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# PARTICLE AND NUCLEAR PHYSICS FOR A KNOWLEDGE-BASED SOCIETY

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## 1. *Knowledge-based society*

Salient features of the contemporary world are globalization and rapid changes, both science-generated. Today one hears that our knowledge is already enormous and that it is necessary only to appropriately apply it. We argue that the development even the existence of the contemporary world crucially depends on our creative capabilities – individual and collective, and it is present research and technological development (RTD), education, science and technology and information and communication technologies (ICT) that mold and increase our creative power. We will include all of these components under the term: knowledge. However, while all these components: RTD, ICT, science and technology and to some extent education are global and can be standardized, the sum of all – knowledge – is understood and contextualized within a specific cultural system. The essential resource of today's world is knowledge, and while resources of earlier eras were and are finite and relatively scarce, knowledge is inexhaustible and it is increased by sharing. Knowledge is also a political power. Knowledge increases constantly. It includes new ideas, discoveries, sometimes serendipitous. Knowledge aims toward complete understanding and leads to greater creativity, better education, life-long and for everybody [1].

Recently, we heard about the end of history, and even about the end of science [2]. Physicists did speak about the end of physics: In his famous lecture Lord Kelvin said that only two small clouds dim the bright sky of physics. But these clouds generated quantum physics and the theory of relativity. A. Michelson said that the future truths in physics are to be looked in the sixth place of decimals. S. Hawking's inaugural lecture in 1980 is entitled "Is there an end in sight for theoretical physics". In 1989 a symposium under the title "The End of Science" was organized in Gustav Adolphus College, Minnesota. Is there really an end in sight for science? For physics? And specifically for particle and nuclear physics? Is science, and is particle physics relevant for building a knowledge-based society?

## 2. *Why are particle and nuclear physics essential in building a knowledge-based society?*

It can be claimed that a famous Thales's question "What from and how is a universe made?" is almost answered. We know that the universe was created in a Big bang 13 billion years ago, and except for a tiny fraction of a first nanonanosecond, it seems that we know how it has developed. We also know that there are three families of elementary particles and we know the forces between them. It seems that complexities and chaos are much more interesting domains of research. The aim of this paper is to argue that particle and nuclear physics did contribute, are contributing and for a foreseeable future will contribute toward building a knowledge-based society. A basic characteristic of human beings is curiosity and there are a number of open questions that we still have to answer. First, we will address some open problems relevant for this conference.

### *2.1. Three nucleon problem, pentaquarks, baryon and meson spectroscopy*

During the last twenty years significant progress was achieved in a study of a three nucleon problem [3,4]: elastic and inelastic scattering observables are almost perfectly explained by the rigorous three nucleon calculations [4] using realistic nucleon-nucleon (NN) potentials [5]. The understanding of $^3$H/$^3$He binding energy represents a clear indication for the three-nucleon force (3NF) and additional evidence for the 3NF comes from the elastic scattering nucleon-deuteron minimum (Nd) [6]. In spite of this remarkable success there are some discrepancies: a) vector analyzing power in Nd elastic scattering at low energies and b) breakup configurations: symmetric space star, quasifree scattering and final state interaction (FSI) [3]. The study of neutron-neutron (nn) FSI in nd breakup is one of the two sources of the nn $^1S_0$ scattering length, $a_{\rm nn}$ [7], and the fact that two recent studies give quite different results: $a_{\rm nn} = -18.7 \pm 0.4$ fm at 13 MeV [8] and $-16.2 \pm 0.3$ fm at 16 and 25 MeV [9] is disturbing. More than 20 years ago it has been suggested [10] that the 3NF is responsible for the difference among $a_{\rm nn}$ extracted from various configurations of the nd breakup. Rigorous three body calculations using Tucson-Melbourne 3NF invalidated this suggestion [4], albeit it is still an open question whether a different 3NF would have a different effect. It has been also suggested [11] that magnetic interaction influences the breakup. Recent studies [12] of the magnetic interaction within a framework of the rigorous calculation show that the effects are most important in the FSI region, but even there they cancel out, and therefore, the magnetic interaction cannot account for the existing discrepancies. Howell has proposed that there is a resonance [13] in a three-nucleon system, but it has to be worked out how this resonance in the three nucleon system produces the observed effect.

