# The Secret of Geniality (V)

**Robert DJIDJIAN**[1]

***Instead of abstract***:

We continue to publish, in a series, the book THE SECRET OF GENIALITY (Yerevan, Armenia, Noyan Tapan Printing House, 2002) by our colleague Robert Djidjian, not only because we all must know the philosophical research and creation (in our domain of epistemology and philosophy of science and technology) from a wider geographic area than that provided by the established fashion in virtue of both extra-scientific reasons and a yet obsolete manner to communicate and value the research; but also because the book as such is living, challenging and very instructive.

The title of the book is suggestive enough to make us to focus on an old problem: the dialectic of the insight, of the discovery – its psychology moving between flashes of intuitions and knowledge stored in memory – and its logic of composition of knowledge from hypotheses to their demonstration and verification. The realm of science is most conducive to the understanding of this dialectic and the constitution of the ideas which are the proofs of what is the most certain for humans: the "world 3", as Popper called the kingdom of human results of their intellection, and though transient and perishable in both their uniqueness and cosmic fate, the only certain proof of the reason to be of *homo sapiens* in the frame of multiversal existence. Therefore, the power to create is the secret of the human geniality, and how to create science is a main part of this secret.

Ana Bazac

***În loc de rezumat***:

Continuăm să publicăm, în serial, cartea SECRETUL GENIALITĂȚII (Erevan, Armenia, Tipografia Noyan Tapan, 2002) de colegul nostru Robert Djidjian, nu numai pentru că toți trebuie să cunoaștem cercetarea și creația filosofică (în domeniul nostru de epistemologia și filosofia științei și tehnologiei) dintr-o zonă geografică mai largă decât aceea oferită de moda consacrată atât din motive extra-științifice cât și dintr-o manieră încă învechită de a comunica și a valorifica cercetarea; dar și pentru că volumul ca atare este viu, provocator și foarte instructiv.

Titlul cărții este suficient de sugestiv pentru a ne face să ne concentrăm asupra unei probleme vechi: dialectica intuiției, a descoperirii – psihologia ei mișcându-se între sclipiri de intuiții și cunoștințe stocate în memorie – și logica compunerii cunoștințelor din ipoteze, și pe de altă parte, demonstrarea și verificarea lor. Tărâmul științei este cel mai favorabil pentru înțelegerea acestei dialectici și constituirea ideilor care sunt dovada a ceea ce este cel mai sigur pentru oameni: „lumea 3", cum a numit Popper regatul rezultatelor umane ale intelecției lor și, deși trecătoare și perisabilă atât în unicitatea, cât și în soarta lor cosmică, totuși singura dovadă

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certă a rațiunii de a fi a lui *homo sapiens* în cadrul existenței multiversale. Așadar, puterea de a crea este secretul genialității umane, iar modul de a crea știință este o parte principală a acestui secret.

## Step 12. WHEN DO SCIENTISTS ALLUDE TO INTUITIVE THINKING?

***"There is no logical path to these laws; only intuition, resting on sympathetic understanding of experience, can reach them."***

*Albert Einstein*

We never can be sure of our understanding of the ways of great discoveries unless we are able to explicate the conception of intuitive thinking. One may constantly doubt with good reason whether had not geniuses of science made their great discoveries just with the help of their immense power of intuition. The latter position is laconically expressed in Poincaré's statement, "*Intuition* is the instrument of invention". So 1et us examine what is assumed by the term "intuitive thinking".[2]

The most apparent feature of the use of the term *intuition* is its striking ambivalence. In one of the recent investigations of the subject the situation is characterized as a "semantic jungle". No surprise that some authors admit that intuition is little understood though highly treasured and sought after.

Yet in one point all writers on intuition are unanimous. They all account just to intuition discoveries and inventions as well as other forms of intellectual insight.[3] Quite naturally, many writers strongly believe that intuition, whatever it might be, is the highest capacity of human mind. Some thinkers go further and insist that reason is only the "*servant*" of intuition. Scientists usually avoid this kind hurting expressions though they would readily agree with Poincaré's general assessment: "It is by logic that we prove; it is by intuition that we discover".

There are three main approaches to the phenomena labeled as intuitive. The oldest tradition is the mystical. Its followers use the term "*intuition*" to indicate intellectual

[2]Though one can trace almost all theoretical conceptions of human cognition back to Aristotle it comes out that he never used the term "intuitive thinking" in his theory of cognition and knowledge. But in the Nicomachean Ethics there is a certain admission of intuitive reasoning. "The intuitive reason, "explained Aristotle, "deals with ultimates at both ends of the mental process; for both the first and the last terms, that is both first principles and particular facts, are intuitively and not logically perceived... As universals then are reached by way of particulars, these facts must be grasped by perception, in other words, by intuitive reason." But one should not take this remark as an assumption of a special type of human cognition. Aristotle had clearly stated in the *Analytics* that the first principles and universals are reached through induction. Since particular facts are grasped by perception, and this is qualified as reached "by intuitive reason", it must be concluded that Aristotle's "intuitive reason" is identical to sense perception.

[3]It must be mentioned here that some writers like to propagate a romantic vision that Einstein created his theory of special relativity just by pure intuition, in complete isolation from the problems of theoretical physics and achievements of his predecessors. For instance, Jeremy Bernstein insisted that "in the creative work of a great physicist, "intuition" – a feeling of how the universe should be – plays a more important role in formulating this axiomatic structure than the results of any given experiment". (Jeremy Bernstein, *Einstein.* New York, Penguin Books, 1973, p.52.) To prove his position, he quoted Albert Einstein's remark on the Michelson-Morley experiment in an interview with a historian of physics a year before his death: "In my development Michelson's result has not had a considerable influence. I even do not remember if I knew of it at all when I wrote my first paper on the subject". But historians of physics and Einstein's biographers are not sure whether did the aging sage recollect the relations of the past correctly. Einstein himself had mentioned that he studied thoroughly Lorentz classical work on electrodynamics. And just in that book Lorentz presented in detail the famous hypothesis of relativistic contraction to overcome the principle difficulty, which arose from the negative result of the Michelson-Morley experiment.

phenomena regarded as extra-sensual, supernatural or even magical. Very close to this position stand writers who consider intuition among other alleged demonstrations of instinctive or unexplainable activities of human intellect. One can include into this group also those conceptions that consider religious experience as a phenomenon going beyond reason and unreachable for human limited powers of rational cognition. At present this approach to intuition is characteristic to writings propagating Eastern mystical teachings like Yoga and Zen Buddhism.

The second tradition comes from philosophers. To build a complete theory of knowledge, philosophers often have to struggle with the problem of "direct" cognition. To overcome related difficulties, some thinkers eventually introduce into epistemology the assumption of the knowledge gained directly by insight or intuition.

The third line of approach to intuition is presented by the conception of unconscious (or subconscious) creative thinking. It was first proposed by Henri Poincaré and soon became the prevailing conception of intuition and insight in the twentieth century psychology.

The most strange general feature of the above approaches is the fact that the mystical approach to intuition is quite logical, in its way, while the Poincaré conception seems lacking logic and reason in its essence. The mystical approach considers intuitive thinking as supernatural and magical. So it is quite reasonable that the proponents of mystical conception regard intuition as a power that cannot be understood. Poincaré tried to propose a rational conception of the process of scientific discoveries. But the main principle of his conception is the statement that scientific discoveries emerge out of unconscious or subconscious activity of human intellect. How can one hope to develop a rational theory of phenomena that are declared being out of reach of consciousness?

Returning to the problem of intuitive thinking we again have to deal with the main difficulty of its study. The phenomenon of intuition remained for many centuries elusive and puzzling mainly because the term was used in different and often incompatible meanings. Modern investigators of intuition were forced to develop special strategy to tackle this state of matters. They start their research by a systematic review of all meanings in which the term intuition is used. And then investigators try to build a theoretical-psychological model of the process of intuitive thinking that could be accounted for all fixed meanings of the term.[4]

Building this kind of "*totalitarian*" conception of intuitive thinking appears to me an impractical task. In fact, this book does not need an all-embracing theory. I will be completely satisfied if I reach a conception of intuition successfully explaining the main features of its demonstration in the process of scientific discoveries. So my research of intuition I limit with cases when scientists feel themselves forced to use the term intuition. As you will see, this approach of self-restriction helps to develop a completely rational conception of intuition that can be called "*the theory of scientific intuition*".

So, when does scientist allude to intuition? First of all, a scientist is driven to use the concept "intuition" when he is asked a straightforward question, "How did you come to your great discovery?" In the long history of science, no scientist was ever able to tell the successive steps of his thought that eventually brought him to his great idea. As a rule, the answer to this seemingly simple question is as follows: "*I made my discovery*

[4] One should posses an unlimited optimism if he is going to build a model explaining all meanings of the term intuition. The Oxford Dictionary tells of twenty different properties of intuition and insight, many of which appear completely incompatible with each other. Webster's New International Dictionary suggests a more limited set of characteristic features of intuition: "Revelation by insight or innate knowledge, a form of knowing that is akin to instinct or a divining empathy and gives direct insight. Quick and ready insight. The act or process of coming to direct knowledge or certainty without reasoning or inferring." But even this limited set involves a striking variety of notions like insight and innate knowledge, instinct and divine empathy, quick processing and ready answers, direct knowledge and complete certainty.

*intuitively*".

Trying to explain to the readers of *The Evolution of Physics* the phenomenon of sudden intuitive illumination, Albert Einstein found it most appropriate to refer to the experience of Conan Doyle's famous hero. So how did Sherlock Holmes found out solutions of numerous mysteries? The apparent answer is as follows, "*He plays his violin, or lounges in his armchair enjoying a pipe, when suddenly, by Jove, he has it!*".[5]

Of course, by telling that discoveries were made by intuition scientists did not unveil the way that led them to their striking success. Most probably, it is objectively impossible to reconstruct the successive steps that had eventually brought to any given great discovery. "*All rising to great place is by a winding stair*", believed Francis Bacon. Yet scientists never appeared capable to account for the steps by which they climbed by this legendary stair. The main reason is that actually there were not successive steps by which the scientist came to his discovery. In the process of his research, a scientist tries so many approaches, suggests and rejects so many ideas, spends so many days and weeks in the full darkness of the labyrinths of the tantalizing problem that there could be few traces of the successive steps of its solution. At least, all writers on intuition agree that when a scientist arrives at his great idea there is little if any awareness of the process by which he reached it. Jurgen Rehm and Volker Gadenne find this point of absence of clear awareness so essential that they define intuition as "judgments with no awareness about the rules for inference".[6] In his original characteristic of intuitive thoughts B. Clynche pointed out, "*I think we mean that we know something without knowing how we came to know it and without being able to prove it*".[7]

Subjectively, no great scientist is ready to admit how many fruitless approaches he had tried and what kind of apparently wrong ideas he had considered on the way to his discovery. Post factum, when the problem is solved, many people can clearly see the direct and wide road that led to the discovery. So it is very hard and painful for an explorer to tell people the real zigzag path of his research that often went in curious and even apparently wrong directions one could hardly expect from a great thinker.[8]

[5] Albert Einstein and Leopold Infeld, *The Evolution of Physics.* New York, Simon and Schuster, 1961, p.4.

