons and electrons, followed by a chain of electron transfer reactions resulting in the production of NADPH and ATP – sources of chemical energy used in cell metabolism (see Frame 1 for details).

FRAME 1

There are three complexes subsequently participating in the electron transport chain in thylakoids: photosystem II (PSII), a cytochrome b6/f complex and photosystem I (PSI). Photosystem II is "heart" of the photosynthetic apparatus. It uses light energy to catalyze water splitting into molecular oxygen, protons and electrons. PS II and PS I are linked by two mobile electron carriers: plastoquinone (PQ) and plastocyanin. The subsequent reactions of the electron transfer through PS II via cytochrome b6/f and through PS I are called a photosynthetic linear electron transfer chain. At the acceptor side of PS I, $NADP^+$ (oxidized form of ***N***icotineamide ***A***denine***D***inucleotide ***P***hosphate) is reduced to NADPH in this reaction: $NADP^+ + H^+ + 2e^- \rightarrow NADPH$. The proton gradient generated by H^+ released from water into the lumen side of thylakoids and by H^+ pumped by PQ through the membrane from the outer to the inner side of thylakoids is a driving force for the ATP formation (***A***denosine ***T***ri***P***hosphate).

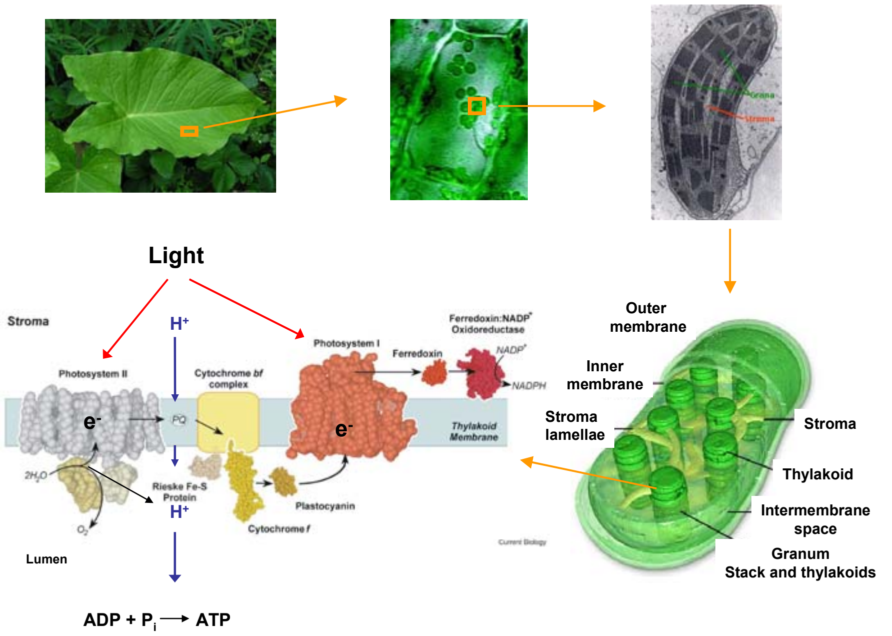

Fig.1. A schematic structure of thylakoids in chloroplasts (green parts of leaves), and a scheme of the linear electron transfer chain in the process of photosynthesis and formation of NADPH and ATP as final products of the light driven photosynthetic reactions

NADPH and ATP produced in photosynthetic light reactions are used in a dark reaction process, known as the Calvin cycle, in which carbohydrates and other organic compounds are synthesized. At this stage of photosynthesis an assimilation of CO_2 occurs. The formation of a six-carbon sugar molecule requires six complete turns of the Calvin cycle, for each of which 3 ATP and 2 NADPH molecules are consumed. The biochemistry of the photosynthetic process can be summarized in the following way:

$$\mathbf{6CO_2 + 12H_2O + 18ATP + 12NADPH \rightarrow}$$
$$\mathbf{\rightarrow C_6H_{12}O_6 + 18ADP + 18P_i + 12NADP^+ + 12H^+ + 6O_2\uparrow}$$

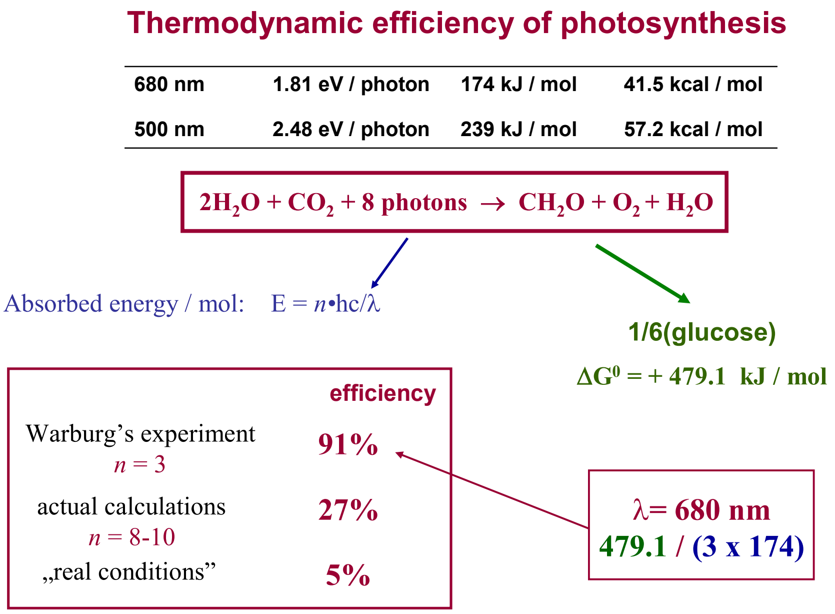

Fig. 2. Thermodynamic efficiency of photosynthesis

In entire scheme 2 it is shown how one can calculate the thermodynamic efficiency of the process of photosynthesis. The final efficiency is only 5% (see Frame 2 for details).

FRAME 2

It is generally accepted that eight moles of photons are required for reduction of each CO_2 mole, it is 8 x 174 kJ/mol, when the wavelength is of 680 nm (the absorption maximum of the PSII reaction center). The free energy of the reaction of the CO_2 reduction to CH_2O (1/6 of a glucose molecule) requires about 479 kJ/mol. Thus, the efficiency of photosynthesis is almost 34% under optimal conditions. In fact, one should consider the higher energy of photons of between 500–680 nm and the requirement of more moles of photons for the reaction of glucose production in natural conditions. The energy of some photons is dissipated and thus not all photons contribute to the reaction. Therefore the efficiency is much lower than 30% and in reality it is only of the order 5%.

The annual flow of sunlight energy toward the surface of the Earth is about 1.4 x 10^{18} kWh but only half of the energy enters the surface. Moreover, only 7 x 10^{14} kWh is utilized by photosynthesis (less than 0.1% of total sunlight energy). However, the "lost portion" of energy can power other processes at the earth's surface such as winds or ocean currents.

Because the current fossil fuel reserve is estimated to be sufficient for only 200 years at the present world annual consumption or even less when the consumption increases with the industrial development of other countries, mankind is searching for new energy sources. They should yield safe, clean and renewable energy. Renewable energy sources can be replenished in a short period of time. The five renewable sources used most often include hydropower (water), solar, wind, geothermal, and biomass. Natural energy sources are shown in Fig. 3.

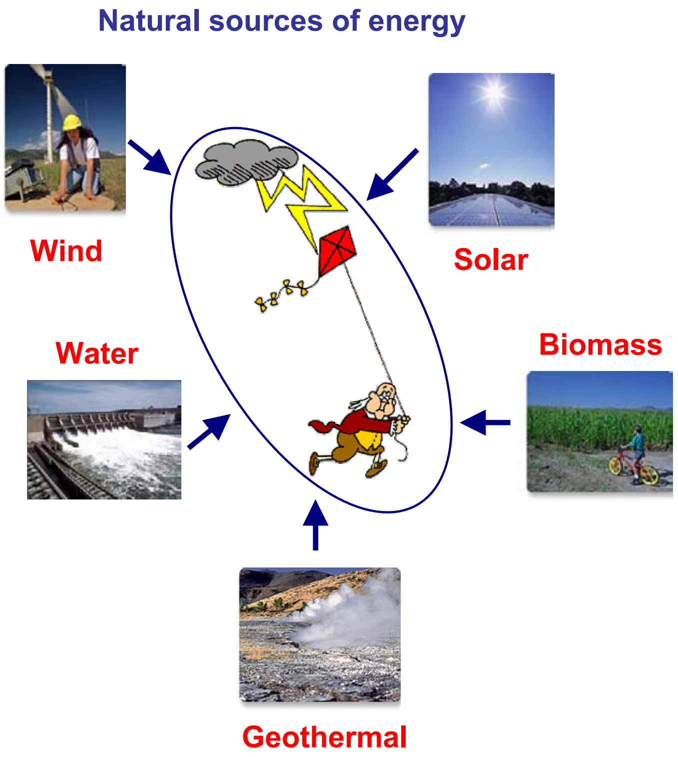

Fig. 3. Natural sources of energy

In view of the energy problems which mankind faces, the issue of biomass and solar energy has attracted recently more and more attention. It is possible to increase the efficiency of the biological energy sources and to decrease the costs of exploatation by genetic modification of photosynthetic organisms which optimally use the photosynthetic process on the molecular level. There are two main directions of genetic and molecular studies: the first one is focused on the selective production of biomass with various fuel source (wood, oil, alcohol) and the second one on the construction of fuel cells based on the combination of processes naturally occurring in photosynthesis.

As an example, we will discuss below hydrogen as biological fuel. Presently it seems to be the best candidate for the fuel in new technological developments. There are many groups of specialists working on that problem including physicists, chemists and biologists. The cleanest way to produce hydrogen is to use sunlight to split water into hydrogen and oxygen. Such photoelectrochemical water splitting is shown in Fig. 4. Fuel cells can work using products of artificial semiconductor systems, which are already on the market, or from natural photosynthetic systems (Fig. 4).

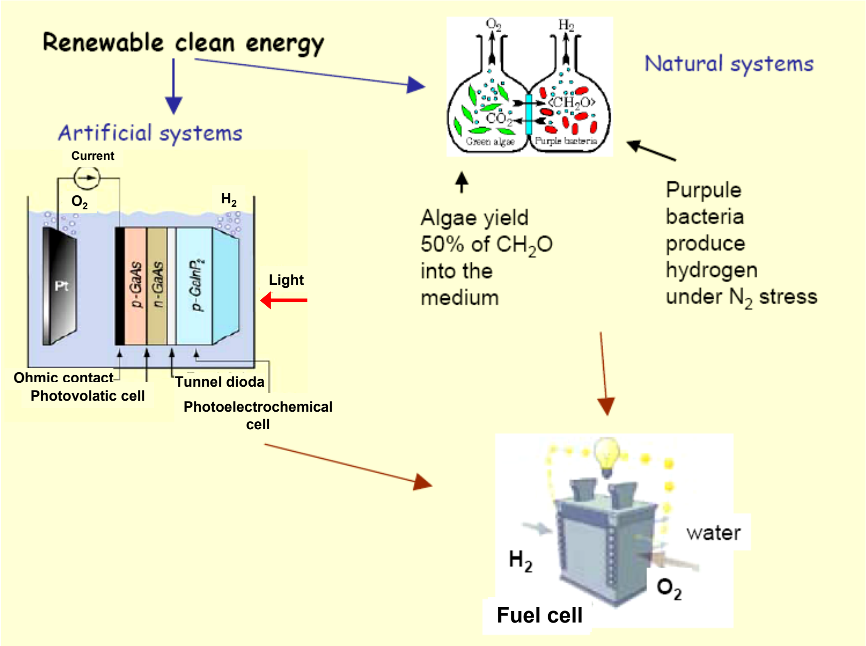

Fig. 4. Natural and artificial systems, which are able to produce H_2

A fuel cell is a device that uses hydrogen or hydrogen-rich fuel and oxygen to create electricity. In the case when H_2 is used, the fuel cell emits only heat and water as byproducts. This means that the energy production is really environment-friendly because it is not related to any air pollution nor greenhouse gases emission. The only problems, but a very important one from the practical point of view, are that the costs of such artificial devices which are too high while their working time is too short. Systems based on photosynthetic organisms could provide a solution to this problem. The present and predicted costs of hydrogen production are shown in Fig. 5. It is clear that the costs and efficiency of natural systems are much better.

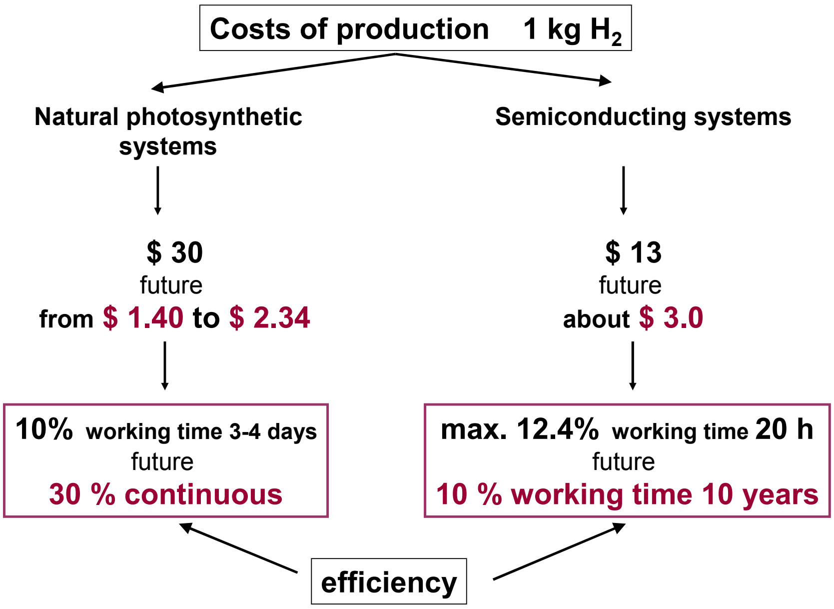

Fig. 5. Efficiency and costs of hydrogen production

In photosynthetic organisms hydrogen is produced along with oxygen. However, the hydrogen producing enzyme called hydrogenase is oxygen sensitive. The presence of O_2 inhibits the formation of H_2. Therefore the efforts of researchers are going in the direction of genetic modification to evolve organisms that can sustain hydrogen production in the presence of oxygen. Another possibility is to manipulate the culture conditions switching metabolism of the natural systems between their photosynthetic growth (an increase of O_2 evolution) and H_2 production phase. It is achievable, for example, in algal cells by controlling sulphur concentration in the medium. Thus, photobiological technology holds – great promise (Fig. 6).