Sigma meson ($\sigma$ or $f_0$) is playing an essential role in the NN force. A recent measurements [14] of the Dalitz plot densities for the process p $\pi^- \to \pi^0\pi^0$n from threshold to 750 MeV/$c$ pion momentum shows a high concentration of events on an island around $m(\pi, \mathrm{n}) = 1.2$ GeV with $\Gamma = 100$ MeV revealing a dominant role of the $\Delta$ resonance in the final state. For the reaction $\mathrm{K^-p} \rightarrow \Lambda\pi^0\pi^0$ in the range of $p_\mathrm{K} = 520 - 750$ MeV/$c$ a similar structure is found at $m(\pi\Lambda) = 1.38$ GeV and a narrow width of 50 MeV demonstrating dominance of the $\Sigma(1385)$ resonance. All of these spectra do not require appreciable $f_0$ ($\sigma$) production. Sigma meson is actually a two-pion correlation.

Are basic hadron properties modified by hadron being imbedded in nuclear matter? While there are numerous theoretical papers, there are only few experimental studies [15].

The last 30 years were characterized by insufficient data necessary to provide definitive tests for various theoretical models describing baryon spectra. High intensity, high duty factor accelerators (JLab, MIT Bates, Mainz) and sophisticated detectors are expected to give answers to some of the open questions, e.g. do missing states predicted by the quark model and not found experimentally exist? Are there other states? hybrids, glueballs? even the Roper resonance is still open as well as the issue whether $\Lambda(1405)$ is a bound $\mathrm{K^-N}$ state? [16]

Recent studies revealed three surprising and important results. First, two extremely narrow mesons containing c and s* (* denotes an antiparticle) quarks [17]. Second, enhancement [18] near pp* threshold. And third, besides baryons and mesons, QCD allows for other quark-gluon configurations. One example is a pentaquark, made of 5 quarks, specifically of 4 quarks and one antiquark. Though there was a search for pentaquark for the last 30 years, only recently four different experiments [19] showed evidence for a pentaquark – $\Theta^+ = \mathrm{uuds}^*$. Since the antiquark s* has a different flavor from any of the other four quarks, it does not annihilate. All four experiments show strong evidence for a pentaquark of mass 1.54 GeV, with a very narrow width, less or equal to the experimental resolution of 22 MeV. In the first experiment a group from the SPring-8 synchrotron led by T. Nakano created $\Theta^+$ by firing gamma rays at a carbon target. V. V. Barmin et al. found a positive strangeness baryon resonance in $\mathrm{K}^+$ collisions with Xe nuclei in the xenon bubble chamber. J. Barth et al. found $\Theta^+$ in photoproduction off proton resulting in the $\mathrm{n\,K^+K^o_s}$ final state. Stepanyan et al. found $\Theta^+$ in exclusive photoproduction from deuteron (see Fig. 1). As early as 1987 Praszalowicz pre-

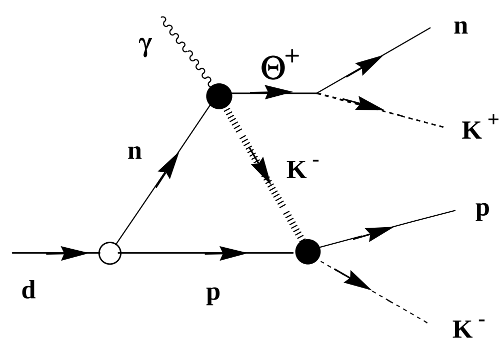


*Fig. 1. Diagram representing exclusive photoproduction of $\Theta^+$ from deuteron.*