[6] Jurgen T. Rehm and Volker Gadenne, *Intuitive Predictions and Professional Forecasts.* New York, Pergamon Press, 1990, p.7.

[7] Quoted in Tony Bastick, *Intuition. How we think and act.* New York, John Wiley & Sons, 1982, p.52.

[8] Only Max Wertheimer claimed that he had succeeded to clear out the details and "concrete events of thought" that brought Albert Einstein to the discovery of the theory of relativity. He was well aware that Einstein's famous papers and more popular lectures give only the final results and did not tell "the story of his thinking". So when in 1916 there appeared a lucky chance to talk with the great genius, Wertheimer tried hard to learn the most exciting point – the steps of thought that brought to the revolutionary discovery. Unfortunately, Wertheimer's account, which was first published in 1945, does not contain any single detail of the presentation of the theory of relativity that had not been widely known by that time. Moreover, Wertheimer insisted that during his talks with Einstein he understood that Michelson's experiments appeared to Einstein as "crucial" ones, very important and even "decisive". (Max Wertheimer, *Productive Thinking.* New York, Enlarged edition 1959, (First edition 1945), pp.213, 217.)

In fact, by 1916, Einstein did not explicitly mention Michelson's results in none of his numerous papers on relativity. For this same reason, one cannot be completely sure also in details of Professor Ishiwara's notes of Albert Einstein's lecture on relativity given in Kyoto in December 1922. According to these notes, Einstein's account of his early research of the problem of relativity was as follows: "While I cannot say exactly where that thought came from, I am certain that it was contained in the problem of the optical properties of moving bodies. When I first thought about this problem, I did not doubt the existence of the ether or the motion of the Earth through it.

"While I was thinking of this problem in my student years, I came to know the strange result of Michelson's experiment. Soon I came to the conclusion that our idea about the motion of the Earth with respect to the ether is incorrect, if we admit Michelson's null result as a fact. This was the first path which led me to the special theory of relativity. (Albert Einstein, *How I created the Theory of Relativity.*

In short, when scientists use the term "intuition" to account for ways that brought them to their great discoveries, in actuality, they just conceal the objective impossibility and subjective inability to reconstruct the successive steps on the way to their discoveries. Bernard Cohen pointed out that Albert Einstein strongly believed that scientists have no certain idea about the process of their discoveries.[9]

Admitting explicitly or implicitly that there were no successive steps leading to revolutionary ideas, many methodologists conclude that intuitive thinking to which they account great discoveries should be non-logical. So it sounds quite convincing when adherents of this viewpoint define intuition as "conscious awareness without logical reason". In the Middle Ages scholars made strict distinction between the logical power of *ratio* and the *intellect*, the latter interpreted as the power of direct insight. Some authors even believed that intuitive thinking is illogical.

The characteristics of the activity of an exploring mind as of non-logical process can be accepted only in some special sense. One just should bear in mind that by the term "non-logical thinking" here is understood the fact that for this kind of thinking there are no strict formal rules. But the absence of a rigorous logic of discoveries does not mean that there is no logic in the process of scientific research. We have proved above that any discovery is made with the help of method of hypotheses, its main phases being the analysis of the problem and idea generation by analogy. Of course, the method of hypotheses does not guarantee solutions of research problems. In that sense, the ways of an exploring mind are non-logical. But the hypothetical-deductive methodology provides the optimal organization of the undertaken research. Analytic-synthetic procedures are the real logic of research and discovery. So if the intuitive thinking is to be accounted for great discoveries, it would be totally wrong to characterize it as non-logical, and least of all, illogical.

Another type of situation inclining people to accept the idea of intuitive thinking is related to the well-known ability of outstanding professionals to solve complex problems almost instantaneously. Many famous physicians were able to diagnose momentarily cases of illnesses that appeared to their colleagues perplexing and puzzling. Talented mathematicians instantly find out solutions of problems that turned on as being very difficult and practically insurmountable for ordinary investigators.[10]

The impression from such instantaneous solutions is that scientists break the complex problems from the first sight, just at the very moment of their presentation. There is, apparently, no time spent for the analysis of the given problem and search of prototype problems, for idea generation and checking of solutions. In the case of such "*instantaneous*" solutions, scientists are again in difficulty to account the intermediate steps of the process of solution. They believe that the true solution was revealed to them momentarily. Naturally, only intuition could be supposed as the mental mechanism of such an insight.

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In: History of Physics. Readings from Physics Today. New York, American Institute of Physics, 1985, p.244.)

It should be noticed here that Albert Einstein had never checked the correctness of details of Professor Ishiwara's notes since they were published in 1923 in Japanese only.

[9] "Einstein said most emphatically," recalled Bernard Cohen, "that he thought the worst person to document any ideas about how discoveries are made is the discoverer." (Bernard Cohen, *Einstein and Newton*. In: Einstein. A Centenary Volume. Ed. by A. P. French. Cambridge, Harvard University Press, 1979, p. 40.)

[10] There is an excellent example concerning Richard Feynman. In 1967, James Bjorken carried on complex theoretical calculations of high-energy electron-proton collisions that were studied experimentally at the Stanford Linear Accelerator. Learning accidentally the main feature of the experimental data and some of Bjorken's results, Feynman succeeded to interpret the data with the help of his own model of elementary particle interactions. And it took Feynman only an evening of calculations. (John and Mary Gribbin. *Richard Feynman. A Life in Science*, p.198.)

But let us not hurry with conclusions. First, let us clear up which type of problems are solved momentarily? An instantaneous correct diagnosis of the illness of a given patient can suggest only an experienced physician who met in his practice many similar cases of diseased people. Similarly, a mathematician is able to see momentarily only solutions of familiar problems that previously did demand a good deal of time and effort.

In general, momentarily solutions are characteristic only for people who have sufficient experience of dealing with a given type of problem. Experts in the given field solve familiar problems quickly and correctly. We can admit they have a significantly strong intuition in their field of activity. But if they are suggested an unfamiliar type of problem, it will take them significant time to reach the solution. Their strong intuition is helpless dealing with unfamiliar problems. So we can now see that momentarily solutions do not require a special type of thinking or some unordinary ability. Simply, in the case of familiar problems, the analysis of a given problem takes place almost momentarily while the prototypes for idea generation are always at hand.[11]

The third source of the assumption of the existence of intuitive thinking is related to the well-established fact of discoveries made in the moment of insight. "*The single ¡right¿ answer comes in a flash of knowing*", believe D. J. Schallcross and D. A. Sisk.[12]

The flash of insight often takes place in circumstances when the explorer had put his research problem aside and was busy with some activity that had nothing in common with his previous research. The explorer himself is usually sure that at the moment of such an insight he had not made any conscious effort to solve his research problem. On the other hand, the solution itself came to the explorer as a momentarily vision of the true idea. George Polya describes the moment of illumination and insight as follows: "*After brooding over the problem for a long time without apparent progress, we suddenly conceive a bright idea, we see daylight, we have a flash of inspiration*".[13] So it is quite natural that people were inclined to explain such a spontaneous vision of the true solution as a clear evidence of cooperation of divine forces. Mathematicians like to quote Gauss' account of one of his discoveries, "*I succeeded not on account of mine painful efforts, but by the Grace of God. Like a flash of lightning the riddle happened to be solved*".[14]

But from the beginning of the twentieth century, almost all psychologists and methodologists explain the phenomenon of spontaneous insight with the help of conception of subconscious creative thinking. Since it is the predominant conception in this field, I will discuss it in the chapter that follows.

[11] Suppose we suggest a brilliant scientist to solve a chess problem. It is quite clear that if the scientist has not sufficient experience in solving chess problems, he will face serious difficulties. Even simple problems, if unusual, will take him a good deal of time and serious effort. But if a problem is an ordinary one and very familiar, its analysis and solution take place almost instantaneously. Considering these cases of fast solutions Mario Bunge pointed out, "Intuition is very fast reasoning, so fast that the process is not appreciated as reasoning".

[12] Doris J. Schallcross and Dorothy A. Sisk, *Intuition. An Inner Way of Knowing.* Buffalo, New York, Bearly Limited, 1989, p.6.

[13] George Polya, *Mathematical Discovery. On Understanding, Learning, and Teaching Problem Solving*, vol.2. New York, John Wiley & Sons, 1965, p.54.

[14] Quoted in W. H. Leatherdale, *The Role of Analogy, Model and Metaphor in Science.* Amsterdam, North-Holland Publishing Company, 1974, p.13.

## Step 13. THE HYPOTHESIS OF SUBCONSCIOUS THINKING

***"Alas! How easily things go wrong!."***

*B. Dowling*

There can be no doubt that people keep reasoning and proving by conscious effort. Already from the fourth century B. C., educated people learned from Aristotle's Analytics the strict rules of deduction and the principles of rational proof. But modern world's attitude to deductive reasoning, especially to its scholastic theory, was that of a dull and unproductive kind of human thinking. What seemed much more attractive was the process of idea generation, especially the mechanisms of discoveries and inventions.

Rene Descartes believed that the ability to solve scientific problems should be determined by some inborn factor. This ability was considered, by contrast to formal-logical thinking, as belonging to a higher level of cognition that could provide productive and creative forms of thinking. "*The human mind*", wrote the French thinker, "*has within it a sort of spark of the divine, in which the first seeds of useful ways of thinking are sown, seeds which, however neglected and stifled by studies which impede them, often bear fruit of their own accord*".[15]

It was quite clear that just theoretical discoveries present the most important instances of creative thinking. So, psychologists were eager to question famous scientists on their personal experience concerning the subtle phenomenon of high level cognition as well as of the special state of mind in the process of great discoveries.