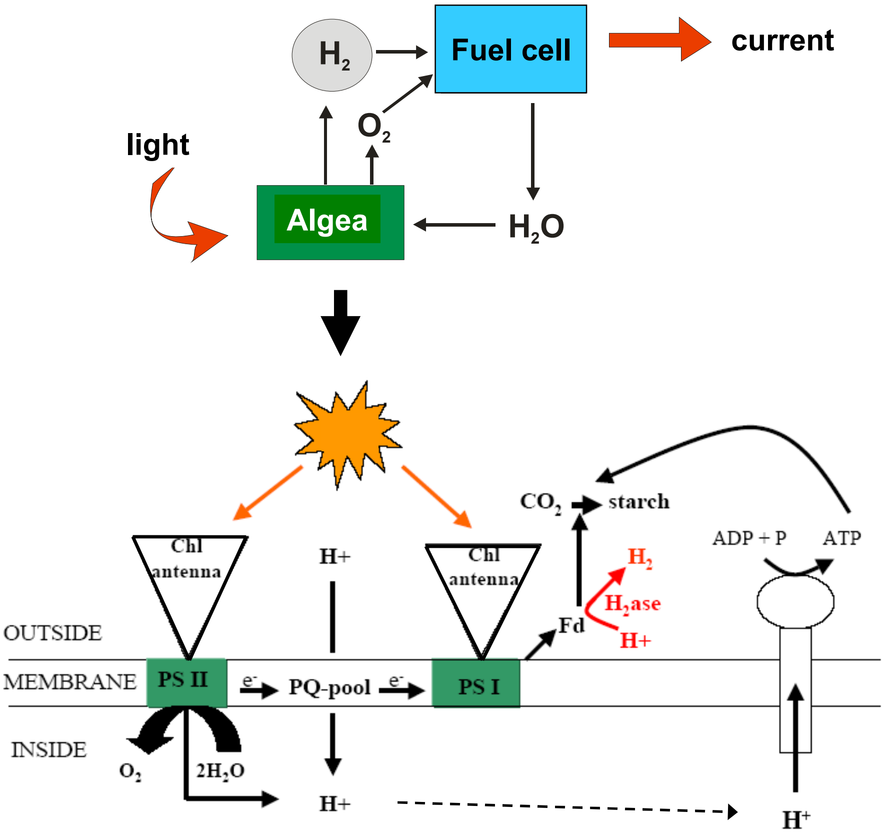

Fig. 6. Algal systems may switch between oxygen and hydrogen production under controlled conditions. The water splitting complex in photosystem II located toward the inner part of photosynthetic membranes is responsible for O_2 evolution. H_2 yield is regulated by hydrogenase (H_2-ase) operating after photosystem I in the outer part of the membranes

There is also another direction of photosynthetic studies. It is concentrated on the recognition of the mechanism of water splitting in the oxygen evolving complex located on the core of photosystem II, which could be a prototype for the biomimicry and formation of new devices with an efficiency of 100% for the light-driven process of water splitting into O_2 and hydrogen ions (H^+). It is known that a manganese cluster containing 4 atoms of Mn and one Ca atom is responsible for water oxidation but the mechanism of H^+ extraction and formation of the O=O bond still remains a puzzle (Fig. 7).

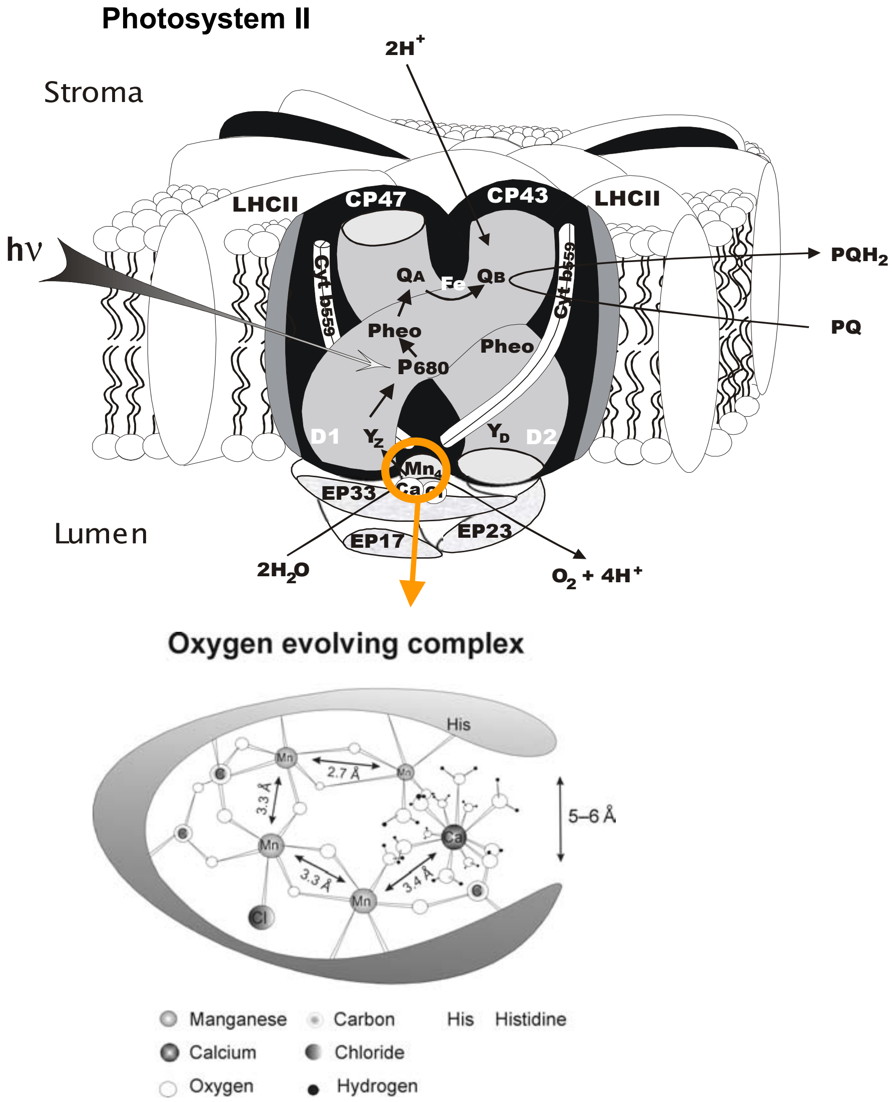

Fig. 7. Scheme of photosystem II with redox active components participating in the linear electron flow within PSII (Tyr – tyrosine, Pheo – pheophytin, QA – plastoquinone bound in site called QA, QB – plastoquinone bound in site called QB, P680 – reaction center of PSII, cyt b559 – cytochrome b559, Fe – an iron atom). A possible arrangement of the oxygen evolving complex containing four Mn atoms and one Ca atom is shown

Physics plays a very important role in this field of investigations. Various physical experimental techniques such as: XANES (X-ray absorption near edge spectroscopy) , EPR (electron paramagnetic resonance), NMR (nuclear magnetic resonance), Mössbauer spectroscopy, fluorescence and absorption spectroscopies, are crucial in studies of the structure of the Mn cluster, spin and valence states of the redox components participating in the electron transfer chain (for example: iron complexes, tyrozines). The interpretation of the data needs a deep understanding of physical phenomena, which allows one to formulate models of photosynthetic energy and electron transfer. Theoretical analysis can certainly be very helpful in the construction of artificial photosynthetic systems.

To summarize, we feel confident that the joint efforts of biologists, chemists, physicists and geneticists will in the nearest future lead to the ultimate goal, which is the discovery of technology for light driven power plants of a high efficiency and low pollution level.

/to be published in *Foton* 93/

A Vampire Story:
Science, Folklore and Beyond

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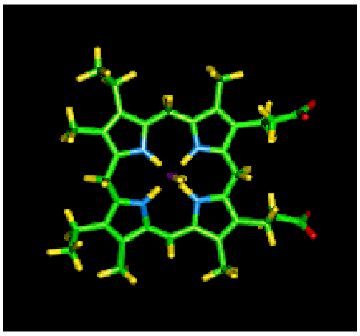
(…) Throughout the vast shadowy world of ghosts and demons there is no figure so terrible, no figure so dreaded and abhorred, yet dignified with such fearful fascination, as the vampire, who is neither ghost nor demon, but yet who partakes the dark nature and possesses the mysterious and terrible qualities of both…
Rev. Montague Summers, "The Vampires in Europe", London 1929

Pieter Brueghel – the allegoric Mad Meg (Dulle Griet); Oil on wood, the Museum Mayer Van den Bergh, Antwerp. The painting fascinates with hidden, mysterious meaning. The possible symbolism of the large woman is sometimes interpreted as a sign of violence, heresy, personification of an evil, a fearsome witch...

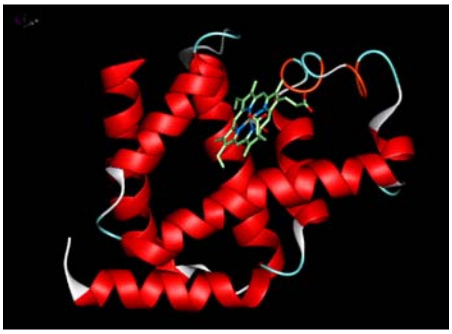
Every single bookstore at the 1733 Leipzig spring fair was selling books about vampires. The German readers' interest had been aroused by the events that had taken place first in Moravia and later in the Serbian territories recently re-conquered from the Turks in the 1720's. Since Serbia was governed by the Austrian military authority and any epidemics would have jeopardized the army's striking ability, the Viennese bureaucratic machinery required detailed reports about every suspicious case. It is thanks to this circumstance that we have got the first and relatively precise description of an age-old Serbian belief. According to the reports, in 1725 mysterious deaths occurred in one village. The inhabitants blamed it on a man who had recently passed away. The report states that the village people dug the corpse out of its grave and pierced its heart with a sharply pointed stick. In 1730 a similar case was reported in another village where a soldier and his family died after eating mutton from a sheep that had been bitten by a vampire in the form of a snake. Fearing that the dead had become vampires themselves, the villagers exhumed and beheaded the corpses. During the winter of 1731–1732, an epidemic of cases was reported in a third village as well. The dispatched military physician first tried to convince the villagers that vampires did not exist and belief in them was a mere superstition...

The Witches' Sabbath by Hans Baldung Grien portraits a midnight meeting of witches, govering to practice their unusual craft and sorcery

Soon, however, all of Europe caught the vampire fever: Periodicals were competing with each other in describing the most macabre details and even the physicians that did not believe in the resurrected blood suckers joined the sharp debates on the subject in the columns of the Nuremberg professional journal *Commercium litterarium ad rei medicae et scientiae naturalis incrementum*. They all did, of course, agree that there were no such things as vampires and although the epidemic as to the had an unknown origin, it was by no means supernatural. The opinions, however, were sharply divided as to the causes of the apparent soundness of the exhumed corpses. The phenomenon came in hand for the believers in *iatromechanics*, *chemiartry* or *iatrochemistry* who explained all bodily functioning by mechanical or chemical processes, as just when their fortunes were fast shrinking, it spectacularly proved their teachings. Georg Ernest Stahl and his followers, who represented the vitalist-animalist school of medicine, rejected the notion that the human body resembles a hydraulic machine where it is the body fibers' contraction and dilation that assure the body fluids' flow and where the blood flow is the most important motion element. In Stahl's work titled *Theoria medica vera*, published in 1709, the "anima", the vital principle, inseparable from the physical body, was seen at work in matter controlling and directing its functioning. The animists had a hard time trying to explain how the vital processes could possibly go on even after death. Yet it was their line of thinking that became prevalent in the 18th century and, in accord with it, the medical debate concerning vampires died out as well...



The basic model of the heme olecule with the iron ion at the center position of the porphyrine structure. Heme is omplex red organic pigment forming the prosthetic groups found in most oxygen carrier proteins like hemoglobin pictured on the right panel

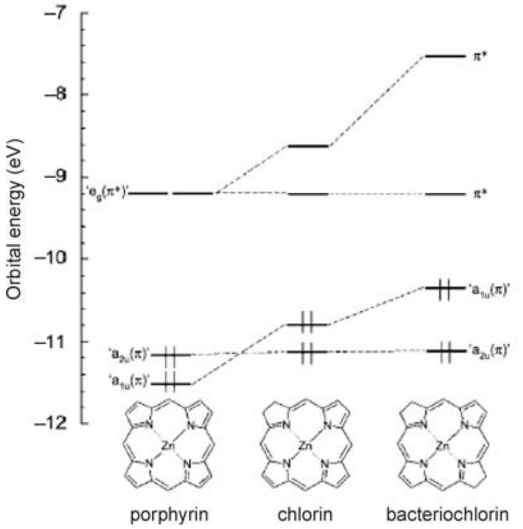


Hemoglobin is a crystallizable, conjugated protein consisting of an iron-containing pigment (heme) and simple protein, globin. In the lungs, it combines readily with oxygen to form a loose, unstable compound called oxyhemoglobin, in a process called oxygenation.