dicted [20] that the hypercharge 2 isosinglet member of the $J = 1/2\, 10_f$ would lie near 1540 MeV. In 1997 Diakonov et at. [21] based on a topological soliton model predicted a $\Theta^+$ at 1540 MeV and estimated its width to be less than 15 MeV. According to Jaffe and Wilszek [22] the minimal SU(3)-flavor assignment is at the top of a $10_f$, also containing a $Y = 1$ isodoublet ($N^+$ and $N^0$), a $Y = 0$ isotriplet ($\Sigma^+\ \Sigma^0\ \Sigma^-$) and a $Y = -1$ isospin quartet ($\Xi^+\ \Xi^0\ \Xi^-\ \Xi^{--}$). In this case $\Theta^+$ would be an isosinglet (see Fig. 2). Differently, Capstick et al. [23] interpret $\Theta^+$ as an isotensor pentaquark and predict $\Theta^{++}$, $\Theta^+$ and $\Theta^0$ having isospin-violating

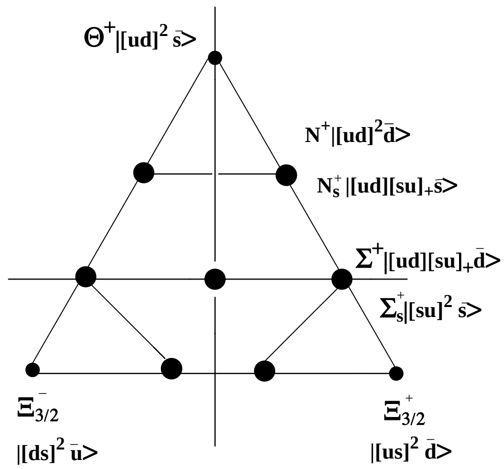


*Fig. 2. Decuplet of pentaquarks.*

strong decays and $\Theta^{+++}$ and $\Theta^-$ weakly decaying. The $J^P$ assignment of the $\Theta^+$ would most likely be 1/2− or 3/2−. The $\Theta^{+++}$ has a structure uuuus* and the most promising process for its production is pp $\to \Theta^{+++}\Sigma^-$ involving one ss* pair creation and $K^+p \to \Theta^{+++}\pi^-$ involving the creation of one light quark pair. Search for $\Theta^-$ (dddds*) could be done via nn $\to \Theta^-\Sigma^+$ but that would require neutron beams of over 800 MeV. Opposite to Ref. [23] Jaffe and Wilszek claim that the absence of the $I_3 = +1$ in $K^+p$ rules out $I = 1$. They predict an isospin quartet $\Xi^+$ (ususd*), $\Xi^0$ (usdsd*), $\Xi^-$ (usdsu*) and $\Xi^{--}$ (dsdsu*). Search for $\Xi^{--}$ could be done at JLab using $\gamma p \to K^+K^+\pi^+\Xi^{--}$ and even better with $\gamma d \to K^+K^+\Xi^{--}$ (note that at energies of 5 GeV the deuteron binding of 2.2 MeV does not matter and that deuteron is an adequate neutron target (see Fig. 3). This process needs lower incident energy since one particle less ($\pi^+$) is produced. Let me make several comments: i) why $\Theta^+$ was not discovered earlier, e.g. the D-line of the AGS-BNL allows K energies up to 1.8 GeV and the threshold for the process $pK^+ \to \pi^+\Theta^+$ is 0.8 GeV, ii) many measurements aimed to study other processes can be reanalyzed to search for $\Theta^+$; this shows the richness of modern particle physics research, iii) international dimension of research: experimental facilities that found evidence for this pentaquark are in Japan, Germany, Russia and the USA, and one paper has 36 institutions from 8 countries, iv) after several decades of arguments between journals and informal forms of publications with priv.com. now becoming a standard reference, the results of experimental and theoretical studies of the pentaquark are circulating through arXiv:hep demonstrating a very high level of maturity of the physics community how to judiciously use this medium.