Henry Poincaré, the prominent French mathematician and physicist, was one of the most famous scientists by the end of the nineteenth century.[16] Quite naturally, the Society of French psychologists asked him to tell some facts and details of his own personal experience in regard of state of mind in which his theoretical discoveries had been made. Poincaré himself liked to speculate upon general philosophical and methodological aspects of science and scientific knowledge. So he readily agreed to the suggestion of French psychologists. Moreover, Poincaré not only recollected some startling facts concerning his own scientific explorations, but also suggested a possible theoretical explanation for them.

The most remarkable fact accounted by Poincaré was about the circumstances in which one of his mathematical discoveries had been made. For several weeks Poincaré was absorbed in the research of a difficult problem in the theory of functions. The investigation advanced very slowly. Feeling himself exhausted by unproductive attempts of solution, Poincaré put aside the stubborn problem and left Paris for a short rest. Poincaré made no attempt to return to his research problem at his vacation. But one beautiful day, during a sight seeing trip, just amidst a talk with his friend, he suddenly realized the solution of the abandoned problem.[17]

[15] René Descartes, *Rules for the Direction of the Mind.* – In: The Philosophical Writings of Descartes, vol. 1. New York, Cambridge University Press, 1985, p.17.

[16] In Donald Davis' assessment, Poincare was "one of the most famous mathematicians of the time". (Donald M. Davis, *The Nature and Power of Mathematics.* Princeton, New Jersey, Princeton University Press, 1993, p.68.)

[17] Since Poincaré's account is the most significant factual basis of all modern conceptions of the psychology of creative thinking, I would like to quote it in more detail. Here is Poincare's story of his study of the so-called Fuchsian functions: "I wanted to represent these functions by the quotient of two series; this idea was perfectly conscious and deliberate; the analogy with elliptic functions guided me. I asked myself what properties these series must have if they existed and succeeded without difficulty in forming the series I have called thetafuchsian. "Just at this time. I left Caen, where I was living, to go on a geologic excursion under the auspices of the School of Mines. The incidents of the travel made me forget my mathematical work. Having reached Coutances, we entered an omnibus to go to some place or other.

To explain this fact of his own creative biography, Poincaré first considered the most probable factor, namely, the positive effect of having a good rest. After the exhausting weeks of research, his tired mind apparently got a good deal of rest. So, returning to his research problem, Poincaré could tackle it with a renewed mental power and consider it from a fresh viewpoint, a circumstance that always appeared very essential in problem solving.

But this reasonable explanation was unacceptable for Poincaré. He was completely sure that he did not attempt to examine the problem during his above-mentioned trip. Poincaré remembered well that the moment the solution flashed his mind he was involved in an interesting discussion with his friend.

The cardinal feature of the accounted phenomenon was that the discovery came all of a sudden, without any conscious effort. So Poincaré concluded that any acceptable explanation should assume some mechanism of unconscious thinking. "*Most striking at first is this appearance of sudden illumination, a manifest sign of long, unconscious prior work. The role of this unconscious work in mathematical invention appears to me incontestable*", summed up his personal observations the French prominent explorer.[18]

This line of argumentation eventually brought to the hypothesis of subconscious mechanism of creative thinking. Along with the conscious work of mind, there should be at work some yet unknown subconscious level. Moreover, the subconscious mind should work continuously, even while the conscious mind was at rest. And the moment when an idea of solution eventually appeared on the subconscious level, this idea would be pushed up to the surface to the conscious level where it would be perceived as a spontaneous solution coming from nowhere.

If one agrees that scientists, taking rest after a hard research, completely abandon their research problem, then Poincaré's account and many similar cases of sudden insight could be explained only assuming the existence of the subconscious level of creative thinking. Possibly that was the reason why psychologists and scientists accepted Poincaré's conception of subconscious thinking almost unanimously.

In actuality, the hypothesis of subconscious thinking meets insurmountable difficulties. Poincaré himself realized some of them. As an experienced scientist he knew well that there might be no insight into the solution of a research problem if it had not been consciously analyzed beforehand. No theoretical problem can be solved without previous conscious efforts to understand it. In face of this undeniable truth, Poincaré had to admit that sudden inspiration and insight "*never happen except for some days of voluntary effort*". Jaques Hadamard, a devoted follower of the conception of subconscious creative thinking, had to st ate clearly: "*Discovery necessarily depends on preliminary and more or less intense action of the conscious*".[19]

Another essential weakness of the conception of subconscious creative thinking is linked to the fact that it neglected at large the phases and steps of the process of problem solving. From all these essential and complex processes only one point was considered, namely, the combination of ideas. At the start of investigation, there are plenty combinations of ideas that can be regarded as useful for the solution of the problem under research. In fact, most of them appear to be of no help for the undertaken research. But the conscious mind perceives only "*fruitful*" combinations or some of those that could be fruitful. How can the conscious mind avoid considering the huge amount of fruitless

At the moment when I put my foot on the step, the idea came to me, without anything in my former thoughts seeming to have paved the ways to it, that transformations I had used to define the Fuchsian functions were identical with those of non-Euclidean geometry." (Quoted in Jacques Hadamard, *An Essay on the Psychology of Invention in the Mathematical Field.* New York, Dover Publications, 1954, p.12.)

[18] Jaques Hadamard, *op. cit.*, p.14.

[19] Jacques Hadamard, *op. cit.*, p.44

combinations? Being completely isolated from the logic of problem solving, Poincaré and his followers failed to realize the role of the analysis of the problem as of the most effective means to cut off all the irrelevant information and possible combinations. For this reason, they could suppose only the possible help coming again from the hypothetical unconscious.[20]

Returning back to the main obstacle of the conception of subconscious thinking. It is almost unanimously accepted that there could be no solution of a serious scientific problem if it is not thoroughly analyzed at the conscious level. To save his hypothesis of subconscious thinking, Poincaré had to add a new assumption: the subconscious creative thinking should be "*triggered*" on by the conscious analysis of the problem under research. The conscious efforts to reach the solution "*set going the unconscious machine*". Without preliminary conscious work over the given problem, explained Poincaré, the unconscious machine "*would not have moved and would have produced nothing*".[21] This artificial ad hoc assumption cannot be properly defended. No one can answer what can prevent the subconscious thinking to begin on its own the investigation and solution of research problems. Especially if one bears in mind that the subconscious mind was supposed to be able to solve problems that appeared unsolvable during intensive conscious research.

Another serious difficulty arises in regard of the phase of "*incubation*". When the problem under research is supposed to be processed on the subconscious level, the period of time during which the solution is found out Poincaré characterized as the phase of "*incubation*". But it is well known that many discoveries have been made in result of the conscious investigation of the research problem just "*sitting at the desk*". So Poincaré was forced to make another additional assumption according to which creative thinking can proceed in two parallel lines – one conscious, the other – subconscious.[22]

If psychologists were not so much fascinated by the romantic hypothesis of subconscious creative thinking, they could easily deny the conception of "*incubation*" experimentally. Suppose a group of students is given a problem of medium difficulty. After a short conscious analysis the students are told, according to the plan of the experiment, to sweep aside the problem till the next meeting. According to the conception of unconscious thinking, in these conditions of the experiment the given problem would be transferred to the phase of subconscious "*incubation*". But if the next meeting with the students of this experimental group were scheduled to take place after several weeks or

[20] "It is obvious that invention or discovery, be it in mathematics or anywhere else, takes place by combining ideas," asserted Jacques Hadamard the principle position of his great forerunner. But being isolated from the theory of problem solving, he could hardly see any other way but that of assuming the unconscious construction of possible combinations of ideas and choosing the fruitful ones among them, again on the level of unconscious thinking. Moreover, forgetting that this assumption itself needs a proof, Hadamard made from it far reaching conclusions on the nature of the subconscious thinking. "This shows us again," insisted Hadamard, "the manifold character of the unconscious, which is necessary to construct those numerous combinations and to compare them with each other." (Jacques Hadamard, *op. cit.*, p.29.)

[21] Some psychologists prefer to speak of the complementarity of the conscious logical investigation and the subconscious intuitive thinking. "Intuition is not opposed to reason, but works with it in a complementary fashion," wrote Frances Vaughan. Yet he, like many other psychologists, believed that the rational and conscious part of research "would, in fact, be useless if it were not complemented by the intuition that gives scientists new insights and makes them creative". (Frances E. Vaughan, *Awakening Intuition.* New York, Anchor Books, 1979, p.150.)

[22] There is plenty of evidence that "the Eureka experience" and insight come after a certain interval of delay time, which sometimes can take weeks, months, and even years. But do these facts prove that during these periods of delay the unsolved problems had undergone the process of "incubation"? Of course, the idea of incubation can be evaluated as a very hypothetical assumption only. "The incubation period," points out Tony Bastick, "has given writers the idea that the subconscious mind has been somehow "reasoning" or working on the information in the same way as the conscious mind would reason, and when the answer is reached it pops into consciousness. Hence they wrongly infer that intuition is the same type of process as analytic reasoning but at a preconscious level." (Tony Bastick, *Intuition. How We Think and Act.* New York, John Wiley & Sons, 1982, p.147.)

months, it would come clear that most of the students had just forgotten the problem, at least its many significant parameters. That would prove that there is neither a process of "*incubation*" nor the hypothetical subconscious level of creative thinking.

There is another insurmountable difficulty for Poincaré's conception also. Ideas produced by a spontaneous insight and illumination are of a very general nature. Insight and illumination give birth to a general scheme of solution only. Moreover, Poincaré was aware that the subconscious is unable to accomplish simplest calculations. But what kind of intellectual capacities are needed for simple calculations? These are the abilities to identify and compare, which, in turn, suppose some minimal memory. Since it is evident that the hypothetical subconscious mind is unable to accomplish even the simplest calculations, it must be admitted that the subconscious intellect is lacking at least one of the above mentioned intellectual abilities. But if subconscious mind has not a minimal memory or is unable either to identify or compare, it never can function as an effective cognitive instrument. That means that if the subconscious level of thinking even existed, it would be absolutely unable to solve any research problem.