Hemoglobin is the protein that is carried by red cells. It picks up oxygen in lungs and delivers it to peripheral tissues to maintain viability of cells

It was not till late XX century when the vampires' story became "scientifically" intriguing again. Hypothesis brought up by chemists and clinicians studying blood disorders was that vampires, those dreaded beasts of folklore and superstition, may have been nothing more than people suffering from a rare (one case in every 200 000 people) class of genetic diseases called *porphyria*. Congenital erythropoietic porphyria (porphyria originates from the ancient Greek word *porphura*, meaning purple) accused for being most likely responsible for the vampiric myth is the disease related to an inherited disorder of heme metabolism.

The molecule of heme is a prosthetic group to many important proteins like eg. hemoglobin which carries oxygen in our blood stream. Heme, whose chemical structure is responsible for the red color of blood is built of a porphyrin block: the very same molecule which in a slightly diverse form occurs in chlorophylls and bacteriochlorophylls – biological pigments involved in photosynthesis. A porphyrin consists of four pyrrole rings joined by methenyl groups. The ligand is a dianion whose negative charge can be countered by two protons usually localized on two opposite nitrogens, or by divalent metal (Fe for heme and Mg for chlorophyll) resulting in a neutral molecule. Biologically functional porphyrins include various peripheral substituents and are naturally embedded in a protein matrix (like heme in the hemoglobin) that provides a unique micro-environment for their physical properties and biological function. This structure is a main motive controlling electronic properties of porphyrins, their optical and redox features, reactivities, rates of electron transfer or spin density profiles.



Energy level diagram calculated for the two highest occupied and two lowest unoccupied molecular orbitals (HOMO – 1, HOMO and LUMO, LUMO + 1) for a porphyrin (P), a chlorin (C) and for a bacteriochlorin (BC). These determine the optical spectra of the chromophores (Gouterman et. al. 1963). Note that the energy gap between the HOMO and LUMO decreases in the order P, C and BC and explains the red-shift of the lowest absorption band of the chromophores which is a HOMO to LUMO transition (adapted from Chang et al. 1081)

The ubiquitous roles of porphyrins in bioenergetics have prompted many experimental and theoretical studies that seek to fully understand and mimic their function by synthesis of new materials of dedicated catalytic and photochemical functions. A good example is the interest in using porphyrins in photodynamic therapy where porphyrin photosensitized generation of singlet oxygen is used to attack tumours. On the other hand, the deficient synthesis of heme in humans suffering from porphyria results in overproduction and accumulation of porphyrins whose burden on the organism can be detected e.g. by a strong red fluorescence of teeth (erythrodontia) or unusual sensitivity of skin to light (cutaneous photosensitivity). Exposure to even mild sunlight can disfigure the skin, cause the nose and fingers to fall off, and make the lips and gums so taut that the teeth, although no larger than ordinary, look like they are jutting out in a menacing, animal-like manner.

Couldn't then the porphyria have been responsible for a vampire tale – especially since the disease is hereditary? A person that is affected by porphyria can seem very scary to the average observer seeing the victim's teeth and nails to gain a fluorescent glow. These traits could perhaps explain the fact that many vampire stories described the vampires as giving off a greenish glow. Humans suffering from the disease are likely to be deformed also in other ways, usually in the facial area. In most cases of porphyria, blood or heme transfusions can supply some relief from the symptoms, and this is still the mainstay of treatment. Interestingly, the heme pigment is robust enough to survive digestion, and is absorbed from the intestine. This means that, in principle, the symptoms of porphyria would be relieved by drinking blood – another possible link with the vampire stories. Chemical studies offer also an explanation of why vampires, or porphyria victims, might well have been afraid of garlic, in accord with existing mythology... Garlic (Allium Sativum) is known to contain a chemical (dialkyl disulphide) that can enhance the symptoms of the disease.

The only portrayal of actual porphyria in the arts is in the play and movie "The Madness of King George", about England's King George III, who had just lost the colonies in America when he was beset with "madness". Some historians hypothesize that he suffered from acute intermittent porphyria. In this form of porphyria, the liver is affected rather than the erythrocytes, and although the victim's skin is not typically photosensitive, the condition is characterized by strong neurologic disorders. In King George's time, his bizarre behaviour and wild outbursts were treated as insanity. It was not until late 70s when a new hypothesis has been formulated after two psychiatrists had revisited king's medical records and noticed a key symptom; dark red urine – a classic and unmistakable sign of a rare blood disorder – porphyria.

As speculated by biochemists, not only humans whose blood contains hemoglobin, but also plants that use the green porphyrin, chlorophyll, to absorb light energy can suffer from the conditions similar to porphyria. Plants make chlorophyll via a pathway very similar to that for heme production in animals. Mutations in the gene for the final step in this pathway lead to a buildup of porphyrins in the leaves. On exposure to sunlight the leaves blister and die. Botanical vampire myth is, however, much less enshrined in legends and not so popular in the history of art.

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/to be published in *Foton* 93/

Heuristic proof of the Theorem of Borsuk and Ulam

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Abstract

We give a heuristic proof of the statement that there exist two antipodal points at which the atmospheric pressures and temperatures are equal.

1. Statement of the theorem

Suppose that at each point x on the surface of Earth, the temperature $T(x)$ and the pressure $P(x)$ are measured. They are supposed to be continuous functions of x. Let the mapping of x into its antipode x' be denoted by A, so that $x' = Ax$.

The theorem of Borsuk and Ulam now asserts the following:
There exists a point x_0 with antipode $x_0' = Ax_0$, for which $T(x_0) = T(x_0')$ and $P(x_0) = P(x_0')$.

Before turning to the proof the theorem is reformulated by first defining the difference functions $F_T(x) = T(x) - T(Ax)$ and $F_P(x) = P(x) - P(Ax)$. These functions are antisymmetric under A, *i.e.*, $F_T(Ax) = -F_T(x)$ and $F_P(Ax) = -F_P(x)$. For the theorem to be true it must now be shown that there exists a pair of antipodes (x_0, x_0') for which $F_T(x_0) = 0$ and $F_P(x_0) = 0$.

2. Proof

Consider an arbitrary real and continuous function $F(x)$ defined on the surface of Earth, with the property that $F(Ax) = -F(x)$. The regions where $F(x) > 0$ will be called *islands*; the regions where $F(x) < 0$ are called *lakes* and the lines where $F(x) = 0$ are *shorelines*. There may be lakes on an island and there may be islands in a lake, but the total land area is equal to the total area covered by water. By definition shorelines cannot intersect, although they can touch each other.

It is clear that for every shoreline s there is an antipodal shoreline $s' = As$, which has no intersection with s. In addition there may be one or more singly connected shorelines which are antipodal to itself. Such a line will be called *equator*. This name may be confusing, because it can have a very irregular and even fractal form. It shares, however, one common property with the Equator where

Neptune rules, in that it divides the surface of the earth into two hemispheres of equal area. This property makes it impossible for two equators to exist, since they necessarily would have to intersect each other, which is forbidden for shorelines. The remaining and essential part of the proof consists in showing that there is always one equator.

For that purpose consider an adventurous traveller, who is living at a point x_s, which is situated on an island. He owns an amphibious vehicle, with which he wants to make a trip to his brother, who is living on a yacht, anchored at the antipodal position $x'_s = Ax_s$, in a lake of the same form as his brother's island.

It can happen that the second shore of the lake around the traveller's island completely encircles his place. This means that on the other side there must also be a second antipodal shore line completely surrounding the point x'_s. Therefore, if there were no equator, the traveller could reach his brother only by crossing an even number of shore lines, after which he finds himself on an island again. The brother, however, lives in the middle of a lake. This leads to a contradiction and consequently there must be an equator. This equator has on one side a continent, which encircles the earth, with its antipodal ocean on the other side.

The situation is illustrated by considering as an example the following function for the temperature

$$T(\theta, \varphi) = 0.2\,\theta^2 \cos\theta + \cos(17\,\theta) + 0.3\cos(19\,\varphi) + \sin\varphi + 2\sin(11\,\theta)\cos(7\,\varphi).$$

The height of the difference $F_T(\theta, \varphi) = T(\theta, \varphi) - T(\pi - \theta, \varphi + \pi)$ is plotted in figure 1.

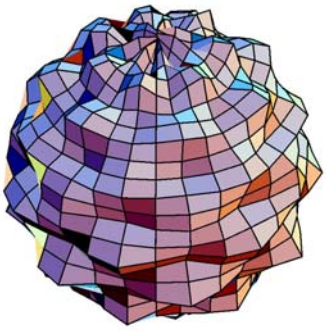

Figure 1. Plot of the temperature difference $T(\theta, \varphi) - T(\pi - \theta, \varphi + \pi)$

The regions where this function is positive and negative are shown in figure 2, which has some similarity with the art of Escher. The third picture gives the shore lines and shows clearly the occurrence of a rather rugged equator, separating a Northern from a Southern hemisphere.

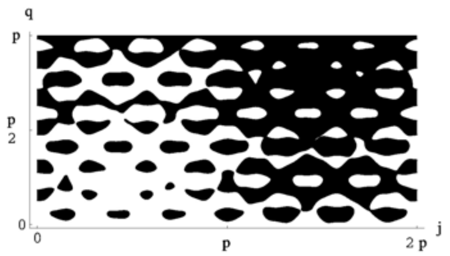

Figure 2. Domains of positive and negative temperature differences

A complication arises when there exist patches *B* together with their antipodal patches *AB*, for which $F(B) = 0$ and $F(AB) = 0$. These will be called *beaches*. It is believed that the occurrence of such beaches will not invalidate the proof of the existence of a single equator.

The proof of the Borsuk–Ulam theorem is concluded by considering the two equators belonging to the functions $F_T(x)$ and $F_P(x)$. These equators must intersect in a pair of antipodal points $(x_0,\ x'_0)$, because each of them is singly connected and divides the surface of the sphere into two equal parts. These are then the points where the temperatures and pressures are equal.

It would be interesting if meteorologists could demonstrate the existence of an "equatorial" band, for which the atmospheric pressure in each point of the band turned out to be larger than in its antipodal point. Although this band may have a very strange form and vary from one moment to the other, its existence is guaranteed by the theorem of Borsuk and Ulam.

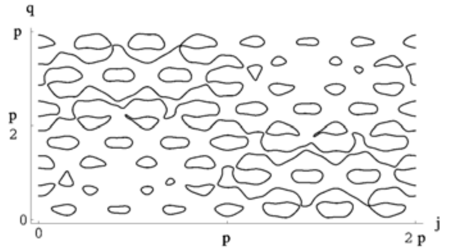

Figure 3. Shore lines and equator

The extensive literature on the Borsuk–Ulam theorem can be traced from the book by Matoušek [1]. However, in spite of this abundance, the author has not yet been able to show that the present proof is a disguised, but equivalent form of any of the many existing proofs.

[1] J. Matoušek, *Using the Borsuk–Ulam Theorem*, Springer, Berlin, 2003.

Dendrites in Nature and in Computer

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1. Introduction

The World is full of “webby”, multibranch objects with tree-like structure, named dendrites, from the Greek word *dendron*: tree. Typical examples are everywhere: connexions of a neural cell, lightnings in the atmosphere, etc. We shall see many more examples. The figures below show the pattern formed by the growth of bacteriae on a planar support, the figure of Hele-Shaw generated by the injection of gaz (or a liquid) into a layer of viscous liquid, and finally, the Lichtenberg figure – an electric discharge inside a dielectric.

Fig. 1. Fear...

Fig. 2. Some examples of natural dendrites

(Currently we have better apparatus than Georg Christoph Lichtenberg (1742–1799). For example, a piece of organic glass is pumped by a beam of electrons from an accelerator, until its explosive discharge. Scientists continue to investigate the properties of those complex sparks, since they provide a plethora of information on the isolation properties of various materials, which is very important in engineering. However, the figures are so nice, that the production of Lichtenberg figures in different frames and shapes became a profitable souvenir business...)

The central picture on the previous page may represent also a section of a piece of coral, or a deposit of metal condensation out of vapour. Many crystals grow showing such patterns, and several young chemists played at home with a little chemical "garden": an aquarium is filled with an aqueous solution of water glass (sodium silicate). Then, we put in some small crystals of metallic sulphates or nitrates: copper, iron, manganese, cobalt, etc., of various colours.

The salts dissolve, and they react with the water glass, producing semipermeable, insoluble membranes of metal silicates. The osmosis makes the water diffuse into the layer between the crystal and the membrane, and this layer expands, until it bursts. Then some salt solution is liberated, and seals immediately the hole, forming new membrane. Since the membrane breaks usually in places where it is fresh and thin, the process produces "fingers" or "tongues", similar to corals.

Of course, it would be preposterous to try to find common *physical mechanisms* responsible for the structure of our blood vessel system, the structure of a neuron, and the affluent system of a big river, but several really distant physical or biological phenomena share some common mathematics. Usually this mathematics is complicated, and some common features need computer simulation in order to have some insight.

2. Dendrites and diffusion; a computer experiment

The following experiment which demonstrates a dendritic aggregation is implemented as a very simple program which can be coded by high-school pupils. A *finite space* represented as a zero-one (2- or 3-dimensional) array, is filled with zeros, only near the center we put one 1 – an immobile "nucleus", a small grain in a vessel filled with liquid. At some small distance of the nucleus we put another grain, not "physically", but we just memorize its position. This second grain may displace itself, and it does so randomly, as in the figure below, at the left. This simulates the Brownian motion, and is implemented as a "drunk's walk": the moving particle makes one step, collides with something, forgets everything, and continues its walk in a random direction...

When this particle eventually touches the nucleus, its position becomes adjacent to that of the immobile grain. Then, it stops and becomes an element of the growing aggregate, the value of the array element becomes 1. The following particles, which start outside the region of the aggregate, undergo the same treatment. Let us repeat this drunk's walk some thousands times. What will be the shape of the growing compound?

The reader who has never seen the solution shown below, could suspect that the nucleus grows as an irregular, but compact blob. But no, we clearly see the appearance of filamentary structures, of dendrites.