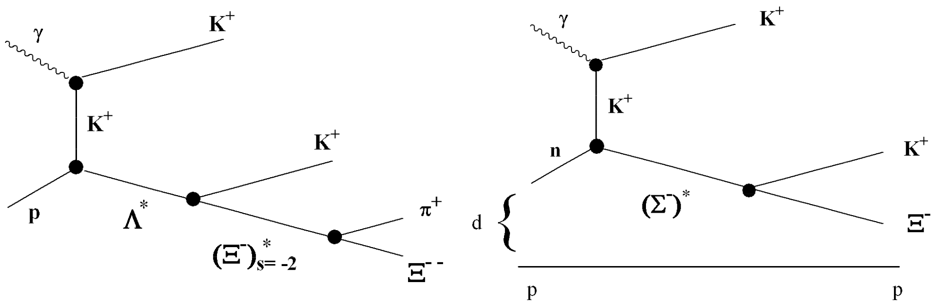


*Fig. 3. Diagrams representing exclusive photoproduction of* $\Xi^-$ *from proton and deutreon.*

## 2.2. *Science and the public*

Now we turn to more profound open questions. Some of them are important not only for physicists but for the public at large, e.g. why particles have the masses they have? and why fundamental constants have the values they have? Anthropic principle can hardly be a satisfactory explanation, albeit coupling with many universes could be an interesting approach. Why are there three families of particles, while the first family seems to suffice? And most importantly: is our Universe 10-dimensional and what is time. The time has been always a crucial concept which is now going through rapid changes. "If everything would be fully determined, there would be no time." wrote Ruđer Bošković in the $18^{th}$ century. Time is redundant. Everything is contained in the initial state. Nothing happens! Dostoyevski wrote: "If everything would be rational, nothing would happen." Describing his feeling about the symphony he recently composed, Mozart wrote to his father: "I can feel my entire symphony in one instant, as if I am looking at the picture." "If nobody asks me, I know," wrote St. Augustin "but if I wish to explain it, I do not know." The list of condemned heresies in the edict of 1277 includes the heretical statement that time exists only in apprehension, not in reality. Different cultures attempt to understand time in different ways: "There was no time when we did not exist" is written in Bhagavad Gita, and Japanese philosopher Dogen said: "Time is existence and all existence is time." However, and old Arab proverb says: Man is afraid of time but the time is afraid of pyramids. In some African cultures time is nonexistent until an event marks it - human beings make through their activities as much time as they need. Though in their everyday speech Bantu people distinguish the entities of time and space, on a level of deeper understanding they merge it into a single concept: *kantu*. Ancient Greeks distinguished between two gods of time, *Chronos* and *Kairos*, where Kairos is a god of a lucky chance – the opportunity to do. The late Indonesian philosopher Soedjatmoko said: "The future is an ethical category because we choose it ourselves." Time, existence of three families of particles and the fact that the universe is composed of matter while the amount of antimatter is small might have a common source.

A. Sakharov argued in 1967 that the violation of CP (i.e. T) and of baryon number conservation could be responsible for the dominance of matter over antimatter. CP violation has been observed in 1964 in the K meson decay, and in 1973 Kobayashi and Maskawa (KM) pointed out that CP violation appears naturally in a Standard model with six quarks. Charm quark was observed in 1974, bottom quark in 1977 and finally top in 1995. Two experiments [24,25] studying B-meson decay: $\mathrm{B}^0 \to \mathrm{K}^0 + \mathrm{J}/\Psi$ were recently done and agree remarkably well with the predictions of the KM matrix. However, preliminary studies [26,27] of the decay $\mathrm{B}^0 \to \mathrm{K}^0 + \Phi$ reveal some problems, but the statistical errors are large. The unitarity of the KM matrix requires $|V_{\mathrm{ud}}|^2 + |V_{\mathrm{us}}|^2 + |V_{\mathrm{ub}}|^2 = 1$. Using the current values for $V$'s: $V_{\mathrm{ud}} = 0.9741(1 \pm 0.0006)$, $V_{\mathrm{us}} = 0.2201(1 \pm 0.013)$ and $V_{\mathrm{ub}} = 0.003 \pm 0.001$ one obtains a slight departure from unitarity. It is a pity that the study of the $\mathrm{K}_{\mathrm{e}3}$ which is proportional to $|V_{\mathrm{us}}|^2$ proposed several years ago [28] has not yet been done.