## Step 14. THE LAW OF CONSTANT ALERTNESS

***"True insight is a divine reward for the never-resting mind."***

*Anonymous*

We have revealed above the characteristic situations where referring to intuitive thinking seems necessary or at least useful. First, it is when famous scientists are unable to recall the successive steps of their great discoveries. Second, distinguished professionals often demonstrate their ability to solve problems in their field of activity almost instantly and effortlessly. The third and most impressive case is that of a sudden insight and spontaneous solution of a difficult research problem. But in all these cases the term intuition just helps to conceal the inability to explain rationally the said startling phenomena.

Now I will show how convincingly one can build the rational conception of intuition and insight on the ground of the above outlined analytic-synthetic conception of the logic of research and discoveries. According to this conception, any research problem is solved by the successive cycles of analysis, synthesis, and verification. Idea generation is always accomplished by an analogy with the solution of some similar problem. Regarding the case of great discoveries, one has to look for very remote prototype problems that often seem to be so irrelevant to the problem under research that only crazy people may consider them seriously.

This is the real logic of great discoveries. But this logic never assumes a sequence of successive steps that can *guarantee* the solution of the research problems. In fact, the logic of scientific discoveries is a kind of logic of *search*, which makes it only probable that the solution of the problem under research will eventually be revealed. On the other hand, this logic provides the optimal way for the search of the solution of a given problem. The analytic-synthetic conception does not make an over-ambitious claim, but it provides the true method of effective research.

Bearing in mind this specificity of the logic of great discoveries, one can easily understand why is it so difficult for famous scientists to tell the sequence of thoughts that actually have brought them to their discoveries. The main point is that there never existed a logical sequence of steps on the way to a great discovery. All was achieved by an unceasing search, by climbing and falling, retreating and sidestepping.

Now let us consider the second case when the term "*intuition*" denotes the ability of outstanding professionals to solve the problems of their field of activity almost without any effort. Let us ask three simple questions. Can a professional effectively solve problems of his field of activity if he is not endowed by sufficient level of intellectual capacities? The negative answer is entirely clear. So we conclude that the first necessary component of intuition is the sufficient level of intellectual capacities, namely the abilities of problem analysis and idea generation.

The second question is the following: *Can a professional effectively solve problems of his field if he has not sufficient knowledge concerning the subject of research?* It is evident that he cannot. So the second necessary component of intuition is the sufficient amount and level of relevant knowledge.

Now the third question.*Can a new-comer have a strong intuition in the given field of activity?* Surely, he cannot. Simplest research problems can puzzle a newcomer. One cannot seriously speak about the intuition of an inexperienced newcomer in a given field. Only the intensive personal research experience brings to the formation of strong intuition. As E. Fishbein had underlined, "*Intuitions base themselves on mental habits*". Only systematic activity and experience form habits. Without personal experience any theoretical knowledge remains a kind of abstract speculation. Only experience provides effective use of general knowledge. Life constantly confirms the wise saying that one thorn of experience is worth a whole wilderness of warning.

With the help of these three questions we have uncovered the *necessary* components of intuition, namely, intellectual capacities, knowledge, and experience. But, perhaps, these three components are also *sufficient* for the formation of intuition? In fact, they are. Consider a professional having high intellectual capacities, deep knowledge of the field of his investigation, and rich personal research experience in the given field. It is quite evident that such a scientist will solve problems of his field most effectively, often without a notable effort. We would have a good reason to say that this scientist has developed strong intuition.

Thus, one must accept that the intellectual capacities of a person together with his knowledge and experience are the necessary and sufficient components for the formation of scientific intuition.[23]

But how can one explain from this viewpoint the really startling cases of spontaneous solutions of difficult problems usually accounted to the activity of the mysterious insight and intuition? If we assume for a moment that shifting aside the problem under research the investigator totally forgets about it, then the assumption of the existence of subconscious creative thinking would seem unavoidable. But in the above discussion we have convincingly demonstrated that the assumption of subconscious creative thinking is completely fruitless.

So let us consider again the situation when a scientist puts aside an important problem he has not succeeded to solve. Does his mind *totally* forget about the unsolved problem the moment the problem is shifted aside? Of course, it does not. Such a problem is just shifted from scientist's short-term operative memory into the general memory. More than that, the stubborn problem has, for many reasons, a very special standing for its investigators conscious mind. First, the problem is evidently very important to him since he has explored the problem to the level of self-exhaustion. Second, the failure to solve a significant problem hurts investigator's pride and self-esteem. These two factors do not permit the scientist to forget the abandoned problem. "*You cannot get rid of your problem, it follows you everywhere*", noticed George Polya. Even putting the stubborn problem aside, the investigator remains continually aware of its existence. "*A number of pioneering studies carried out during the early years of the century showed that people are surprisingly good at focusing their attention upon a given task and ignoring irrelevant*

[23] I have presented my conception of intuition first in my book —em The Methodological Analysis of the Process of Discoveries and Inventions, Yerevan, 1984 (in Russian).

*events in their immediate surroundings,*" pointed out James Reason.[24] When asked by friends how he succeeded to make his great discovery of the law of universal gravitation, Newton revealed his secret, "*I continually kept thinking about it*".

My hypothesis is that in the case of spontaneous insight this awareness is of an extreme level. In regard of the abandoned important problem the mind of a scientist seems to be in a state of constant alert. The important problem, even put aside and apparently abandoned, remains for its investigator actually the problem no.1. Each new piece of information, each new association is processed in the light of this dominant task. In Leibnitz' words, scientist's "*spying attention catches whatever seems relevant*". Such a constant readiness to hit the target brings, sooner or later, to an analogy, to some remote prototype problem that gives birth to the idea of solution. A biographer mentioned on Newton, "*What he thought, he thought on continually*". Newton himself described his attitude as follows: "*I keep the subject constantly before me and wait until the first dawnings open slowly, by little and little, into a full and clear light*".[25]

To prove further my hypothesis of the state of constant alertness, I would like to examine what kinds of ideas are produced by spontaneous insight. Any discovery is started by insight, but no discovery is born as a complete creation. A discovery first comes to light only as a general idea, as the main principle of solution. The moment of insight illuminates just the general idea, the main pattern. Only further examination reveals the complete structure and provides detailed proof of the new theoretical conception. Characterizing solutions brought to light by momentary insight, Poincaré himself mentioned that the only thing that the subconscious creative mind is able to uncover is the general idea of solution. This kind of insight or illumination is the departure point for further complete theoretical elaboration by the investigator.

*Being in the state of constant alert, the mind of an investigator conceives all new information as a hint or possible way that can lead to the solution of the problem he was forced to shift aside. So when investigator's searching mind meets such an information and realizes that the long awaited idea is finally found out, there arises a feeling of illumination, of a sudden clear vision of the truth.* Naturally, the investigator perceives this momentary vision of the true path as some divine insight, as an instance of heavenly illumination. In actuality, it was just the moment when some new information or momentarily association helped the investigator to realize that the problem under research could be solved by analogy with a certain prototype problem.

It is interesting that the insight, which helped Poincaré to build his conception of subconscious thinking, was just a case when an investigator succeeded to see a remote analogy leading to the solution of his research problem. In his paper, Poincaré recalled that he, in the moment of sudden illumination, had realized that there was an analogy between the particular problem of the theory of functions he was unsuccessfully exploring and the non-Euclidean geometry, which he knew quite well.[26]

[24] James Reason, *Human Error.* Cambridge, Cambridge University Press, 1990, p.27.

[25] Quoted in Richard S. Westfall, *Never at Rest. A Biography of Isaac Newton.* Cambridge, Cambridge University Press, 1980, p.174.

[26] In face of the importance of my claim that insight and illumination are just the moments when a scientist realizes the existence of an analogy between the problem he intended to solve and some problem already solved, I would like to present a direct evidence from Poincaré's famous story. "At the moment when I put my foot on the step," tells Poincare, "the idea came to me, without anything in my former thoughts seeming to have paved the way to it, that transformations I had used to define the Fuchsian functions were identical with those of non-Euclidean geometry." You see, all the illumination was the realization of the analogy (or identity, in Poincare's terms) between the Fuchsian functions and non-Euclidean geometry. In the second important case of Poincaré's story, the insight again revealed an analogy. Here is Poincare's own evidence. "One morning," recalled Poincaré, " walking on the bluff, the idea came to me, with just the same characteristics of brevity, suddenness and immediate certainty, that the arithmetic transformations of indefinite ternary quadratic forms were identical with those of non-Euclidean geometry". (Quoted in Jacques Hadamard, *An Essay on the Psychology of Invention in*

That the exciting moment of illumination is just the moment when an explorer realizes some helpful analogy can be clearly traced also in Paul Dirac's recollection of the circumstances of his discovery of the method of matrix commutation in quantum mechanics.[27]

It is widely accepted that analogy is the most usual means of idea generation during normal conscious research. I am sure, if people read more carefully the essay of Poincaré and noted that his psychological interpretations concerned just a case of analogy, they would be less inclined to adopt the romantic and mysterious conception of subconscious thinking.[28]

It should be realized also that the flash of insight more readily illuminates the mind of a man who has sufficient level of the necessary components of intuition – analytic-synthetic abilities, knowledge and personal experience – and has carried on sufficient amount of preparatory conscious research of the problem. An ingenious idea takes its sudden birth when two remote pieces of information (that of the problem under research and of the prototype problem) meet each other spontaneously. But to realize the historic meeting, one has to have the necessary abilities and, what is even more important, one must be on constant alert. "*Hunches, global grasps, and other forms of intuition*", explained Mario Bunge, "*occur as a result of the careful analysis of problems, as a reward for patient and often obsessive preoccupation with them*".[29] E. W. Sinnot even insisted on the necessity to be "*immersed' in the subject of the undertaken research:* "Such inspirations, it is well recognized, rarely come unless an individual has immersed himself in a subject. He must have a rich background of knowledge and experience in it... without this flash the creative process might never have been able to get started*"*.[30]

*A good theory is the most practical thing. Conversely, a bad theory can be very damaging. Consider the conception of subconscious creative thinking. If one strongly believes that discoveries are made on the level of subconscious mental processes, then it will be quite reasonable to suppose that any conscious effort to solve the problem under research is directly hindering the process of subconscious discovery. Advocates of such an extreme viewpoint advice scientists:" Let the subconscious to do the work*".[31] A similar advice you can meet in the works of writers propagating the mystical interpretation of intuition. They teach to rely fully on intuition and inner feelings. "*Intuition can and does cut through confusion to show you what is true*", declares Frances Vaughan. But

*the Mathematical Field.* New York, Dover Publications, 1954.)