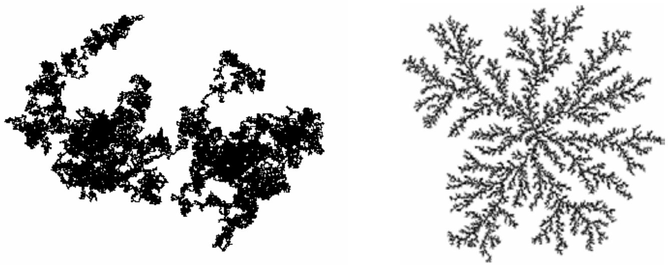


Fig. 3. A sample of a random “diffusion” path, and the result of the aggregation of diffusing particles

Why does this happen? It is *much* easier for the moving grain to collide with the external “corona” of the existing structure, than to pass through narrow channels near the center of the cluster. One can estimate that about 75% of the cluster, forming its central part, does not evolve any more, while the dendrite growth is mainly peripheral. The evolution is quite unstable. If a new particle makes a little “bump” on an existing branch, it will increase the probability that new particles stop at this bump, so it will grow faster than its neighbourhood.

In principle that is all. We can make the array more complicated, so that different zones within the “web” indicate the age of the local particles, and this may be coded as colour. We can choose different initial positions of particles, or restrict its movements to the vicinity of the nucleus; instead of waiting until it comes back, we destroy it, and start with a nearer one.

This will accelerate our simulation. Another way of making it faster is to generate steps bigger than 1 pixel, e.g., the smallest distance between the grain and the cluster, and random direction, with the angle within $[0, 2\pi)$. This is a classical “computer cheating”, but algorithmically correct. We lose only the relation between the real time, and the simulated one, since the speed of diffusion has no physical meaning anymore. Plenty of other optimisations are possible, some of them are based on the analysis of some extended neighbourhood of the grain, while in Nature particles are blind, they “feel” the collision only when it takes place.

3. But why this similarity of forms?

Why this experiment is interesting? Well, since the dendrites are everywhere, we can put forward a hypothesis that the *abstract* mechanisms of their generation are – at least partly – universal. If our simulation works well we may be able to understand better their character. We **know** that the topology of several geometric objects are often invariant and universal.

In particular, we can see why the “chemical garden” dendrites have some formal affinities with our clustering process. The diffusion aggregate grows by glueing new particles from outside, while the chemical dendrite from inside, but in both cases the appearance of ***new elements***, new “fingers” increases the chance that the growth will continue at their position. The rich becomes richer, there is no “social justice” in this phenomenon...

On the other hand, the sparks (lightnings, Lichtenberg figures, etc.) are regions of ionized, conducting gas, extending from electrodes. We know that the electric potential of an electrode is constant, but the field intensity depends very strongly on the surface curvature, it is stronger near edges and corners. There, it becomes easier to ionize new volumes of gas, and to extend the region occupied by the spark.

We might say a few words about the theory. Several fields (such as the electric field, or the field of velocities of an uncompressible liquid) fulfil the Laplace differential equation. In two dimensions its form is $(\partial^2/\partial x^2 + \partial^2/\partial y^2)V = 0.$ We could prove that if for a given point (x, y) in the space outside the cluster we sum the values of the electric field at the points on the space boundary, from which we get to the given point by following *random paths*, the result will give us a numerical, approximate solution of the Laplace equation! Such a random way of solving this equation is effectively used in many problems in physics and engineering. Random numbers and functions are often useful for solving completely deterministic problems.

A similar mechanism may be applied to the Hele-Shaw figures. We have to analyze the dependence of the liquid surface tension which tries to confine the introduced droplet of liquid, on the local curvature of its surface. Again this is unstable. The analysis of the growth of bacteriae may be left as an exercice. It is sufficient to take into account the fact that the bacteriae must get some food, and if they are too numerous, they poison the environment, making the reproduction more difficult. Corals (or ordinary trees) which also grow in a dendritic way, are too complicated to discuss here, although, as for the bacteriae, the fact that the food (or light) is outside, also plays its role.

It might be useful to look at a counter-example. A forest fire behaves differently. Despite the fact that there is more oxygen outside, and it comes from outside rather than from above (convection), the form of the burning region is blobby rather than dendritic, since the air is in constant motion, and a heated-up tree, well inside the burning zone catches fire much easier.

4. Fractal dimension of dendrites

The mechanism of DLA (*DiffusionLimited Aggregation*), described and simulated already long ago, has been analyzed in details quite recently, in 1981, by T.A.

Witten, and L.M. Sander. We cannot discuss here many interesting details, but we can say a few words on the *topological dimension* of the generated cluster. Our simulation is powerful enough to measure it. But what is this dimension? We know that we live in a 3-dimensional space. A "normal" material object of a given density possesses a mass, which – by the definition of density – is proportional to its volume, and thus to l^3, where l is some characteristic linear parameter of the object, e.g. the radius of a sphere, if the object is more or less spherical.

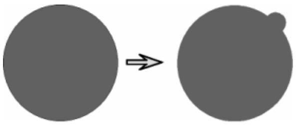
In 2 dimensions the surface replaces the volume. A compact blob will have the dimension 2. A thin thread (line, path) which would be created if its constituent particles positioned themselves one behind the other, without drastic changing of direction, nor self-intersections, would have the dimension 1. The characteristic attribute would be the *length* of the object as a function of the number of particles.

While simulating DLA, we might measure the dependence of the radius – maximal or average – of the aggregate, on the number of particles forming it. It turns out empirically that in the limit of large number of particles, the dependence is $N = \mathrm{const} \cdot \mathrm{r}^{1.7}$. Such a non-integer dimension is called *fractal*. We observe a very curious phenomenon, this non-integer exponent is relatively invariant, it has the same value for many distinct physical systems. The DLA process in 3 dimensions, which is as easy to simulate as the 2D version, but much, much slower, gives us the fractal dimension approximately equal to 2.5.

Of course, scientists use much more elaborate models. For example a moving particle may, with a certain probability, refuse to attach itself to the cluster, and continue to move. This gives dendrites more compact and "furry", like a flake of soot. The dependence of the fractal exponent and the viscosity of the particles gives us interesting information on the structure of such matter.

5. Model of Hastings and Levitov

We shall discuss now a not well known (and rarely taught) model of dendritic development, based on the theory of analytic functions. This is a complex and involved model, and the reader is not expected to follow all the details. But the foundations are straightforward to explain. In 1998 M.B. Hastings and L.S. Levitov noticed that the solution of the 2D Laplace equation use the theory of functions on the complex plane, and the s.c. conformal transformation. By itself, this was known for many years.

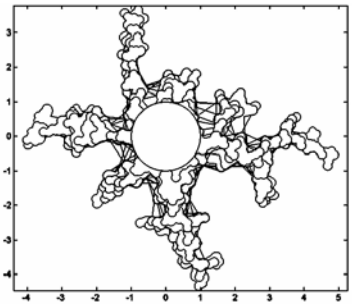


They reasoned: let's analyze the transformation $f_{r,\phi}(z)$ of a unit disk on a complex plane z, i.e., the region which fulfils the constraint $|z| \leq 1$, into a disk with an extruded "finger", as shown in this figure.

The parameters (r,ϕ) specify the position and the orientation of the extrusion. The angle ϕ will be randomly drawn from the interval (0 – 2π), and r depends on the stage of the generation process. The function f will permit the construction of **much** more complicated transformation which makes a dendrite out of a unit disk. If we knew this incredibly complicated function $D(z)$ which specifies the dendrite containing, say, N particles (local extrusions), then $D(f(z))$ will describe the dendrite with one more element. So, we take a computer, we begin with $D_0(z)$ which defines the disk of radius R, and we iterate. The function f is not *very* complicated, but it is not too pleasant either, for example $f_{r,\phi}(z) = e^{i\phi} f_r(z) e^{-i\phi}$, where

$$f_r(z) = \sqrt{z}\left\{(1+r)\frac{1+z}{2z}\left[1+z+z\sqrt{1+\frac{1}{z^2}-\frac{2}{z}\frac{1-r}{1+r}}\right]-1\right\}^{1/2}$$

(Additionally, during the iterations we must rescale r, in order to preserve correct proportions.) We can easily show that already the second or the third iteration create functions so complicated that almost impossible to write down analytically. However, we can do it numerically, storing in the memory of the computer an array which represents the function contour. Each iteration produces a new geometric layer. A few initial stages are shown below. Here r does not decrease too fast, so we obtain a finger-like structure, not filaments.



We shall not discuss the programme which creates this figure, it is not very simple. Our aim was to demonstrate that the theory of complex functions, sometimes presented to students in an abstract way, finds some unexpected applications in physics. We show also that computers enable us to manipulate *functions* which are so complicated, that impossible to put down on paper, since they are the outcome of several thousands of iterations.

Our text contains also some philosophical ideas, since it argues for the *unity of Nature*. In many, apparently very distinct contexts we see phenomena of unstable geometrical evolution. We introduce the Laplace equation (often being the conclusion of some conservation laws and the continuity), we operate upon a system with a short memory (Markov systems), and we build some mathematical models for those systems. Often, if we succeed, we realize that those models are similar. So, the behaviour of all those systems is similar, despite dramatic structural differences between them.

Sometimes a tree-like development is not relevant to a single object, but it is distributed among several generations, and many, many years. From a goal-oriented perspective sometimes used to analyze evolution, a neuron "wants" to communicate with as many neighbours as possible. The blood vessels "want" to irrigate the biggest possible volume of a body in an economical way. So, the instabilities do not concern individuals, but genetics: speciments which possessed those more branched apparata, were more clever or more robust, so that they could transmit their genes more efficiently.

The generation of dendrites is a simple, but characteristic, archetypical example of *morphogenesis* which is the source of the richness of forms in the Universe.

/from *Foton* 84/

King Midas' funeral feast

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Pomeranian Pedagogical Academy in Słupsk

Can we know what was in the menu at a feast 3000 years ago? Yes, we can!
In 1999 archaeologists discovered in Minor Asia, in land of ancient Frigia, a tomb full of precious objects of all kinds: pearls, noble stones, expensive materials and subtle bronze dishes. The richness of the funeral indicated the high rank of the dead man, and the place and age of the tomb pointed at a similarity with ancient Greek cultures. Almost, almost King Midas' tomb.

At the bottom of the bronze cups (called *situla*), formed in the shape of a sheep's head, there were some remains, almost invisible to the naked eye. The remains from the funeral feast? However, there was too little (and slightly out of date!) to taste it. But the appetite increased!

Luckily there is modern Science. It will tell you (and the police) not only how much you have drunk but also what kind of alcohol! Different techniques used to find out what was eaten during King Midas' funeral feast are commonly called **spectroscopy** (from the Greek word *spectrum* meaning a ghost).
It was a rich feast, that of Midas at his funeral: inside over 100 cups and plates the scientists found 16 different kinds of alcohol: among them, good quality wine, barley beer and fermented bee's honey. On the dishes there were found the remains of at least 14 kinds of meat, mainly sheep and goat. First, the meat was grilled, then detached from the bones, and next mixed with Mediterranean herbs and spieces. Wines and beer were mixed in different proportions and served in elegant cups. The remains were loaded for King's Midas road through Styx river.

Well, well, such a funeral feast is enough to take a place in **mythology** forever!

P.E. McGovern, D.L Glusker, R.A. Moreau, A. Nunez, C.W. Beck, E. Simpson, E.D. Butrym, L.J. Exner, E.C. Stoutt, *A funerary feast fit for King Midas*, "Nature", 23–29/12/1999, p. 863.

/from *Foton* 92/

Spectroscopy is the study of **spectra** i.e., the dependence of physical quantities on **frequency**.

Spectroscopy is often used in physical and analytical chemistry for the identification of substances, through the spectrum of emitted or absorbed radiation. A device for recording a spectrum is a **spectrometer**.
Spectroscopic methods used in the analysis of the remains of the funeral feast of king Midas:

1. **Infrared (IR) absorption analysis** – enables the identification of certain functional chemical groups in chemical compounds – the vibrational frequencies of paricular groups of atoms depend on their mass and chemical bond type, just like the frequencies of a mechanical oscilator depend on the spring constant of the spring.

2. **Mass spectroscopy** – enables measuremenst of charge-to-mass ratio of chemical compounds or their fragments (after their ionization); to avoid fragmentation of complicated organic compounds ionization with proton exchange or electrospray ionization is used.

3. **Chromatography** – division of different liquid (or gas) fractions in a column due to different diffusion constants of the molecules.

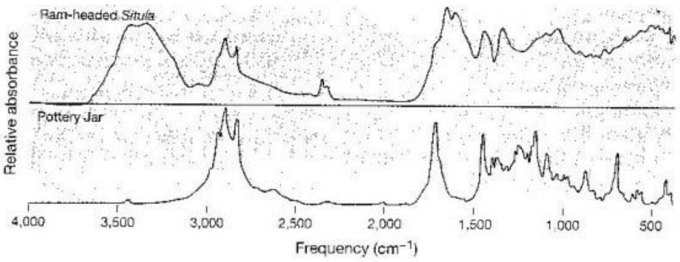

Fig. 1. Infrared spectrum of the content of a *situla* (cup in the shape of a sheep's head) and food remains from the ceramic bowl

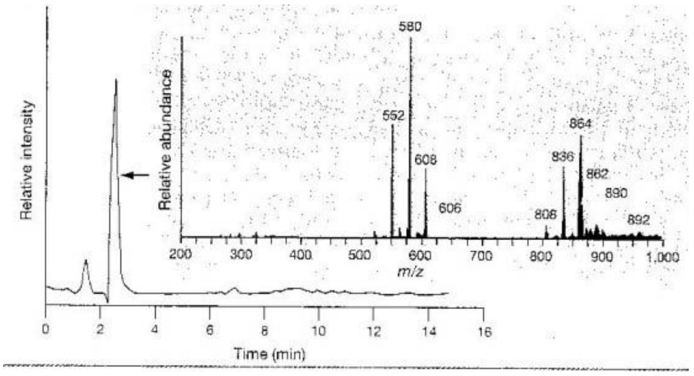

Fig. 2. Chromatogram of the food remains. In the inner pannel – the mass spectrum of the remains

The theory of Brownian Motion: A Hundred Years' Anniversary

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Marian Smoluchowski (1872–1917)

The year 1905 was truly a miracle year, *annus mirabilis*, in theoretical physics. Albert Einstein published four important papers that year: Two papers laying foundations for the Special Theory of Relativity, one explaining the photoelectric effect that would win Einstein the 1921 Nobel Prize in physics, and one explaining the mechanism of Brownian motion[1]. An independent explanation of this last phenomenon was published the following year by a Polish physicist Marian Smoluchowski[2]. An explanation of the origin and properties of Brownian motion was a solution to a nearly 80 years old puzzle, a remarkable feat, but nobody expected it to be a major breakthrough that would reshape the whole physics. This was, however, the case and we will try to explain why.