Future would not be a future if it did not contain surprises. Our research is full of surprises, which often significantly modify our worldview. Evidence for large cold dark matter ($\sim 25\%$) and dark energy ($\sim 70\%$) or a departure from Newton's law is a major surprise, albeit astronomers have been searching for dark matter for the last 70 years. Two features of our research should be emphasized: First, bursting of new ideas, some are wrong and some seem to be wrong and then turn out to be right, as e.g. the cosmological constant introduced by Einstein and reappearing in dark energy. Attractive ideas that turn out not to be fruitful, e.g. steady state and nuclear democracy. Second, progress in our research unites the very small – elementary particles and astronomy. It is important to ponder that a much broader consilience – jumping together – of all sciences and arts, advocated by E. O. Wilson, could be a very fruitful approach in building a knowledge-based society.

The public recognizes the value of science: 84% in the USA and EU considers that science provides higher standard of living, better general working conditions and healthier life, about 80% that scientific research is necessary even if there is no immediate benefit, between 61% and 73% consider that science gives more benefit than harmful effect, and 70% that science leads to enjoyment of life. Public confidence in leadership of the scientific community is constant throughout over 30 years studies and it is second only to that of a medical profession (which is, however, decreasing) and much higher than in politicians, media and business [29]. Lack in confidence in political structures, media and business is shown also in a much broader international study done in 2002 [30] . Though the public appreciates research and is interested in scientific discoveries, their overall knowledge is not adequate: while about 80% know that the center of the Earth is very hot and 20% understand the term DNA, less than 10% understand the term molecule [29], and only 70% Americans accept Copernicus' concept, 53% accept evolution and only

33% accept Big bang (10 years ago the percentage was 38%).

Scientific activity gives incremental results and major sudden breakthroughs which introduce "new literacies" creating thereby a chance for resetting to zero technological and economic advantages accumulated in some places. Though science is an elitist activity governed by the Matthew's effect "unto him that hath more is given" scientific breakthroughs can act as great equalizer. The values of science and democracy are concordant, in many ways identical. Science and democracy began in the same place and at the same time – 6 c BC Greece. Neither science nor democracy is perfect, but they are the best we have. We should try to achieve Galileo's aim: "that a reasoning of a humble individual should be able to prevail the authority of thousands." [31]

### *2.3. Science vs. politics*

Each scientific discipline has a well-defined domain, and even science – the sum total of all scientific disciplines, inter- and multidisciplinary activities – has a well-defined domain. On the contrary, politics permeates everything. Even if you are not interested in politics, you are always encompassed by politics. Disraeli, Talleyrand and Bismarck said that politics is the art of possible – kind of a very good excuse. Attempting to define science Medawar said: Science is the art of soluble. It would be quite useful if politics would also become the art of soluble [31]. It is interesting to compare various opinions about what is science. Rutherford said "There is physics and there is stamp-collection". Marx said: "History is the basic research." and Aristotle "Politics is the master science and the end of politics is not knowledge but action." Though it is clear that the future is the knowledge-based society, and all politician express their support for RTD and education, most politicians do not actually understand what does it mean to build a knowledge-based society.

### *2.4. Complex research infrastructures*

To work at the forefront of RTD in all branches of scientific activity is necessary to have access to state-of-the-art research infrastructure. As Derek de Solla Price emphasized the progress of science can be traced with progress in instruments. Since research infrastructure became more and more complex, it is no longer something one has in his/her own laboratory. This immediately creates a gap between those who have access and those that do not. More importantly, humankind is depriving a significant portion of its member of the possibility of doing research. Since talent is a rare gift it is obvious what enormous damage is done by not assuring an easy access to research infrastructure.

In 1989 the European Commission started the programme to assure access to research infrastructure (ARI): Large installation plan (1989–92), then Access to large-scale facilities (1990–94) and including mobility and training of researchers (1994–98). In the ARI action under the Fifth Framework Programme 139 infrastructure were supported and in addition 37 RTD projects improving the ARI were funded. Complex infrastructure is not only a necessity for physicist. Though half of the users are physicists, the number of other researchers is constantly increasing.