[27]Paul Dirac, yet an unknown young physicist, intensively worked over his problem for several weeks, day after day. Only on Sundays he put aside his research and went out of town, wandering in surrounding hills. Yet he could not get himself completely free of his research problem even during these outings. Dirac did not consider his research problem consciously, but he felt its presence at the periphery of his mind. And all of a sudden, during a routine walk, there came the insight that the problem of the commutation of Hiesenberg matrixes has a direct analogy with so-called Poisson-bracket. (Paul Dirac, *Recollections of an Exciting Era. – In: History of Twentieth Century Physics.* Proceedings of the International School of Physics "Enrico Fermi". Course LVII. New York, Academic Press, 1977, p.121.)

There are so many recollections of prominent scientists on their discoveries made occasionally during a regular quiet walk that one has to consider seriously whether was not Nietzsche right when he declared, "Only ideas won by walking have any value".

[28]W. H. Leatherdale noticed the connection of the flash of insight and a corresponding analogy. He explained that the feeling of irrelevance of the insight and preceding conscious efforts is an illusion. (W. H. Leatherdale, *The Role of Analogy, Model and Metaphor in Science.* Amsterdam, North-Holland Publishing Company, 1974, p.20.)

Close to this position came also Philip Johnson-Liard in his paper on the role of analogies in creative problem solving. (Philip N. Johnson-Liard, Analogy and the Exercise of Creativity. In: *Similarity and Analogical Reasoning.* Edited by Stella Vosniadou and Andrew Ortony. Cambridge, Cambridge University Press, 1989, p.313.)

[29]Mario Bunge, *Intuition and Science.* Englewood Cliffs, NJ, Prentice Hall, 1962, p.117.

[30]Quoted Tony Bastick, *Intuition. How We Think and Act.* New York, Wiley & Sons, 1982, p.27.

[31]See, for instance, D. E. H. Jones. *Let Your Unconscious Do the Thinking.* – "New Scientist". L., 1979, vol. 83, No. 1171, p.722 – 723.

such an advice is entirely misleading. Without conscious analysis no theoretical problem can be solved. There would be no discovery if one formulates the problem and then puts it aside hoping naively that the subconscious creative forces of his intellect would solve the problem.[32]

I would like to mention that rejecting the idea that besides the conscious thinking there exists also a special kind of subconscious thinking, I am in no way denying the existence of unconscious mental processes. I fully accept Wilhelm Wundt's remark that human consciousness realizes only the results of mental processes. All the mental processes going on in the brain are out of reach of human senses, and just in this sens they can be qualified as being unconscious.

Some finishing notes. I have proved above that intuition is the entity of problem solving capacities, knowledge and experience. So, every one has an intuition, but *just corresponding to the level of his intellectual capacities, knowledge and experience in the given field of activity.* Intuition is not alien to ordinary people and ordinary research. Just different people have different level of intuition, and different problems require different power of insight. "*All of us*", prove Tony Bastick, "*have this ability. In various degrees they [intuitions] pervade everything we do. They vary from the scientific awesome moments of creative inspiration to the day-to-day hunches and "*feelings*" which guide our common actions*".[33]

Actually, we use the term "*intuition*" only in cases of its strong and impressive demonstrations. There is no need to speak of intuition when every one sees the way to the prototype problem and to the solution itself. But when the helping analogy is so remote that there is no logical way to it or when only rich personal experience is helpful to find it out, people are inclined to account the solution to some unknown factor, calling it by mysterious term "*intuition*".

## Step 15. THE LAW OF GREAT AMBITIONS

***"Fortune helps the brave."***

*Terence*

Again we return to the central question of our investigation. How it happened that the real geniuses of science, far from being endowed with outstanding intellectual abilities of talents, still succeeded to make their great discoveries?

Since it is extremely difficult to propose any satisfactory general answer to the question, let us consider the cases of each one of the real geniuses separately.

Michael Faraday carried out over 16,000 experiments to discover the laws of electromagnetic phenomena. So there can naturally arise the question if were not these 16,000 experiments enough for any scientist to discover the same laws?

Charles Darwin kept gathering new evidence on the evolution of species for almost 23 years after his return from the voyage of the *Beagle* until being pressed by the discovery of Alfred Wallace. One can agree with Loren Eiseley that without Darwin's *A Naturalist's Voyage around the World* there might have been no Wallace. But not less

[32]Strictly following the conception of unconscious thinking one can land finally at a position neglecting knowledge and experience. Reason and knowledge might appear superficial and unnecessary. Instead, students should follow T.S. Elliot's advice, "In order to arrive at what you do not know, you must go by a way which is the way of ignorance". (See, for instance, Frances E. Vaughan, *Awakening Intuition.* New York, Anchor Books, 1979.)

[33]Tony Bastick, Intuition. How We Think and Act. New York, John Wiley & Sons, 1982, p.2.

legitimate seems the assumption that Darwin, without the stimulus of Wallace, would hardly discover the mechanism of evolution.[34]

Gregor Mendel made his great discovery experimenting with peas, which appeared to be extremely helpful for genetic analysis. But Mendel failed to corroborate the laws of genetics in his following experiments. So it can be supposed that Mendel's discovery was determined mainly by the lucky choice of the experimental plant. (It is well known that a lucky circumstance, in general, had always been an important factor in empiric discoveries.)

There remains only Albert Einstein's creative biography to help us to reveal the secret of geniality. So what is the secret that helped Einstein to make his great discoveries?

To find out the answer we have to consider scrupulously the ways and steps through which Einstein made his discoveries. As it was mentioned above, an explorer meets unsurpassable obstacles when he tries to reconstruct the real path that brought them to the given discovery. To solve a serious scientific problem one has to try a huge number of different ideas and hypotheses, the predominant part of them having little to do with the final solution. So when an idea comes out to be the successful solution of the problem under research scientists cannot, as a rule, recall the strict sequence of thoughts by which the idea was born. Moreover, Paul Dirac insisted that a scientist readily forgets the way he made his discovery. Especially in view of the fact that explorers come to their discoveries by confused and winding ways, often following wrong directions of thought, while after the discovery is made it appears so clear what a simple and direct way could bring to it.[35]

Einstein's *Autobiographical Notes* contain no single sentence about the steps and ways of his discoveries. Except of few pages dealing with different aspects of his intellectual development, the remaining content of the notes is devoted to the discussion of the general aspects of the theory of relativity. In addition, Einstein himself reminded the reader that "*every reminiscence is colored by today's being what it is*". So he concluded that what he had said in these autobiographical notes were true "*only within a certain sense*". I would like to mention also the story of the first wonder he experienced in his life when at the age of four he watched the striking behavior of the needle of a magnetic compass. Einstein begins this story with the words: "*I can remember – or at least believe I can remember*".

In regard of the steps which led Einstein to his great discoveries, the most reliable source are the letters Einstein wrote those days. We will see in the following discussions how much instructive these letters are. Anyhow one should not have too big expectations. If Einstein's letters contained a clear-cut presentation of the paths, which led him to his historical discoveries, his biographers would long ago reveal the secret of his genius.[36]

Explorers find only things they are looking for. Hints are useful only when the explorer is ready to conceive them. The important evidence contained in Einstein's letters can be functional only in the case if we have a heuristic conception, a hypothetical expectation of the "*secret intellectual weapon*" of the real geniuses of science. Hence, to reach an adequate understanding, we have to consider the problem, first of all, theoretically.

So I formulate the central question of my discussion: "*What is the most necessary condition for an explorer to make a fundamental theoretical discovery?*"

[34] "In fact, the more one examines the relationship of the two men the more one is impressed with the likelihood that without the stimulus of Darwin, there might have been no Wallace, just as, without the stimulus of Wallace, Darwin might never have got around to formal publication," sums up his position Loren Eiseley. (See Loren Eiseley, *Darwin's Century. Evolution and the Men Who Discovered It.* New York, Anchor Books, 1961, p. 157.)

[35] Paul Dirac, *Recollections of an Exciting Era.* in: History of Twentieth Century Physics, p.109.

[36] In actuality, the predominant number of books on Einstein's life and scientific heritage had been written before the publication of his letters in the *Collected Papers of Albert Einstein.*

I am going to prove that the answer to this principle question is as follows: To make a fundamental theoretical discovery, one has to be, first of all, *ambitious.* I mean, one has to have a strong inner conviction that he is able to solve the most fundamental problems of science, this conviction being supported by strong determination to solve them.

Consider a scientist satisfied with the routine of solving *ordinary* research problems, publishing numerous papers and discussing them with his colleagues. He will soon become a good professional and can eventually make some positive contribution to the advancement of science. But such an investigator has practically no chance to make a great discovery. Einstein once mentioned that he should be glad that he failed to enter the scientific ranks immediately after graduating from Zurich Polytechnic Institute. An academic career, explained Einstein, compels a young man to immediate scientific production, which is easy to accomplish dealing with second rate problems.

If a scientist has no ambitions, if he does not attempt to reveal the basic laws of nature, if he is not in a constant search of answers to the fundamental questions of science, then no great idea would come to his mind. Moreover, even confronted face to face with a great idea, he would not be able to recognize its real value and see its basic importance for the building of a new revolutionary theory.

Only basic questions give birth to great ideas. "*Great deeds demand great obstacles,*" underlined Loren Eisley. If a fundamental question did not strike the mind of a scientist, and if it did not catch his attention, then he will never make any great discovery. Not being involved in basic analysis of a fundamental problem, a scientist will miss its solution even observing closely the particular idea that could lead to a revolutionary theory.

Loren Eiseley revealed a really striking case concerning Sir Charles Lyell whose *Principles of Geology* had immensely influenced young Charles Darwin. The point, which amazed Eiseley, is really exceptional. In the second volume of *Principles of Geology* where many important topics of biology were discussed Lyell formulated the law of the struggle for existence and showed its dominant role in the life of species. Yet Lyell failed to realize that with the help of this law one could explain the mystery of evolution of life on the earth.

Here arise two questions of extreme theoretical importance. How it happened that Sir Charles Lyell, convincingly demonstrating the huge impact of the universal struggle for existence on the living world, did not yet use it to build a radically new theory of evolution? Second, why did not Charles Darwin use the important idea of Lyell, which he learned on the board of the Beagle in 1832, for his goal of building the theory of evolution and, instead, prolonged his great discovery until the publication of the *Origin of Species* in 1859?