Robert Brown (1773–1858)

Brownian motion takes its name after a Scottish botanist, Robert Brown. Brown was a highly respected man in his time, not, however, for the discovery that he is now famous for, but for his classification of the plants of the New World. It was during this research that Brown noticed in 1827 that pollen in water suspension which he examined in his microscope displayed a very rapid, highly irregular, zigzag motion. Such motions had been observed even prior to Brown, but only in organic molecules, and their origin was delegated to some mysterious "vital force" characteristic of living matter. Brown was not satisfied with this explanation, which could possibly fit the living pollen. Instead, he noticed that an identical motion was displayed not only by living pollen, but also by dead pollen and by fine inorganic particles.

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[1] A. Einstein, *Über die von der molekularkinetischen Theorie der Wärme geforderte Bewegung von in ruhenden Flüssigkeiten suspendierten Teilchen*, Ann. Phys. 17, 549–560 (1905).

[2] M. von Smoluchowski, *Zur kinetischen Theorie der Brownschen Molekularbewegung und der Suspensionen*, Ann. Phys. 21, 756–780 (1906).

Incidentally, Brown used pulverized fragments of an Egyptian sphinx in his experiments, which did not influence the results, but nicely demonstrates the intellectual climate of the time. In conclusion, this motion must have had a physical origin. But which? Brown, limited by his laboratory equipment, was only able to show that this motion was not caused by currents (flows) in the liquid, nor by convection, nor by the evaporation of the solvent.

Albert Einstein
(1879–1955)

The origin of the motion discovered by Robert Brown remained a mystery, one of the many scientific facts that did not have an explanation, but nobody doubted that sooner or later such an explanation would be provided. The problem of Brownian motion did not seem to be particularly important, but nevertheless, many people tried to solve it. First, the observations made by Brown himself, that neither flows in the liquid, nor convection or evaporation caused the motion, were confirmed. Next, chemical composition, the shape of the container, and several forms of external influence were eliminated as possible causes. After Maxwell and Boltzmann formulated the so-called kinetic theory, people tried to describe the Brownian motion in terms of that theory, in particular by determining the velocity of Brownian particles. All those attempts failed.

Even though they are now only of historical interest, it was important in the time of Einstein and Smoluchowski that scientists had tried all those approaches with little success because the failure of conventional explanations prepared the ground for the revolutionary one proposed by these two men. We should remember that the remaining Einstein’s achievements from his miracle year, the Special Theory of Relativity and the concept of a photon, were for many years heavily opposed by some leading physicists.

So what was the explanation proposed by Einstein and Smoluchowski? They realised that movements of Brownian particles were caused by collisions with molecules of the solvent. These molecules move erratically in display of their thermal energy, of which the temperature is a certain measure. Molecules of the solvent are too little to be observed directly, but particles of the suspension, even though they are tiny from a human point of view, are true giants in comparison with the molecules of the solvent, and can be observed directly. Today this explanation may seem to be trivial, but it was far from being trivial a hundred years ago. It is perhaps difficult to believe, but a hundred years ago the atomistic hypothesis, or the hypothesis that matter is grainy and cannot be continuously divided infinitely, was not commonly accepted. On the contrary, some researchers treated it merely as an unsupported working hypothesis, and others, including such eminent figures as Wilhelm Ostwald, the 1909 Nobel Prize in chemistry winner, and Ernst Mach, opposed it vigorously[3]. Albert Einstein and Marian Smoluchowski claimed that motion of the particles of the suspension provided a proof of existence of the molecules of the solvent, and what is more, that by examining the Brownian particles, one could get much insight into the properties of the molecules of the solvent. Einstein and Smoluchowski provided also a quantitative tool for assessing the Brownian motion: They discovered that the observed mean displacement of a particle (squared) was proportional to the duration of the observation, and that the proportionality constant was related to the so-called diffusion coefficient. These results rendered feasible many specific measurements; in particular it was now possible to experimentally determine the value of the so-called Avogadro constant. A French physicist Jean-Baptiste Perrin conducted such experiments a couple of years after the papers of Einstein and Smoluchowski were published, which won him the 1926 Nobel Prize.

It is worth noting that explaining the Brownian motion was not Einstein's intended goal. He did not know the experimental data on Brownian motion very well. Einstein aimed at establishing a connection between the diffusion coefficient and the temperature, in which he succeeded, but being a genius, he guessed what the thermal motion should look like. Smoluchowski, on the contrary, knew the experimental data on Brownian motion very well and intended to explain them. It is now clear from the surviving correspondence between Marian Smoluchowski and Albert Einstein that Smoluchowski obtained his results prior to Einstein but decided to publish them only after he was impressed by the work of Einstein.

The papers by Einstein and Smoluchowski discussed here have also answered several other questions. First, they provided a microscopical explanation of diffusion (molecules of the substance that diffuses are "pushed through" by the collisions with the molecules of the solvent), second, they provided a derivation of a differential equation known today as the diffusion equation[4], and third, they explained why the previous attempts to describe the Brownian motion in terms of velocities had failed. Smoluchowski noticed that displacements of Brownian particles seen in a microscope resulted from a huge number of collisions with the molecules of the solvent: the displacements were *averaged* over many such collisions. It is now apparent that the mean time between two consecutive collisions is much shorter than the smallest time interval that we can measure even now, at the beginning of the 21st century. If this is the case, then neither in the time of Brown, nor in the time of Einstein and Smoluchowski, not even today, can we observe two

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[3] It is not surprising that Einstein, who esteemed Mach very much, immediately sent him a copy of his publication.

[4] This equation, resulting from heuristic laws originally formulated by a German physiologist A. Fick, was already known at that time, but its derivation from first principles was lacking.

consecutive collisions. Any two observed zigzags of the trajectory are separated by a multitude of other zigzags that we have failed to observe. If this is so, we can assume that a collision takes place in every instant of time, and consequently, that a Brownian trajectory has a zigzag at every point, and that it is completely random. The velocity of a particle is undetermined at the moment of a sharp turn. We can of course measure the average velocity but this last quantity is of little importance from a fundamental point of view.

This point demands special attention. The Newtonian dynamics, commonly used in times of Smoluchowski and used today with great success in the analysis of *many* phenomena, says that a trajectory of every particle, of every "material point", can be described by a certain differential equation. To write down this equation, it is necessary and sufficient to know all forces acting on the particle. This is the essence of the Second Principle of dynamics. The forces may vary in space and time, but if their changes are continuous, the resulting trajectory is smooth, perhaps very complicated, but smooth in a mathematical sense. This was the canon of physics, and to attack this canon would nearly amount to a sacrilege. Smoluchowski claimed that a trajectory of a Brownian particle was not smooth, that it had many zigzags, indeed that it had a zigzag in every single point. This was a real revolution, a deviation from a well-established paradigm, but the point was that this approach led to results that agreed with the experiment while all the others did not. The diffusion equation mentioned above does not describe a trajectory of a single particle, but a mean, collective behaviour of a multitude of particles, like for example a drop of ink put into a water tank, or a lump of sugar used to sweeten the tea[5]. Even though the trajectory of a single particle, consisting entirely of zigzags, can be really awkward, the collective behaviour of many such particles can be quite decent if we only agree not to be bothered by *really* tiny details. This is the essence of a probabilistic approach.

As we can see, displacements of Brownian particles can be modelled by a random process. The works of Einstein and Smoluchowski have become one of the cornerstones of Probability Calculus and the theory of Stochastic Processes, which are now one of most prominent branches of mathematics. Stochastic modelling has become a key method in many areas of science and technology, ranging from physics, through engineering design, to biology, ecology and social sciences. Even this would not be possible without the works of Einstein and Smoluchowski.

Einstein and Smoluchowski have discovered that viscosity and other forms of dissipation are, on a molecular level, caused by thermal motion of particles; this law is now known as the Fluctuation-Dissipation Theorem. Some time later Marian Smoluchowski has shown that variables used to describe any sufficiently

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[5] Tea and sugar is a standard example, which is the sole reason for my using it, as I personally prefer the unsweetened tea.

large (or macroscopic), but finite, system in a thermal equilibrium must vary in time in a manner that we now call Gaussian White Noise; this is the very same noise that causes the Brownian motion. In other words, Brownian motions are necessarily displayed by any macroscopic physical system in equilibrium.

Since Brownian motions, or rather thermodynamical fluctuations that cause them, are common, we need to learn how to live with them. Thermal noise is usually detrimental: it is this noise that causes disturbances in communication lines, the measurement errors, the power loss in transfer lines and so on. However, it turns out that without the noise, the whole world as we know it would collapse. The noise can act constructively: it can sustain signals that would otherwise dissipate, it can amplify, not weaken, signals (this is known as the stochastic resonance), and finally, the noise is an indispensable component in many crucial biochemical reactions without which the biological life in its current form could not possibly exist. The thermal noise must be taken into account when designing nanorobots and molecular motors that have long been dreamt of by science fiction writers and are now becoming the subject of serious research. Nanorobots are, for example, supposed to travel through human body in blood and repair various microdefects. One needs to remember, though, that particles in the environment intended for nanorobots are in a ceaseless thermal motion. If a nanorobot were scaled up to the human size, the fluctuations would have to be similarly scaled up. Simple calculations show that thermal fluctuations would then reach the strength of a hurricane. Designing nanorobots and molecular motors is thus as difficult as designing machinery that would work seamlessly during Katrina[6], or better still, that could use Katrina's force to their own benefit! But nature manages to do so: It has designed natural molecular motors, for example the kinesins, or proteins that move on intramolecular membranes. This example shows that science is, in fact, one and indivisible: Understanding many biochemical mechanisms would not be possible without this branch of theoretical physics that has been started with the works of Einstein and Smoluchowski a hundred years ago.

A group of physicists based in Jagellonian University in Krakow is active in research on this particular branch of physics and its applications not only in other branches of physics, but also in molecular biology, ecology, financial mathematics and social sciences.

Marian Smoluchowski is considered to be the most prominent Polish physicist. His papers are still quoted and an important equation used in physics is named after him. Jagellonian University Institute of Physics is named after him as well, and the most important prize awarded by the Polish Physical Society is called the Smoluchowski Medal. As we have said, Jean-Baptiste Perrin, who

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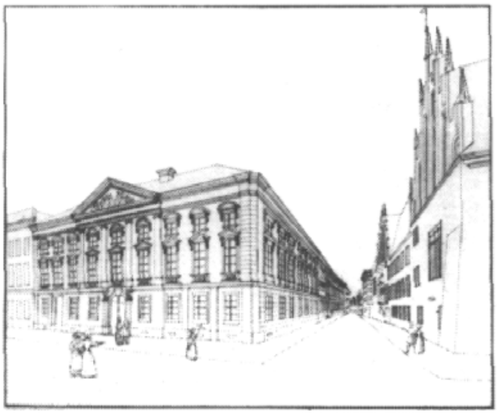
[6] Katrina was the name given to a Category 5 hurricane that drowned New Orleans in August 2005.

based his measurement of the Avogadro number on the theory developed by Einstein and Smoluchowski, received his Nobel Prize in 1926. Albert Einstein received the Nobel Prize in 1921. Even the arch-opponent of the atomistic hypothesis, Wilhelm Ostwald, received the Nobel Prize. We can only wish that Marian Smoluchowski belonged to the elite club of the Nobel Prize laureates. Alas, Marian Smoluchowski, professor of the University of Lvov and of Jagellonian University in Cracow, died of dysentery in 1917 aged only 45, when the Great War ragged the world and before the importance of his scientific achievements was fully recognized.



Kołłątaj Collegium, the old Physics Dept.

/from *Foton* 91/

Albert Einstein – an icon of the 20th century – some myths

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Albert Einstein is one of the icons of the 20th century. He is also considered one of "twelve men who were inflaming women with desire, because they sacrificed love for a higher cause, and men with jealousy, because of their passion, fame, wealth and skills of seducing" (description from a popular journal). Among those twelve there was only one scientist. Indeed, in terms of popularity Einstein matched the greatest stars of cinema and sport. He became one of the symbols of the 20th century. His face is recognized even by children in remote corners of the world.

The 20th century abounded with prominent physicists who changed the face of physics. Einstein occupies an extraordinary position among those greats.

Having established the general theory of relativity, he became one of the three greatest physicists in history. Newton, Maxwell and Einstein form this great trio.

Einstein's status as an icon of the 20th century is well justified, but the public has not really appreciated the significance of his discoveries. Einstein became a legend during his lifetime, but a number of incorrect ideas about him have contributed to the rise of his legend.

It is not true that Einstein was engaged in physics "for only twenty years", and that "the rest of his life he devoted to music, family, and social activities in aid of peace." **The entire sense of Einstein's life was physics**.

And, even though it is true that (what has been awkwardly named) "The Special Theory of Relativity" (1905) was about to be discovered by other scientists (H. Poincaré and others were close to a similar discovery), it was Einstein who clearly formulated the theory, thanks to his extraordinary intuition. Yet, it was not for this theory that he was awarded the Nobel Prize. He received it for his explanation of the photoelectric effect.