There are now 24% chemists, 12% from life sciences and even 2% from economic and social sciences. Status distribution is: 34% predocs, 18% postdocs and 48% senior researchers. Age distribution is: 30% younger than 30, 36% from 30 to 40, 18% from 40 – 50, 12% from 50 – 60 and 5% older than 60. Examples of ARI are: analytical facilities (e.g. life sciences and trace gas, and European cultural heritage), astrophysical (European Northern Observatory and hopefully Croatea nearby Dubrovnik), nuclear and particle facilities, synchrotrons, free electron lasers, and also legal science through information-communication technology and language typology resource centre [32].

### *2.5. Measurements and indicators*

Measurement is at the beginning of all civilizations. The art of measurement is nowhere developed better than in physics. We appreciate how important is to improve the accuracy and also to assess the influence of other factors. Aristotle did measure the motion of bodies and nevertheless came to a wrong conclusion about the force. Astrologists and alchemists also measured, but used an incorrect worldview. Nevertheless, their data were useful to Kepler and Newton. Physicists are measuring observables far from the everyday domain: extremely small (fraction of the size of a proton) and extremely large distances (size of the universe), and similarly in time, mass, density etc. Physicists introduce observables that are completely outside the everyday world, and yet the world depends on them: isospin and strangeness.

Nowadays there is an overwhelming tendency to measure and to formulate indicators [31]. Well-known examples are GDP and GDP/capita. Many attempts to improve GDP/capita are done introducing purchasing power corrected GDP, differences between GDP's of the poorest and the richest 10% of the population, and enlarging the concept to include social indicators resulting in human development index (HDI). Recently attempts were made to measure various features, e.g.: environmental sustainability (Finland and Norway lead the list), economic freedom (from 1995 till now Croatia and Bulgaria improved from 3.50 to 3.15 and 3.35, respectively), freedom in the world (in 1981 there were 1.61 billion free persons, i.e. 36% and in 2002 there are 2.5 billion or 41% of the world population, or expressing in terms of countries more than 15 countries became free in that period totaling now 85 free countries, 59 partly free and 48 not free countries), globalization which includes economic, technological, political and personal aspects (Ireland, Switzerland and Singapore leading, and Croatia being $23^{rd}$) and even happiness. An extensive World Value Survey was done with Iceland, the Netherlands and Denmark leading in happiness, life satisfaction and subjective well being. These indicators are strongly correlated with perception of one's own freedom particularly at work and much less with GDP/capita. Indeed, it correlates with GDP/capita when it is less than about $ 9000, but happiness is nearly constant for higher GDP/capita. As we know, being rich is not everything. There is a much higher correlation between happiness and the sum of political and economic freedom and the rule of law.

## 3. *Happiness*

Justification for supporting research is usually done by arguing that it contributes to economic progress. V. Bush in his famous "Science – Endless Horizons" introduced the linear model: basic research push model: more basic research gives more economic benefits. Critical assessment found many shortcomings in this model, and a completely opposite linear model: market pull, was introduced. Real situation is much more complicated [33] and in this paper we tried to show that basic research in particle and nuclear physics has many benefits and it is crucial in building a knowledge-based society and it also does contribute to individual happiness. After all as Aristotle wrote more than two thousand years ago in his Nichomachean Ethics: "The activities of Gods are contemplation, the human activity that comes closest to it will be most like happiness. The greater a person's power of thought, the greater will be his happiness." Hence, science leads to happiness.

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## *Note added in proof*

In January 2004, the evidence for two new pentaquarks $\Xi^{--}$ (1860) (quark content dsdsu$^*$, electric charge -2 and strangeness -2) and $\Xi^0$ (quark content dsusd$^*$) and their antiparticles has been reported (Phys. Rev. Letters 92 (2004) 042003). The Croatian group, spokesperson K. Kadija, led the analysis of the NA49 collaboration data obtained in the proton-proton scattering at 158 GeV. The study of pentaquarks is continuing and some recent experiments failed to find evidence for any of the reported pentaquarks.

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