Loren Eiseley tries to explain the failure of Lyell supposing that the famous scientist was handicapped by his non-progressionist general conception of the living world.[37] But this argument does not work satisfactorily. If the non-progressionism were the real reason, it would not prevent Charles Darwin to build his theory of evolution much earlier since he was completely free from such a prejudgment.

Everything neatly matches its place when we notice that Lyell never intended to build a new theory of evolution of species. In the absence of such an intention, no observation or idea could lead Lyell to the formulation of a new evolutionary theory. Even if he were successful to discover all the laws of organic evolution, he would not compose from them a new theory since he did not consider such a task.

The same is true in regard of young Charles Darwin, before he undertook the task of developing a new theory of evolution. In 1832, when Darwin studied Lyell's volume, he was an inexperienced naturalist very far from a dream to elaborate a theory of his

[37] Loren Eiseley, *Darwin's Century*, p.106-108.

own. So no idea of Lyell's work could lead young Darwin to the formulation of the new conception of the origin of species.

In general, hints are useful only for a mind preoccupied by the search of solutions. Even an idea decisive for the complete solution of a problem will be of no use for a scientist if he is not involved in its investigation.

Albert Einstein was a living legend of twentieth century physics. The traditional image of Einstein is that of a very sympathetic, shy and lonely young man who had never been appreciated by his teachers and professors, but instead, at the age of 26, produced from nowhere three papers containing the greatest discoveries of the century. Such a legendary phenomenon of a one-month long mental explosion that revolutionized physical science for many decades is really unexplainable. Thanks to god, the reality was essentially different.

Though markedly shy and a bit lazy, Albert Einstein was very ambitious from the first years at the Zurich Polytechnic Institute. Already in 1895, just before starting his studies at the Institute, he outlined a program for the investigation of the difficulties of the conception of the ether – the basic instrument of classical field theory.[38] The general impression of Albert Einstein as of a student was that of a young man "*who thought he knew more than his elders and betters*".[39] "*Elders*" were his professors, "*betters*" – his friends who were more successful in their learning and academic efforts. In fact, Einstein's high self-appraisal was not a mere exaggeration common to many youngsters. It was based on his ability to see, sometimes just to feel the weaknesses of the widely accepted conceptions and theories.

Most of all he was disturbed by the strange statue of ether in the classical electromagnetic theory. Related to it, he became dissatisfied with the conception of the absolute motion in the Newtonian mechanics. Already in September, 1899 he mentioned in his letter to his sweetheart Mileva Marič that he had written to Professor Wien about "*the relative motion of the luminiferous ether against ponderable matter*", which topic, according to Einstein, was treated by classical theory in a very "*stepmotherly fashion*".[40] In an earlier letter of August, 1899 he told Mileva the reason of his dissatisfaction with classical theory in a more detailed way: "*I am more and more convinced that the electrodynamics of moving bodies, as presented today, is not correct... The introduction of the term "*ether*" into the theories of electricity led to the notion of a medium of whose motion one can speak without being able, I believe, to associate a physical meaning with this statement*".

Einstein was not satisfied either with Planck's new conception. Usually the situation is presented in a very simplified form according to which Einstein immediately approved Planck's theory and developed it further suggesting the idea of light quanta. In actuality, Einstein had serious doubts in regard of quantum conception of radiation. "*About Max Planck's studies on radiation*", wrote Einstein in a letter to Mileva Marič in April 1901, "*misgivings of a fundamental nature have arisen in my mind, so that I am reading his article with mixed feelings*".[41]

Ambitions are necessary, but not sufficient for great deeds. An acquaintance of mine

[38]Albert Einstein, *On the Investigation of the State of the Ether in Magnetic Field.* Albert Einstein – Caesar Koch, summer 1895. *The Collected Papers of Albert Einstein*, vol.1, p.4.

[39]Ronald W. Clark, *Einstein. The Life and Times.* New York, The World Publishing Company, 1971, p.74. On another occasion, Ronald Clark directly mentions that young Einstein was really ambitious even in the ordinary meaning of the term: "There was also his personal ambition. It is fashionable to think of Einstein as a man insulated from the problems of real life, never worrying about money, scornful of honors and careless of the position which the world accorded him. Later on, as the most famous scientist in the world, he could afford to be causal. But earlier ... he had perfectly valid reasons for wishing to press on for recognition." (*Ibidem*, p.131.)

[40]*The Collected Papers of Albert Einstein*, vol.1, p.135.

[41]*Ibidem*, p.162.

was completely sure he could become one of the best chess players in the world if he went for it seriously; but he did no real effort in that direction, and he was never the best even in our friendly circle. Great ambition must be supported by hard work.

Ambition is a very positive factor if it functions as a driving force for great efforts. Just as in the case of Albert Einstein. Popular stories tell us of a genius who in a short period of several weeks realized the most important problems of physics, concentrated on them and revealed the absolute truth concerning the deepest secrets of nature.

The reality was far different from this exciting but simplistic picture. Biographers prove that the above-mentioned program formulated by young Einstein for the investigation of the problem of ether should be dated summer 1895. So it took Einstein over 10 years to solve the problem of the electrodynamics of moving bodies. Einstein's letters to Mileva Marič clearly show that he was deeply involved in the investigation of relativity and electromagnetic radiation at least during the period of six years preceding his famous publications.

Moreover, letters to Mileva Marič prove that already in 1901 Einstein formulated to himself the concrete problems of his 1905 fascinating papers. In March 1899, Einstein wrote that his "*broodings*" about radiation were "*starting to get on somewhat firmer ground*". In August of the same year, he mentioned his intention to present the electrodynamics of moving bodies "*in a simpler way*". A month later Einstein wrote to Marič, "*A good idea occurred to me in Aarau about a way of investigating how the bodies' relative motion with respect to the luminiferous ether affects the velocity of propagation of light in transparent bodies*". In April 1901, he mentioned his considerations in regard of Max Planck's quantum conception. The same month he wrote of his lengthy talks with Michele Besso on luminiferous ether, absolute rest, molecular forces, surface phenomena and dissociation. It is remarkable, that just the days when he studied the electron theory of metals he was preoccupied with Planck's quantum hypothesis. This lucky coincidence could spark Einstein's first insight into his future photon conception of light. A sentence of the December 1901 letter proves that already from this days Einstein was brooding over the concrete problem of his most famous 1905 paper: "*I am now working eagerly on an electrodynamics of moving bodies, which promises to become a capital paper*".[42]

Einstein's letters prove that there was neither a direct insight into the secrets of nature nor a declaration of the final truth. Einstein was curious himself whether something will come out of his broodings. Several times he mentioned that his thoughts had "*again sunk back into the sea of haziness*". Not all of his expectations came out to be true. In December, 1901 he wrote, "*I got again a very self-evident and important scientific idea about molecular forces... If this were true, then this would be end of the molecular-kinetic theory of liquids*". As we know, the molecular-kinetic theory succeeded to survive.

Now I would like to discuss another aspect of my thesis of great ambitions. In their social relations and claims, all my real geniuses were very shy and unpretending individuals. Yet, in regard of their destination in science their ambition was enormous, though often well hidden.

Socrates was widely known for his modest way of life and the ability to talk even to child as an equal to him. Yet, he was enormously ambitious and believed that his single occupation – life long talks with anyone ready to listen to him – was predestined by the Heavens. In Plato's *Apology*, Socrates expressed his belief straightforwardly, "*Now, this duty of cross-examining other men has been imposed upon me by God; and has been*

[42] *The Collected Papers of Albert Einstein*, vol.1, pp.126, 131, 133, 135, 162-163, 187. Some of these ideas are mentioned also in two letters to Marcel Grossmann. In April 1901 Albert wrote to his friend, "As to science, I have a few splendid ideas, which now only need proper incubation. I am convinced that my theory of atomic attraction forces can also be extended to gases". Some months later Albert wrote of his new idea of a simple method "of investigating the relative motion of matter with respect to luminiferous ether that is based on ordinary interference experiments". (*Ibidem*, pp.165, 181.)

*signified to me by oracles, visions, and every way in which the will of divine power was ever intimated to any one*". So he held it natural that the world had decided that he was in some way superior to other men.

In the case of Charles Darwin, the task of proving his ambitiousness is significantly easier since I found direct evidence in his *Autobiography.* Recalling days of his voyage on the *Beagle*, Charles Darwin mentioned the following. "*As far as I can judge of myself, I worked to the utmost during the voyage from the mere pleasure of investigation, and from my strong desire to add a few facts to the great mass of facts in Natural Science*". It sounds like a quite modest attitude of a freshman. But immediately Darwin added the crucial sentence: "*But I was also ambitious to take a fair place among scientific men.*"

Of course, we must not take for granted the recollection of the sixty-seven years old maestro of the odd thoughts that crossed his mind at his early twenties. It is quite usual that events proceed in autobiographies the way they should or could happen in the light of later great achievements of their authors.

There is strong reason to believe that months of solitude on board of the *Beagle* and the exciting experience of wondrous observations on the oceanic shores and in pampas and mountains of South America radically changed young Darwin's whole approach to life. Darwin was sure that not the years at the Edinburg and Cambridge universities, but rather the voyage on the Beagle provided "*the first real training and education*" of his mind. The evidence of the *Autobiography* is entirely convincing here. "*Looking backwards, I can now perceive how my love for science gradually preponderated over every other taste... I discovered, though unconsciously and insensibly*" recalled Darwin, "*that the pleasure of observing and reasoning was a much higher one than that of skill and sport.*"

When science becomes the highest value of life, one unavoidably begins to dream of great discoveries. The exciting dream naturally brings with it a desire to realize it and become a famous discoverer. Desires lead to intentions, and strong intentions can eventually convince the dreamer that he has the abilities to achieve his fascinating task. At least, long after the voyage, Charles Darwin could be sure he not only dreamed of making his own modest contribution to natural science, but that he was full of ambition to become a prominent naturalist.