Einstein's greatest achievement, the one that elevated him to the top rank among physicists, is general relativity, which is the theory of gravitation in relation to the geometry of physical space and time. At the time of its discovery, this theory could not be anticipated from any experiment or physical phenomenon. Formulating such a theory required great intellectual courage and effort. Having developed it, he was so confident that he pretended to be disinterested in the results of the only measurements that were possible at the time to prove the theory (Eddington's observations of the deflection of starlight during a solar eclipse.)

Nowadays, although not many people are aware of it, Einstein's theory is used in global positioning systems. The precision of GPS is contingent upon calculations which have to include the effects of general relativity.

After the discovery of this theory Einstein started to work on another problem, one which has not yet been solved: the unification of gravitational interactions with other interactions. In order to understand the meaning of the unification of interactions, it is worth recalling a few facts from the history of physics. By formulating the famous law of gravity, Newton unified phenomena that take place on the earth (falling objects) and ones in space (the movement of planets). Maxwell is included into the great trio because he ultimately unified electric interactions with magnetic interactions**.** Today we understand that the force which attracts dust particles and creates thunderbolts originates from the same interaction that determines the position of a magnetic needle. This "electromagnetic interaction" also enables us to generate and receive radio waves, and we now know that light is also an electromagnetic wave. Einstein recognized the need for the unification of the fundamental interactions and spent the rest of his life on this problem. He failed to solve it. Important experiments were conducted in later years, after the nature of all interactions had been better understood, but the road towards a successful solution of the unification problem is still ahead of us even though success has been achieved in unifying the electromagnetic interaction and the so-called weak nuclear interaction. Numerous groups of prominent physicists have been working on this problem for many years. Einstein worked alone.

Pondering the physical problems, that one in particular, and physics in general (Einstein was also a philosopher) filled Einstein's life. He joined the peace movement not because of his keen interest in social activities, but because of a sense of obligation. He was well aware of his popularity and the authority he enjoyed. He used his image for the purpose of propagating pacifism. After World War I, he was severely criticized for his pacifistic ideas. He was one among innumerable intellectuals in Europe who had been seduced neither by nationalistic ideals nor by communism. He was a super-intelligent individualist, with his feet firmly on the ground.

Einstein, like every famous person, was extremely popular among women. Quite possibly, he occasionally might have taken advantage of this. Nonetheless, he reserved his emotions only for physics.

He was neither a perfect husband nor a perfect father. The primary thing he expected from family life was absolute quietness. His first marriage, to his university friend Mileva Marič, did not stand the trial of time. Many unfavorable circumstances contributed to its failure: a premarital child (a girl) who had been given up for adoption, a poor financial situation and a family life that had been interfering with his intensive thinking about physics. Two children (boys) and a neurotic wife in a poor household certainly must have distracted the genius from his work. Perhaps he was happy to escape to the comfortable and *petit bourgeois* house of his remote cousin Elsa.

It seems that the long-lasting relationship with Elsa could only have worked because she created for him a comfortable asylum that kept him away from mundane matters. It is hard to say what kind of happiness Einstein found in this relationship. Most likely he did not search for it; Elsa said nothing about it. Was she happy? She was not very young when she married Einstein. She had the opportunity to understand him well and she accepted her role. Einstein donated his Nobel Prize to Mileva, his first wife, not to get rid of the problem and preserve his good image (he was already a public person); he was truly concerned about her and their sons (one of them had already been showing serious symptoms of a mental illness).

While he had been able to enjoy intellectual conversation with Mileva (though it is not true that she allegedly contributed to the discovery of the special theory of relativity), in this respect Elsa was not a match for him. Among other women who were absolutely devoted to him was Helen Dukas, his perennial secretary and later a warden of his heritage. Einstein was also close to his sister Maia and stepdaughter Margot. However, it seems he never considered women as equal partners. Undoubtedly he felt respect for Maria Skłodowska-Curie and there was a sort of friendship between them.

Einstein did not exchange many letters with women. He put correspondence from his numerous fans, often well-known women, into a special box for letters from cranks. Hence, his exchange of letters with the wife of a great physicist, Max Born, were exceptional; the two of them discussed various ethical problems.

Until the end of his life Einstein was an active physicist and philosopher. Like many other famous physicists of the time, he enjoyed relaxing with music. And in the way he performed physics he was like a great artist.

The story that Einstein was allegedly a poor student and that he had problems in school is unproven. He showed his talents very early. As a high school student, he demonstrated great independence of thought and opinion. At that time he clearly showed his aptitude for mathematics and his passion for science. He already had a deep interest in philosophy and literature. He was, however, poor at foreign languages. He did not believe in wasting time on things he didn't like.

Unlike young Smoluchowski in Vienna, who had been lucky to be introduced into physics by Hoefler, Einstein did not find such a tutor and mentor in the Leopold's High School in Munich. Yet his teacher in Munich recognized his great talent and let him organize his course of study individually. This was quite unusual for a German school known for its strictness, but how can we blame a teacher who could not match his genius student?

Einstein did not like Munich and eventually he moved to Switzerland to a modern school in Aarau, where he could catch up on his education. Without protest he subjected himself to the school discipline. He managed to do this relatively easily, as he established peer friendships, which are so important for maturing men.

As physicists, we are glad it turned out that capricious public opinion made Einstein an idol of the 20th century. And even though we have to tolerate the fact that his image diverges from reality, we can strive to learn the truth about the person he was.

Mileva and Albert Einstein (1903) [*Physics Today*, Sep. 1994, p. 38]

/from *Foton* 88/

Questions asked by high school students to Professor Koshiba, the Nobel laureate 2002

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Three years ago a few hundred high school students were asked to formulate questions to the Nobel laureates of 1999. From among those questions some were chosen and presented via the Internet to Professor Koshiba, the Nobel laureate of 2002. Professor Koshiba was kind to answer. The interview was not very interactive. Some questions, from which we could learn how Professor Koshiba became interested in physics, remain not answered.

Could you share with us, how do you come up with an idea for which one gets the Nobel Prize?

– Don't know how to answer.

How long have you been working on the problem for which you were awarded the Nobel Prize?

– 20 years.

What do you like the most in the profession of a physicist?

– To find something new.

Do you prefer to work alone or in a group?

– In small groups.

Did you enjoy your school?

– Yes, and no.

Did you like physics and mathematics at school?

– Not particularly

Did you have a private tutor, like many Japanese schoolchildren have today?

– No

When you were young, did you like to talk with your parents or anyone from your family about physics?

– No

What were your hobbies and your favorite subjects at school?

– Nothing particular

What is you hobby at the present time?

– Listen to Mozart

Did your children enjoy physics as well?

– No

Do they work in physics?

– No, but son is engineer

This is a very personal question: How did you meet your wife?

– Meeting was arranged by our common senior friends.

Do you ever talk with your wife or children about your work and progress in the research

– No

Do you enjoy reading literature?

– Sometimes

What kind of sport did you practiced?

– None

Young Masatoshi
in kendo dress

Family picture.
Masatoshi Koshiba first from right

Foton thanks Professor Koshiba for the pictures from his collection.

/from *Foton* 82/

Questions asked by high school students to Prof. Roy Glauber, the Nobel laureate 2005

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Could you share with us, how do you come up with an idea for which one gets the Nobel Prize?

– *Think hard about a lot of things you don't understand.*

How long have you been working on the problem for which you were awarded the Nobel Prize?

– *The essential work was done over a couple of years, but its consequences have kept me busy for the last 35 years.*

What do you like the most in the profession of a physicist?

– *Developing new understandings.*

Do you prefer to work alone or in a group?

– *Theorists mostly work alone, but they have to remain in close contact with others.*

Did you enjoy school?

– *The more creative parts, yet. But school had its dull times too.*

Did you like physics and mathematics at school?

– *Yes, they gave me a constructive feeling – and new insights.*

Did you do many extra things outside the requirements of the school curricula?

– *Yes, all sorts of reading and experimentation.*

Do you remember a book or an article that had an impact on your interest in physics?

– Popular books by Sir James Jeans and Arthur Eddington in the 1930's.

When you were young, did you like to talk with your parents or anyone in your family about physics?
– No.

What were your hobbies and your favorite subjects at school?
– Hobbies: building model lanes, trains, then building telescopes and optical instruments.

What is you hobby at the present time?
– Work and reading.

Did your children enjoy physics as well?
– Not very much.

Do they work in physics?
– No.

This is a very personal question: How did you meet your wife?
– I'm no longer married. I met my ex-wife, as the sister of a poet I knew.

Do you ever talk with your wife or children about your work and progress in research?
– Yes, I did all the time, when I had them at home.

Do you enjoy reading literature?
– Yes.

What is your favorite music?
– J.S. Bach, L. Beethoven.

What kind of sport did you exercise?
– Skating and skiing.

Courtesy American Institute
Photograph by Jack Stager

A YOUNG PHYSICIST STUDIES LIGHT

/from *Foton* 92/

Albert Einstein and Ignacy Mościcki's, Patent Application

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Fig. 1. Einstein at the Patent Office in Bern

Much was said and written during the 2005 World Year of Physics about Einstein's work in the Bern, Switzerland Patent Office (Fig. 1). He took the post (Technical Expert 3rd Class) there after completing his studies at the Zurich Polytechnic (later called ETH) in 1900 and unsuccessful attempts to obtain a university position. However, little seems to be known of the patent applications he examined during his five years at the office in Bern. This paper discusses one of those applications – one that was submitted by a rather remarkable individual. It is well-known that Einstein's period in the Patent Office, in spite of a very turbulent family life, was the most fruitful of his career. Great attention has, of course, been given to Einstein's papers of 1905 (his *Annus Mirabilis*), but what was he doing during the hours spent in the office? What sorts of patent applications did he work with? We know one specific example because the inventor himself is well-known. In 1905 Einstein reviewed the construction details of a special arc furnace employing a rotating electric arc and used for the production of nitric acid, needed in the manufacture of agricultural chemicals and in other industrial applications. The system was invented by Ignacy Mościcki. The field generated by an electromagnet was used to rotate the arc. The 26-year-old physicist and the still young (38) but already renowned inventor and scholar met and discussed the patented idea. Einstein was curious to know why an electric arc changed its orientation in a magnetic field. A sample drawing illustrating the patented idea is shown in Fig. 2.

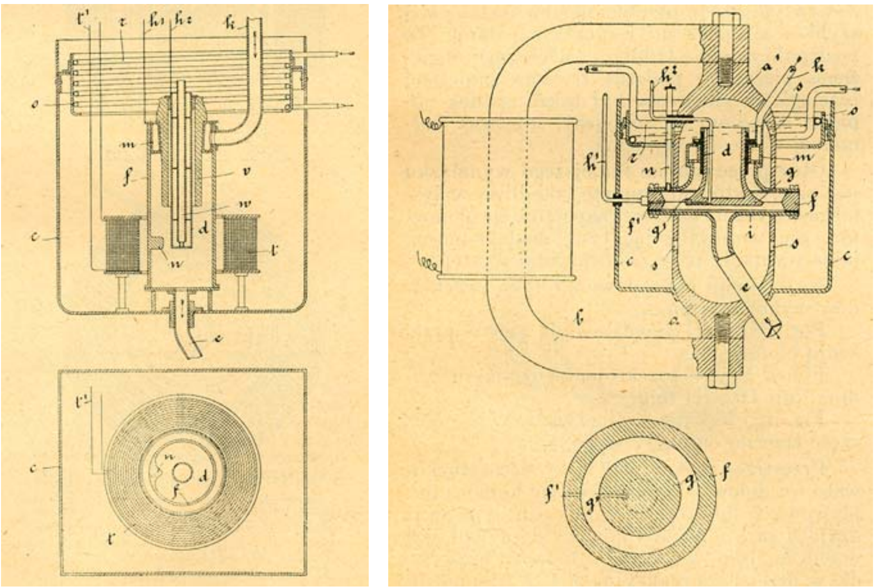

Fig. 2. Drawings from the Swiss Patent Office (Patent No. 35840).

It looks as it is rather technical, but of course Einstein had studied at a technical university and it was no problem for him to read and understand such diagrams. Also, we know that electrical engineering was his family business (his father Hermann and uncle Jacob were involved in the production of dynamos and electric motors). We don't know how many patent applicants Einstein may have met during his working years in Bern, but we do know that he met Ignacy Mościcki personally. Who was Ignacy Mościcki (Fig. 3)? He was a Pole and former assistant to Józef Wierusz-Kowalski (1896), professor of physics, and rector (provost) at Albert-Ludwigs University in Freiburg, Switzerland.

Mościcki was very skilled in laboratory work; in Freiburg he organized an instructional modern physics lab. He was also a very productive inventor. His specialty was electric technology, especially high-voltage (100,000 V) capacitors and methods for safely transmitting electricity over long distances. Mościcki needed high-voltage capacitors for creating electric arc discharges. At that time this subject was quite fashionable and many other physicists were working on it, among them William Crookes. Electric arcs in air result in the production of nitric oxide. Mościcki patented a method for the cheap industrial production of nitric acid, and he was one of the first to use atmospheric nitrogen to produce nitric acid on an industrial scale. As a designer of super-power capacitors, he was recognized as one of the best European specialists in the field. He became a successful businessman in Switzerland. After WWI he became professor of electrochemistry at Lwów Polytechnic in Poland (now Lviv, Ukraine) and in 1925 was elected rector. That same year he moved to the Warsaw Polytechnic and the next year he became president of Poland.

Fig. 3. Ignacy Mościcki (1867–1946), scholar, scientist, and inventor; holder of honorary doctorates from numerous Polish and foreign universities; president of Poland (1926–1939).

How did this come about? As a young student of chemistry in St. Petersburg, Russia, Mościcki was an active socialist. Later, back in Poland, he participated in a failed attempt on the life of the tsarist governor of Warsaw. In 1892 he was threatened with arrest and escaped to London where he met Józef Piłsudski, who was to become one of the most important people in Polish history. In 1920 Marshal Piłsudski led the forces that defeated the Soviet army at the Battle of Warsaw. This and subsequent battlefield successes led to Poland's victory in the Polish/Soviet war and saved weakened by WWI Europe from the threat of Soviet conquest. After Piłsudski engineered a coup d'etat in Poland, Ignacy Mościcki was asked to become the president. He gave up his academic positions and served as president of the Republic from 1926 until the outbreak of the WWII in 1939.

Among his other titles, Mościcki is known as the father of the chemical industry in Poland. A town in southern Poland (Mościce) is named after him. And one of his many patent applications was studied by a young technical expert, Albert Einstein, in Bern, Switzerland.

This paper was published by *The Physics Teacher*, Vol. 44, April 2006, p. 212. The article of Karl Mamola "Einstein in my homeland" *The Physics Teacher*, Vol. 43, December 2005 was reprinted in *Foton* 91.

The egg race

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Everyone knows how to recognize whether an egg is or is not boiled. The egg should be “spun” on a table. If it is boiled then it will spin easily and move quickly, otherwise it will swing and then stop (a raw egg).

We were stimulated by the TV show of Aneta Szczygielska and Jerzy Jarosz to perform an experiment with eggs[*]. We arranged a kind of a race. The eggs were put on the top of an inclined plane. We bet which egg would be faster. The result of this race was surprising, even for a physicist. The boiled egg (the dark one) was slower.

The race of other rolling (along an inclined plane) objects might also be very exciting. Try to compare the result of a race between two cans of cola one shacked before a race and second one not.

/from *Foton* 85/

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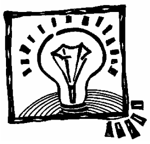
[*] Shown in the pictures.



Mysterious eggs

Aneta Szczygielska, Jerzy Jarosz
Institute of Physics Silesian University, Katowice, Poland

Why is the result of the “egg race” so surprising? Why do we expect the hard-boiled egg to be the winner? Everyone knows how to distinguish the hard-boiled egg from the raw one... – this is the reason why our intuition fails in the prediction of the race result. Our experience tells us that it is easy to make the hard-boiled egg spin and once set in motion it is turning for a long time. On the contrary, the raw egg does not turn easily and stops quickly. We tend to attribute to the hard-boiled egg a property which can be described as “easiness of turning” and we expect it to roll down faster than the raw egg deprived of this quality. However, the result of the race forces us to verify this expectation.

Let us first consider why does the hard-boiled egg spin so easily while the raw one doesn't. The difference is that in the first case the eggshell is strongly tied together with the inner parts and by setting the egg in motion we make the whole mass spin. In the case of the raw egg – we basicly turn only the eggshell while the inner parts remain almost immobile. The work involved in the case of turning the hard-boiled egg is much greater than in the case of the raw one and, in consequence, the energy of the rotational motion is much greater than the one acquired by the raw egg. However, if we turned the raw egg long enough we could make it spin just as well as the hard-boiled one.

The situation looks different when the eggs are rolling down the slope due to gravity. The gravitational force acts on the whole egg and the speed is determined by several factors. At the top of the inclined plane both eggs have the same potential energy. When they roll down it changes into kinetic energy of motion in a straight line and rotational motion. At the bottom of the slope (and at each point of the inclined plane) the sum of both types of kinetic energy must be the same for each egg. The inner part of the raw egg is not turning with the same angular velocity as the eggshell so its rotational kinetic energy is smaller than that of the hard-boiled egg. In consequence, the kinetic energy of motion in the straight line is greater for the raw egg and this is why it wins the race!

Using the conservation of energy principle and assuming that eggs of mass m and radius r roll down the plane of length l inclined at the angle α, one can easily obtain the formula for the time needed to roll down the plane:

$$t=\sqrt{\frac{2l}{g\sin\alpha}\left(\frac{I}{mr^{2}}+1\right)}$$

where I stands for the moment of inertia of the egg.

This equation yields that the smaller the moment of inertia of the object, the shortest the time *t* to cover the distance *l*.

By the way, there is a very important reason for the yolk of the egg not to take part in the rotational motion. In the upper part of the yolk the germinal disc is situated which remains always on top, closest to the source of heat – the body of the lying hen. It enables proper temperature to be maintained which is essential for the developing new life.

/translated by Katarzyna Cieślar/

/from *Foton* 86/

Lion Cub – a physics competition for junior high and high school students

Piotr Goldstein, Adam Smólski

The Polish-Ukrainian Physics Competition "Lion Cub" stems from the Kangaroo Competition in mathematics.

Thousands of pupils who enjoyed the math contest encouraged Ukrainian physics teachers from Lvov to organize a similar competition in physics. The first round of the new competition took place in 2001 and it was a great success! Lions are the symbol of Lvov, so the name was born. In Poland a "Lion Cub" started in 2003. More than 21,000 students from 1300 schools took part in it in 2006.

The competition consists of 30 multiple-choice questions, which should be answered in 75 minutes. You have to hurry up: the problems are sometimes hard, often tricky, they rather refer to precise thinking than to acquired knowledge. The topics are not restricted to the typical school syllabus. Nevertheless the participants really enjoy the contest.

Let us look at a few examples

In the building of the Lion Cub Inc. Ltd. all lifts move with the same speed in shafts emptied of air. Sometimes the lifts break off and fall. Just now one of them is overtaking another one. Both of them broke off above, at the same height, either while standing on one of the floors or while uniformly moving between them. It is definitely true that

A. the overtaken lift broke off later than the overtaking one,
B. at the moment of the break off the overtaking lift was moving upwards,
C. at the moment of the break off the overtaking lift was standing at one of the floors,
D. at the moment of the break off the overtaking lift was moving downwards,
E. at the moment of the break off the overtaken lift was standing on one of the floors.

The correct answer is E, but in order to prove it we need detailed analysis of the answers A – D to decide that they are false.

There are also questions in which the incorrect answers ("distracters") simulate common student mistakes:

The planets revolve around the Sun. What forces act on them, in an inertial frame of reference?

A. Centripetal and centrifugal forces.
B. The gravitational force from the Sun and other celestial bodies only.
C. The friction force of cosmic ether.
D. The gravitational force from the Sun and other celestial bodies as well as the centrifugal force.
E. The gravitational force from the Sun and other celestial bodies and additionally the centripetal force.

And some of them attempt to confuse the student's mind:

A lift moves down with an acceleration a. A man in the lift drops a coin. What is the acceleration of the coin with respect to the Earth? Air resistance may be neglected.

A. $g + a$. **B.** $g - a$. **C.** g. **D.** a. **E.** 0.

The competition selects a group of high-level students who understand physics deeply. But I hope that it is great fun also for the others and a low score is no shame. One can really learn a lot from the bare analysis of the problems.

Polish Physicists in Philately

Jerzy Bartke
The Henryk Niewodniczański Institute of Nuclear Physics
Polish Academy of Sciences

Famous people and important events become subjects of various postal-philatelic items: stamps, postal stationery (i.e. postal cards or envelopes with an imprinted stamp), special cancellations. In this article we will present philatelic items related to Polish physicists.

Following the chronological order of periods of their activity we begin with Karol OLSZEWSKI (1846–1915) and Zygmunt WRÓBLEWSKI (1845–1888). They were both professors at the Jagellonian University: Olszewski from 1876, Wróblewski from 1882. They investigated low temperature phenomena. They were the first to liquify the components of air: nitrogen and oxygen, in 1883, they also liquified and solidified carbon dioxide. They determined critical parameters for hydrogen, liquefaction of which was achieved in 1896 by Karol von Linde. The Polish Post devoted to Karol Olszewski and Zygmunt Wróblewski a stamp issued in 1951 on the occasion of the 1-st Congress of Polish Science, and an illustrated stationery card issued in 1964 for the 600-th anniversary of Jagellonian University. The illustration on this card shows the historical apparatus for liquefying gases.

Maria SKŁODOWSKA-CURIE (1867–1934) was honoured with a great number of stamps, postal stationery and special cancellations – one can assembly them into a large collection. More philatelic items were probably devoted only to the pope John Paul II and to Copernicus.

Maria Skłodowska-Curie often appears together with her husband Pierre Curie on stamps of earlier editions. We can mention here the stamps issued by France and its colonies (1938, 22 stamps of common design), Monaco (1938), Afganistan (1938), and Panama (1939–1949, altogether 22 stamps of repeated design). In

Poland in 1938 two postal stationery cards with the effigy of Maria Skłodowska-Curie were issued: a 15 groszy one for inland mail and a 30 groszy one, with bilingual inscriptions, for foreign mail. After the 2-nd World War a number of stamps were issued: in the series "The Polish Culture" (1947), on the occasion of the 1-st Congress of Polish Science (1951), in the series "The Famous Poles" (1963), for the 100-th anniversary of Maria Skłodowska-Curie birthday (1967), for the 100-th anniversary of the discovery of radium and polonium (1998), and also an envelope (1993) and a postal card (1994). The rarest stamp featuring Maria Skłodowska-Curie is the Turkish one, issued on the occasion of the International Women's Congress which took place in Istambul in 1935. The catalogue price of this stamp is now 400 euros. Two stamps of Suriname from 1950 are also very rare. Many stamps related to Maria Skłodowska-Curie were issued in 1967 at the 100-th anniversary of her birth, and later in 1998, at the 100-th anniversary of the discovery of polonium and radium. Other anniversaries of her birth, several anniversaries of her death, and anniversaries of rewarding her with the first (1903) and the second (1908) Nobel Prizes were also commemorated with stamps and special cancellations. We reproduce some of them. Apart from stamps, we show a few special cancellations: a rare Polish one "50 years of the discovery of polonium and radium" (used in 1948 in seven towns), the French cancellation "100 years from Maria Curie birth", and two items somehow related to Maria Skłodowska-Curie: the special cancellation "25 years of the Maria Skłodowska-Curie University in Lublin", and the machine franking of the Electric Power Company in Tomaszów Mazowiecki which is located in the Maria Skłodowska-Curie Street (this topical franking is the "discovery" of the author of this article).

Marian SMOLUCHOWSKI (1872–1917) was professor at the University of Lvov, and from 1913 at the Jagellonian University. He was a many-sided scientist, active in various fields of natural sciences, but mainly in physics. Most important are his works on kinetic theory of matter. On the basis of this theory he explained, independently of Albert Einstein, the Brownian motion (the Einstein-Smoluchowski formula). He also presented statistical interpretation of the 2-nd law of thermodynamics. The Polish Post honoured him in 1938 with two illustrated postal cards (similar to those for Maria Skłodowska-Curie), and with another card issued in 1964 on the occasion of the 600-th anniversary of Jagellonian University, showing the building of the Institute of Physics named after Marian Smoluchowski.

Marian DANYSZ (1909–1983) and Jerzy PNIEWSKI (1913–1989) conducted in Warsaw research in the field of high energy nuclear and elementary particle physics. While investigating interactions of cosmic ray particles registered in nuclear emulsions flown to the stratosphere, they discovered in 1952 the first hypernucleus, in 1962 the hypernuclear isomers, and in 1963 were co-authors of the discovery of the first double hypernucleus. In this way Danysz and Pniewski initiated a new branch of physics: the hypernuclear physics, and were allegedly nominated to the Nobel Prize, unfortunately without success. The Polish Post devoted to them the illustrated postal card issued in 1993. The imprinted stamp shows the microphotograph of the first event interpreted as a decay of a hypernucleus.

Kindergarten of Physics – where science meets youth

Dagmara Sokołowska

Marian Smoluchowski Institute of Physics
Jagellonian University, Cracow, Poland

The idea of inviting young high school students to join the Cracow School of Theoretical Physics in Zakopane, a prestigious annual international conference, was born in the early eighties. From the very beginning it was a very good idea and a few years later it was formalized into the so called "Kindergarten of Physics".

At the beginning the participants came only from the university classes of Cracow's high schools, where physics and mathematics were taught by university scientists. Nowadays, some students apply by themselves, some are the winners of a *Physics Olympiad* and other competitions e.g. *First Step to the Nobel Prize*, *Physics Tournament* and *Lion Cub*. Many students come from small provincial towns and villages.

The idea of the "Kindergarten" is to invoke the old traditional method of teaching based on a close relationship between the master and his disciple. Close personal contact of young students with top physicists is unique and it proves to be the best educational method of all. It is the role of the master to stimulate an intellectual activity of his disciple who must then think, understand and discover for himself.

High school students can participate in the ordinary school lectures, if they wish to do so, but they also have a program prepared especially for them. It consists of lectures, seminars, workshops, individual discussions with physicists during joint meals and problem-solving competitions. Students are encouraged to present (usually for the first time in their life) their own seminars on subjects in physics they are interested in.

Anyone attending the conference can participate in the scientific activities of the "Kindergarten" and many scientists do. The idea has been appreciated by the participants of the school and described as refreshing.

In June 2005 the XLV Cracow School of Theoretical Physics was organized by the Institute of Physics, Jagellonian University in collaboration with the Institute of Nuclear Physics, AGH University of Science and Technology and the Polish Academy of Arts and Sciences. Twenty-two high school students accompanied by two physics teachers were invited to the "Kindergarten of Physics 2005" – a special workshop prepared in the Year of Physics. Over five days the students had the following lectures and workshops:

"Asymptotic freedom – what it is and why it is important"
"Elementary presentation of Einstein's treatment of Brownian motion and its impact on our way of thinking"
"Introduction to differential equations – workshop" (in Polish)
"Solitons" (in Polish)
"Searching for life in the Universe" (in Polish)
"Astrophysics" (in Polish)
"RHIC program and some early results"
"Einstein's contacts with Polish Scientists" (in Polish)
"Neutrinos – in the past and today" (in Polish)
"Superposition in Classical and Quantum Physics" (in Polish)
"Short History of Black Holes" (in Polish)
"About the Scientific World"
"Supersymmetry and Asymptotic Freedom"
"Wounded nucleons in D-Au collisions under 200 GeV" (in Polish)

During the seminars young participants presented (in Polish) the following topics chosen by themselves:
"Polish Project of an Artificial Heart"
"A new telescope in Niepołomice"
"Einstein – de Hass experiment"
"Planetary Systems"
"The ideas for time traveling"
"Quantum Computers"
"Theories of the Origin of the Universe"

After a successful seminar during the "Kindergarten of Physics" the lecture entitled "Quantum Computers" was presented by our high school student Izabela Balwierz during the International Summer School for Young Physicists organized by Perimeter Institute for Theoretical Physics in Waterloo, Ontario, Canada.