Indeed, already eighteen months after his return from the voyage on the *Beagle*, Darwin opened the first of his note-books in which he collected all kind of information concerning the problem of species. That was the first step of the very ambitious task of creating the theory of evolution of species. Moreover, in one of his note books Darwin directly declared his ambitious goal: "*My theory would give zest to recent and fossil comparative anatomy; it would lead to the study of instincts, heredity, and mind heredity, whole of metaphysics.*"[43]

It is important to realize that geniuses of science explored the secrets of nature in full accordance with hypothetical-deductive conception of the logic of scientific investigation we have outlined above. For instance, Einstein paid full attention to correct formulation of basic problems of theoretical physics. He devoted over six years to the detailed analysis and research of electrodynamics. Einstein tried and verified many ideas and hypotheses until he came to his revolutionary discoveries.

But if Albert Einstein made his epochal discoveries with the help of the universal method of hypotheses which directs the research of each one scientist, why it happened the way that just Einstein succeeded to solve the most fundamental problems of physics? What was his advantage compared to many other scientists?

The answer is the same – the great ambition. Einstein's ambition drove him to the investigation of the most fundamental secrets of nature. He never lost energy and time

[43] *The Life and Letters of Charles Darwin*, p.370.

to consider ordinary problems of physics. His task was exceptional. All his attention was dedicated to the exploration of basic laws, principles and fundamental conceptions of physics.

It was a sort of gamble. There was no guarantee that his efforts would succeed. But he was victorious. Einstein's great ideas determined the progress of physics for a whole epoch. Loren Eiseley wrote about Charles Darwin's theory of evolution that "*the thought of the world would never be the same afterwards*". These words are even more true applied to Albert Einstein's revolutionary discoveries.

## Step 16. THE PASSION TO REACH FOUNDATIONS

***" I have no particular talent, I am merely extremely inquisitive."***

*Albert Einstein*

Ambition leads to formation of irrepressible passion when converted into purposeful activity. Passion in action is like real obsession. Passion transformed into obsession belongs to most damaging things. But the obsessive passion for knowledge provides the power of creative cognition. Just passionate people obsessed with the desire to understand the foundations of nature make greatest scientific discoveries. Grand passion takes the whole intellect of the discoverer into its service. "*Nothing succeeds in which high spirits play no part*" said old sage.

The leading role of science and scientific discoveries in the life and progress of modern society is well recognized. Making science is an important field of social activity. In this sense, science has become the passion of many intellectuals. Today it is quite easy to understand the passion for knowledge so characteristic to many prominent scientists. Yet there is one important difference. Lord Byron, the great admirer of beauty and young ladies, wrote the following wonderful lines: "*Man's love is of man's life a thing apart. 'Tis women's whole existence*".

Science holds the most dominant position. Yet scientific research never absorbs talent's entire interests. Love of knowledge is geniuses' whole existence. Many biographers have mentioned Einstein's passionate personality. His all-absorbing passion was science. Antonina Vallentin rightly noticed that the passionate love of science always remained with him. In a letter to his sister Maja, Einstein commented on his everlasting passion, "*As in my youth, I sit here endlessly and think and calculate, hoping to unearth deep secrets*". From the years at the Zurich Polytechnic, Einstein made himself a rule to concentrate upon significant problems of physical science. "*In this field, however*", recalled later the great scientist, "*I soon learned to scent out that which was able to lead to fundamentals and to turn aside from everything else*".[44]

Aristotle believed that science and knowledge come from human curiosity. Einstein insisted that there could be no scientific progress without passionate devotion to the great goal of revealing the secrets of nature. "*The scientific method itself*", explained Albert Einstein, "*would not have led anywhere, it would not even have been born without a passionate striving for clear understanding.*"[45]

Einstein devoted all his life to the research of foundations of the physical world. A passion for understanding the universe seemed to him as natural as the passion for

[44] Albert Einstein, *Autobiographical notes.* in: *Albert Einstein: Philosopher-Scientist*, p.17.

[45] Albert Einstein, *The Common Language of Science.* In: Albert Einstein, *Ideas and Opinions.* New York, Crown Publishers, 1954, p.337.

music.[46] "*Joy in looking and comprehending is nature's most beautiful gift,*" believed the great physicist. In his later years, Einstein revealed the only and principal motif of his entire life. "*My scientific work is motivated by an irresistible longing to understand the secrets of nature*", wrote the aging sage.

Ronald Clark proves that Einstein's obsession to explore and understand nature caught him early and set fast for the rest of his life.[47] Einstein's passion to explore the physical world was so strong that he was ready to devote everything and sacrifice anything to this great goal. This steely and persistent determination, concluded Ronald Clark, separated Einstein from other men.

The passion to understand the secrets of nature, the continual super-concentration on the fundamental problems of science eventually resulted in many strange personal features, which today are perceived as canonic characteristics of a genius of science. Einstein's dress and habits were causal and shocking sometimes while his absentmindedness gave rise to many humorous stories.

Friederich Adler, who was very close to Albert Einstein at the beginning of his academic career, noticed in a letter that Einstein "*in all practical things is absolutely impractical*". Mileva Marič wrote to her friend how many troubles have been caused to Einstein by his way of speaking. Ronald Clark mentioned Einstein's facility for being "*his own worst enemy*". By the by, as Einstein became unanimously accepted as the greatest mind of the century, the awkwardness and strangeness of his behavior and habits were perceived in a more tolerant manner. Eventually all the oddness and eccentricity in Einstein have been understood as the stigmata of an extraordinary genius.

Boris Kuznetsov begins Einstein's biography with an epigraph from Shakespeare: "*He was a man, take him for all in all*". With all the feelings and interests of an earthly human being. Nevertheless, Einstein the patriarch of the twentieth century scientific community was markedly different from the Einstein at the beginning of his academic career. Einstein-the patriarch was a personification of the ideal of a scientific genius deeply absorbed into the secrets of nature and completely ignoring all other aspects of personal and social life. "*Einstein's fundamental indifference to titles, positions, and money is so complete that it seems exaggerated*", mentioned Antonina Vallentin who was close to Einstein's family in the years of his unprecedented popularity.[48]

Einstein-the beginner, judging outwardly, was much different. He eagerly struggled for his professorship, moved from Zurich to Prague University and back again, gaining higher salary and better position. Einstein made friends, met famous scientists of Europe, looked after his children, lectured, traveled, played violin with members of royal families, and enjoyed life as it could a young man in his early thirtieth. But I have no doubt, if he had to choose between the comfortable life of a university professor with an ordinary contribution to science and that of the hard life of a Patent Office expert who somehow managed to make an epochal discovery, Einstein would definitely prefer the latter. Anyone who has a little bit knowledge of Einstein's life and work, I am sure, will agree with me. It proves that, not only at his patriarchal age, but also through all the years of his youth and maturity, the highest value and the dominant motive of Einstein's personality was the love for science.

This sacred love endowed Einstein with enormous strength and determination to go

[46] "There exists a passion for comprehension," wrote Einstein, "just as there exits a passion for music. That passion is rather common in children, but gets lost in most people later on. Without this passion, there would be neither mathematics nor natural science. Time and again the passion for understanding has led to the illusion that man is able to comprehend the objective world rationally. By pure thought, without any empirical foundation – in short, by metaphysics." (Albert Einstein, *On the Generalized Theory of Gravity.* In: Albert Einstein, *Ideas and Opinions.* New York, Crown Publishers, 1954, p.342.)

[47] Ronald W. Clark, *Einstein. The Life and Times.* New York, 1971, p.32.

[48] Antonina Vallentin, —em The Drama of Albert Einstein. New York, 1954, p.119.

forward with his explorations even in the disastrous years of total neglect. Due to the same sacred love, Einstein did not swerve from his great task of the explorer of nature also in the later years of total admiration and unprecedented worldwide popularity.

Thus we come closer to *Albert Einstein's main secret – the enormous ambition in regard of his potential abilities of an explorer.* And this in strong cohesion with factors that put into action the huge potential energy of his ambition, namely *the sacred love for science and obsession with the fundamental problems of physics.*

These factors are quite sufficient to understand what kept Einstein in unceasing research of the most difficult problems of physical science. A tradition coming from ancient thinkers acknowledges that genius is only a great aptitude for patience. Our analysis helps to understand the source of this enormous patience. Only an obsessive passion can keep an explorer inseparably tied to an absolutely stubborn and unyielding problem, which often becomes the object of a life-long research. What else can force a scientist for long years, day after day to return to the same stubborn problem that never promised any sign of possible solution? Over twenty years, Einstein started each morning by a new attempt of creating the theory of the unified physical filed. Only an unlimited passion to understand the foundations of nature could lead Einstein on this hard and painful path; for there were few results that this investigation was able to present to scientific community. The undertaken research seemed so unproductive that it seemed justified to publish even the negative results to save other scientists from wasting their time and effort.

But no hardships were able to divert Einstein from his passionate work. "*I am an old man mainly known as a crank who doesn't wear socks. But I am working at a more fantastic rate than ever, and still hope to solve my pet problem of the unified physical field*", wrote Einstein to his old friend during these years of persistent and pathetic research.[49]

The later years of Einstein's research should be a real torment to him since he had to deal with an extremely complex mathematical apparatus. When the last formulation of the generalized theory of gravitation was published many theoreticians admitted that they would need at least a year to understand it. The author himself did not see initially how he could derive any particular conclusions of his basic equations to verify them experimentally. To apprehend fully the huge dimensions of Einstein's efforts, I would like to remind that he met unsurpassable mathematical difficulties already elaborating his first theory of gravitation until he got the helping hand of his close friend Marcel Grossmann.

No doubt, Einstein would continue his titanic work if even he did not see any real perspective for its successful completion. So it was a great justice that to his seventieth birthday Einstein at last succeeded to reach a significant generalization of his theory of gravitation. Nevertheless, he continued his research to the last days of his conscious life.

Socrates, another prominent "*real*" genius, was ready to continue his "*search into true and false knowledge*" even after the inevitable transition into the better world. If it were true that death is a journey to another world, what good could be greater than this? What would not a man give if he might converse with Orpheus and Musaeus, and Hesiod and Homer?

Socrates continuously demonstrated a passionate striving for the truth and inquiry. "*I have no particular liking for anything but the truth*", declared the great thinker. His entire life and even his death seem specially designed to prove that he was just unable to alter his sacred passion, even if he had "*to die many times*".[50] Passion and the "*inspired*

[49] *Helle Zeit; Dunkle Zeit.* Ed. Carl Seelig. Zurich, 1956, p.50.