Zakopane – where the "Kindergarten" takes place – is a well known Polish mountain resort (Tatra Mountains). One hundred years ago it became the winter capital of Poland. During the summer it is also full of tourists and scientists. In view of the landscape it is the best place to show a refreshing view on physics.

/from *Foton* 90/

First Step to Nobel Prize in Physics

Waldemar Gorzkowski

First Step to Nobel Prize in Physics *is an annual international competition in research projects in physics. All the secondary (high) school students* regardless of the country, type of the school, sex, nationality etc. are eligible for the competition. The only conditions are that the school cannot be considered a university college and the age of the participants should not exceed 20 years on March 31 (every year March 31 is the deadline for submitting the competition papers). There are no restrictions concerning the subject matter of the papers, their level, methods applied etc. All these are left to the participants' choice. The papers, however, have to have a research character and deal with physics topics or topics directly related to physics.

The project belongs to the out-of-school education. *Participation in the competition does not involve any agreement or consent of the school or educational authorities*. The pupils conduct their research in the way and conditions that are the most convenient for them.

Characteristic features of the *First Step* are:

1. The criteria used when evaluating the papers do not depend on age – there are no *discounts* for the young age of participants.

2. There are no prizes such as cameras, video, etc. There are no financial prizes. Instead, the winners are invited to our Institute for one month research terms (usually in November). During the terms they are involved in the real research work going on in the Institute.

3. The proceedings with the awarded papers are published every year.

The competition is supervised by the Organizing Committee which consists of all members of the Scientific Council of the Institute. The papers are evaluated by the Evaluating Committee nominated by the Organizing Committee. In the first two competitions only Polish physicists participated in the Evaluation Committee. In the third competition one foreigner took part in evaluation of the papers. In the fourth competition the number of physicists from foreign countries was 10. In the fifth competition number of foreigners in the Evaluating Committee was 14. At present the majority of the judges are from abroad. Several years ago a collective body named International Advisory Committee has been created. At present it consists of 24 persons with substantial experience in work with high school students.

The materials on the competition are disseminated to all the countries mostly via diplomatic channels. The competition is also advertised in several physics magazines for students and teachers. (Every year about 30 articles on the ***First Step*** are published in several countries). Different private channels are also used. In the first fourteen competitions the students from 76 countries participated.

The ***First Step*** (as far as we know) is the only competition that publishes proceedings including practically ***all the awarded papers***. Due to that all our most important decisions may be verified.

The main aims of the competition are:

1. Promotion of scientific interests among young students;

2. Selection of outstanding students (this point is especially important in case of pupils from countries or regions in which access to science is difficult) and their promotion (very often our winners are sent to better universities and receive appropriate financial help from the local authorities);

3. Enhancing motivation of students to scientific work;

4. Stimulation of schools, parents, local educational centers, etc. to greater activity in work with students interested in research (we know that in some countries, some regions and even in some schools preliminary local selections are organized, sometimes such selections involve large numbers of participants);

5. Establishing friendly relations between young physicists (recently all winners are invited to the Institute at the same time, they are accommodated in the same place, they cooperate with each other, etc.).

If you are interested in details (including terms and conditions of participation, please visit our home page:

http://info.ifpan.edu.pl/firststep

or

www.ifpan.edu.pl

Waldemar Gorzkowski
President of the Organizing Committee

girep
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sur l'Enseignement de la Physique

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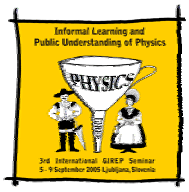
- as a member of GIREP, you will belong to the family of GIREP members, you will be in good company,
- you will receive GIEREP newsletters, you will be informed about news and trends in physics education,
- through participation in GIREP conferences and seminars you will influence the future of physics education



JUST STEP IN!

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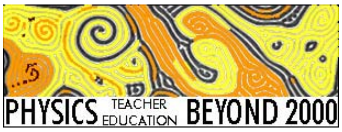
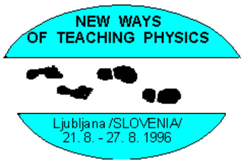
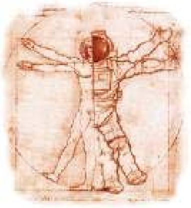
FEES: The current fee is EURO 20 (+ 1 EURO expenses) for one year.







GIREP 2002
Physics in new fields and modern applications

Strong

Marko Budisa
Faculty for Mathematics and Physics, University of Ljubljana,
Slovenia

Strong

Strong
I crush a cracker
Hard as rock
With my bare hand
The crust disintegrates
Into smallest crumbles
I spend a lot of energy
Breaking apart chemical bonds
Between matter consistent
Yet I know nothing of the little atom
And when I merely poke it
It answers
Joyfully
With a single energy packet
With a single photon
Only then I realize
The power of Weakness
The nucleus decays
Emitting a fast electron
And a neutrino
How strong Weakness is
How weak Strongness is
That which I am looking for
Is hidden
In the last neutron
Just about to decay
In the last corner of Universe
Where you are waiting
For your prince
And facing passing bandits
Sorry
But I was busy
Discovering the truth
That the Weak force
Caused a nuclear explosion
While I was being
Strong

August 2005, Ljubljana GIREP; http://www.girep2005.fmf.uni-lj.si/

Marco, one of the most charming organizers of GIREP 2005 in Ljubljana passed away in autumn 2005.

/from *Foton* 91/

Science in the Jagellonian University Museum

Maciej Kluza
Jagellonian University Museum

The collection of historical scientific instruments

The collection of scientific instruments in the Jagellonian University Museum comprises more than 2300 objects. It is the most important collection of that kind in Poland. Among the most important objects is an ensemble of medieval astronomical instruments, including the Moorish Astrolabe from 1054 – the oldest scientific instrument in Poland. There is a unique of brass instruments, including a torquetum, an astrolabe, and a celestial globe made by Hans Dorn (c. 1480). All these instruments belonged to Martin Bylica from Olkusz, a student and professor of the Cracow Academy and a court astronomer of the Hungarian King to Matthias Corvinus. He bequeathed them to his Alma Mater. There was a celebration of the whole Academy when the instruments came to Cracow in 1493. They were probably seen by Copernicus who studied here at that time. Another important object is the Golden Jagellonian Globe made at the beginning of the 16th century. In fact it is a mechanical armillary sphere with a clock mechanism and a small globe inside. The name of the newly discovered continent – America – was put on the globe for the first time. It was donated to the Academy by Prof. Jan Brożek, a mathematician and astronomer working in the early 17th century. His donation comprised a few instruments and a significant number of books. An astrolabe and a diptych ivory sundial from this donation are still exhibited in the Museum.

There are 55 globes in the collection of scientific instruments. The most splendid are: cellestial and terrestrial globes made by Gerhard Mercator in the middle of the 16th century and four globes of Willem Blaeu (early 17th century). Two globes made by Abel and Klinger in Nuremberg are from the first edition of globes with a map in Polish.

An important part of the collection, closely related to the history of the University, is an assortment of instruments from the first Astronomical Observatory founded in 1791. It includes either instruments used for astronomical observations like telescopes and quadrants (e.g. Dollond's telescope, quadrants made by Ramsden and Canivet) as well as meteorological instruments (barometers, thermometers and hygrometers), sundials, astronomical clocks and surveying instruments (graphometers, sextants, circumferentors).

Another significant group of instruments is the equipment of Prof. Karol Olszewski's cryogenic laboratory, the place where liquid air was obtained for the first time. The set of instruments includes condensing apparatus, compressors, cryostats, gas cylinders, vacuum flasks as well as instruments for spectroscopic and X-ray research. Numerous instruments from the late 19th and early 20th century were given to the Museum by faculties and departments of the University. This group comprises optical tools (spectroscopes, polarimeters), tools for electrostatic experiments (leyden jars, electrostatic machines, electroscopes), electric meters, spectral tubes, areometers, thermometers, surveying instruments (theodolites, levels) and chemical glasses.

The Museum houses also an interesting collection of microscopes (18th–20th century), a collection of drawing tools (Gourdin's pantograph from 1786), and a collection of calculating aids (Neper rods from the 17th century, Thomas de Colmar's arithmometer, c. 1870).

The collection of scientific instruments is a valuable source for research on the history of science and history of the Jagellonian University. It points to the fields of knowledge which were developed at different times (e.g. astronomy in the 15th century) and helps to understand details of the experiments conducted with the use of particular instruments.

Educational interactive exhibition "Ancient and modern sciences"

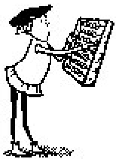
The exhibition was opened in 2000–2005. It was a pioneer project in Polish museums. For almost 5 years the exhibition was visited by more than 95 thousand visitors. The exhibition was addressed to students, who were the vast majority of the guests. The aim of this exhibition was to present in an interactive way some phenomena and show them in a historical context. Therefore, the interactive exhibition was bound to the collection of the scientific instruments. In the historical building of Collegium Maius, the location of the Museum, the guests had unique opportunity first to see antique instruments and next, in the interactive exhibition, to use a copy or a model of the previously seen instrument, and perform an experiment or a measurement following the instruction.

The subject matter of the exhibition was chosen from the three fields important in the development of science during the history of the Jagellonian University, namely, physics, mathematics and astronomy. Every branch of science was presented in a separate room.

The world of waves

20 exhibits dealing with different features of wave motion. Phenomena such as polarisation of light, interference, diffraction, mechanical vibrations and resonance were presented. The majority of the experiments showed the properties of sound and light.

Between an abacus and a bit



The historical timeline of the development of calculating tools was shown with the use of models of different calculating aids. The models shown in the exhibition included an abacus and frame abacus, two models of Neper bones – the first tool for multiplication, a slide rule, a mechanical arithmometer and a computer.

Astronomical Room

Two topics: “To measure time” and “Angels on earth and in Heavens”. Models of different astronomical tools used for angular measurements and copies of such historical instruments as a torquetum, an astrolabium, a horary quadrant and a cross-staff were presented. Tools used to measure time: sundials, a clock mechanism and a set used to send a time signal by Polish Radio completed this part of the exhibition.

The “Ancient and modern sciences” in 2005 was transformed into a travelling exhibition and began a journey around several museums and universities in Poland. In September 2005 it was shown in Lublin and in March–June 2006 in Częstochowa. The exhibition is expected to visit Sandomierz, Jarosław and Białystok.

The interactive exhibition “Senses”

The subject area of this exhibition is focused on the human body, its biology and physiology. It is an attempt to explain is now of us how our sense organs are build and how they work. The exhibition is organised as three “theme-islands” dealing with different aspects of senses.

The first theme is *"Receptors – the gateway of the nervous system*". The aim of this part is to provide a basic knowledge about the structure and functions of the sense organs, and to show their diversity. This is presented with the use of 28 experiments. The visitor can learn understand the structure of ear and the role it plays in the hearing process and have an opportunity to test an osteo-tympanic conduction of sound. A model of an eyeball explains the constitution of the eye and the mechanism of accommodation. Other exhibits show the function of the retina and the pupil, clarify phenomena of an afterimage and a persistence of vision and give an opportunity to test colorvision and peripheral vision. Three exhibits concern the senses of touch and smell. The visitor checks his ability to recognise shapes and letters by touch as well as try to recognise several different smells.

"*Mono and stereo*" – the second part, focuses our attention on the consequences of the fact, that some organs of our senses are dual. Thanks to them we can see in three dimensions and localise the source of the sound. Several experiments deal with the three-dimensional pictures. Different types of 3D pictures like anaglyphs, holograms, lenticular images, steropairs and pictures seen by polarising glasses (like in IMAX) are presented. A computer presentation of 3D photos designed for the shutter glasses and a model of the mirror stereoscope supplement the review of 3D methods. Two experiments show the properties of hearing – in the first the visitor has to find the exact place where the long pipe was hit, in the second the visitor would learn that it is much easier to distinguish a sound from a noisy background if the source of the sound is in a specified position.

As a supplement, two experiments were added to this room. One deals with smell. Some organic compounds may have different optical isomers that are the same in every way except being non-superposable mirror images of each other. Carvone is an example of such a compound. The two isomers of carvone have different smells – spearmint and caraway. The other shows properties of touch.

The visitor is invited to put his left hand on a hot plate and right on a cold one, and then to put both hands on a lukewarm plate – he would feel that the plate is cold and warm at the same time.

The human brain does not analyse all information arriving from the sense receptors. Whether it is due to evolution or just by accident, the analysis of stimuli is very selective. We see, hear and sense only what is important for survival and safety. If we knew which information is neglected we would know how to *"deceive our senses"*. This is the topic of the third part of the exhibition.

The most popular result of such deception are optical illusions. Geometrical illusions – a Poggendorff line, a big model of "Cafe wall" and different variants of "Grey steps" presented at the exhibition are only a few examples of such phenomena.

Other senses may also be fooled. Our hearing does not always recognise the pitch of the sound. One may test his tone memory or play on the "strange piano". Touch is not able to measure temperature. When touching plates made from different materials we feel that some of them are cold (metal, glass) and others are warm (wood, cork). A thermometer reveals that all plates have the same temperature.

The last group of experiments is related to the co-operation of senses. It is very difficult to maintain balance on one leg while watching a moving panel with a striped pattern or to write one's own name while seeing only a mirror image of one's moving hand.

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tel: + 48 12 422 05 49, + 48 12 663 13 07, fax: + 48 12 422 27 34,
e-mail: info@maius.in.uj.edu.pl

We recommend also the Technical Museum of Cracow with the interactive exhibitions "Playing with Science"

http://www.mimk.com.pl/

JAGELLONIAN UNIVERSITY
CRACOW