[50] Addressing the people of Athens and his judges, Socrates announced: "if you say to me, Socrates, this time you shall be let off, but upon one condition, that you are not to inquire and speculate in this

*madness*" should be highly appreciated if one's longing after wisdom had caused them.

A further illustration provides Niels Bohr. For many years Bohr persistently tried to convince Albert Einstein, as well as any other skeptically minded physicist, that his probabilistic interpretation of quantum mechanics was correct. Sometimes this unlimited persistence created comical situations. Shortly after Erwin Schrödinger published his famous papers on wave mechanics, he was invited to lecture at the Copenhagen Institute. Schrödinger should be unhappy that he accepted the invitation. From the very first day, he was involved in exhausting discussions that continued for long ours. Bohr proved him uninterruptedly, with almost fanatic conviction, how wrong was the classical interpretation of wave mechanics. Eventually, Schrödinger broke down under the pressure. He got ill. But it did not help him. Bohr was always at side of his bed, persistently repeating, "*Come on, Schrödinger, you must accept that...*".[51]

One should bear in mind that Einstein's obsessive love for science had quite a definite object. Foundations of nature and fundamental principles of physics were the main preoccupation of his thoughts. "*For me,*" explained Einstein his attitude to science, "*interest in science is restricted to the study of principles, and this offers the best explanation of my work. That I have published so few papers derives from the same circumstance: a consequence of my ardent desire to understand the principles is that much of my time has been spent on fruitless efforts*".[52]

Einstein's obsessive determination to build a unified field theory followed from his passion to understand and reveal the very foundations of the physical world. He was deeply convinced that beneath the surface of the apparently different gravitational and electromagnetic phenomena there should be a deeply hidden physical entity.

The insight of a cardinal truth occurs by a lucky blending of experience and motivation. If it were allowed to draw a general principle from a single observation, Einstein's attitude to science and knowledge would be the best ground for the above statement. Yearning for the most fundamental laws of nature was young Einstein's sole motif of life. By 1905, he had an extremely rich experience in deliberating upon the most basic problems of physics. This gave him an overwhelming advantage compared to the most prominent physicists of the century.

## Step 17. THE LAW OF INDEPENDENCE OF THOUGHT

***"At the frontiers of science explorers must be brave."***

*Anonymous*

Revolutionary ideas never appear in a mind full of deep and uncritical respect to the great names of science. To be a revolutionary, one has to have a skeptical mind. "*The seeker after the truth*", insisted René Descartes, "*must, once in the course of his life, doubt everything, as far as possible*".[53]

way any more, and if you caught doing so again you shall die; - if it was the condition on which you let me go, I shall reply: Men of Athens, I honor and love you; but I shall obey God rather than you, and while I have life and strength I shall never cease from the practice and teaching of philosophy..."

[51] Werner Heisenberg, *Erinnerungen an Niels Bohr aus den Jahren 1922-1927.* In: Werner Heisenberg, Schritte über Grenzen. Munchen, 1973, S.62.

[52] Albert Einstein, *Lettres a Maurice Solovine.* Paris, 1956, p.49.

[53] René Descartes, *Principles of Philosophy.* In: *The Philosophical Writings of Descartes*, vol.1. New York, Cambridge University Press, 1985, p.193.

Radical skeptics often went to the extremes. For instance, Metrodorus of Chios declared, "None of us knows anything, not even whether we know or do not know, nor do we know whether not knowing and knowing exist, nor in general whether there is anything or not." (Quoted in David Park, The How and Why. Princeton, Princeton University Press, 1988, p.24.)

Actually, no student can escape the feeling of admiration with fundamental theoretical science, especially when one starts learning mathematical theories with their clear and transparent concepts and absolutely strict proofs. Albert Einstein and Charles Darwin, my specimens of geniality, admired Euclid's geometry from their early youth.

Fundamental theories are the basis upon which science is built. Due respect to foundations of science is quite natural. But if you regard a fundamental theory with an unlimited respect, you will never be able to reconstruct it radically. If one admires a theory, he cannot question its truth. But in absence of a question, no one will search for a more adequate answer. Let us consider some illustrations of these general statements. Immanuel Kant was denied a minute chance for revolutionary discoveries in mechanics, geometry, and formal logic since he was completely convinced that Newton's mechanics, Euclid's geometry, and Aristotle's logic were examples of the absolute truth. By contrast, Kant doubted and rejected all philosophical teachings of his day. No surprise that his *Critique of Pure Reason* suggested a radical reconstruction of the entire philosophical theory of human cognition.

Skepticism is the best ground to grow freethinking. Possibly John Milton meant this important point of human cognition in his beautiful phrase, "*Suspicion sleeps at wisdom's gate.*"

There is no absolute truth for a skeptical mind. If one is skeptical enough, he can question the most fundamental laws of science and cast doubt on the most apparent and evident truths. A skeptic may deliberate whether do parallel lines ever cross each other? Skeptical mind is able to question the necessity for the product of $A$ and $B$ to be equal to the product of $B$ and $A$. Skeptics can doubt even that $c + c$ is equal $2c$.

Extreme skepticism is often annoying.[54] But the history of science proves that just skeptics had made the most fundamental scientific revolutions. "*If a man will begin with certainties, he shall end in doubts; but if he will be content to begin with doubts, he shall end in certainties,*" pointed out Francis Bacon.

For educated men it was quite evident that given a straight line $L$ and a point $P$ on the same plane one can draw only one straight line passing through the point $P$ and parallel to $L$. But a skeptic appeared there and asked, "*How do you know that?*" Trying to prove him this obvious truth, mathematicians discovered the non-Euclidean geometry where one of the most evident mathematical truths – Euclid's fifth postulate – did not hold.

When Heisenberg was told that according to his most promising paper one must conclude that the product of the matrix $A$ and matrix $B$ was not equal to the product of $B$ and $A$, he thought that all his conception was ruined. But the reaction of Paul Dirac, one of the greatest skeptics of his generation, was completely different. Developing his theories he thought it was quite legitimate to make "*any assumptions if they did not immediately bring to contradictions*". As a physicist, he never had a slightest doubt that $A$ and $B$ variables should be commutative. But the non-commutative matrixes in Heisenberg's paper did not seem to him enough ground to reject flatly the new conception. Dirac concentrated all his attention upon Heisenberg's surprising result. Soon he proved that postulating the difference of the matrix products $AB$ and $BA$ to be equal to $h/2\pi$, one arrives at the most fundamental principle of quantum mechanics. When the paper with Dirac's interpretation was published he got a letter from Hiesenberg. "*I have read your wonderful work with great interest. All your results are completely correct if we believe, of course, in the new theory*", wrote with relief the author of the paradoxical

[54] "Skepticism," noticed Bertran Russell, "while logically impeccable, is psychologically impossible, and there is an element of frivolous insincerity in any philosophy which pretends to accept it." (Bertrand Russell, *Human Knowledge. Its Scope and Limits.* London, Allen and Unwinn, 1948, p.9.)

discovery.[55]

Possibly, just the skeptical approach helped Hendrick Lorentz to deny the Galilean transformations of classical mechanics which, in a sense, included the most evident assertion $u + u = 2u$. Lorentz suggested instead that in the case of electromagnetic radiation some special form of transformations must be used, the conclusion from which should be the extravagant $c + c = c$ for the speed of light. Consider a mental experiment when a space ship is passing near the Earth with a speed equal to the speed of light c and a light beam is sent from the space ship in the direction of its motion. Then, according to Lorentzian transformations, the speed of that beam in regard of the Earth would be not $c + c = 2c$, but it will just remain the same $c$.

There is no doubt that Einstein's new approach to the electrodynamics of moving bodies was supported and directed by his skepticism. Only a good portion of skepticism could allow him to plunge into the critical review of basic concepts of classical physics. There were many manifestations of Einstein's positive scientific skepticism prior to the moment of his great discovery. The skeptical approach was first invoked in Einstein at the age of twelve when being influenced by popular scientific books he gave up believing in the stories of the Holy Scriptures. "*Through the reading of popular scientific books*", recalled Einstein, "*I soon reached the conviction that much of the stories in the Bible could not be true*".

It is very probable that Einstein's critical perception of the most fundamental scientific conceptions was significantly supported by his inborn skepticism that developed further and strengthened itself by the circumstances of his childhood and youth. Ronald Clark, discussing in detail young Einstein's personal features, proved that his skeptical attitude in regard of widely accepted beliefs was developed as early as at the Gymnasium.[56]

In the following years, Einstein's skeptical approach extended to the very foundations of physical science. Only a well-developed skeptical mind would permit him to think of putting an "*end*" to the molecular-kinetic theory of liquids. Earlier he boldly assumed that "*the electrodynamics of moving bodies, as presented today, is not correct*". Young Einstein expressed serious doubts concerning the newly born quantum conception of radiation. Such a skeptical perception of the foundations of physical science convinced Einstein that he understood the principle problems of physics more deeply than "*his elders and betters*" who appeared fully satisfied with classical theories.[57]

Very close to the skeptical approach stands the *independence of thought*. Actually, skepticism and independent thinking are two sides of a coin.

Skepticism has mainly a negative function. But to make a discovery, one has to

[55]Dirac mentioned also that his position was definitely more advantageous than that of Heisenberg. He had not be worried too much that the non-commutative matrixes will ruin the new theory. Secondly, he had some hope that Hamiltonian equations, which he knew well, could help him to understand the real cause of the difficulty. (Paul Dirac, *Recollections of an Exciting Era.* In: *History of Twentieth Century Physics*: Proceedings of the International School of Physics "Enrico Fermi". Course LVII. – New York, Academic Press, 1977, p.121.)

[56]"Not giving a damn about accepted beliefs was an attitude which certainly developed at the Gymnasium," concluded Clark. (Ronald W. Clark, *Einstein. The life and Times.* New York, The World Publishing Company, 1971, p.13.)

[57]I would like to note here the parallel between Einstein's skeptical attitude and that of Socrates. The famous ancient thinker was well aware that Athenians were especially delighted when he gave them chance to hear the "cross-examination" of a pretender to wisdom. Even the greatest thinkers could not avoid Socratic irony. Socrates questioned and denied even the views of Protagoras though the latter was the only philosopher whom Socrates accepted as "the wisest of all living men".

Nietzsche believed that skepticism provides the freedom of a mind "through strength and superior strength". But one cannot exclude that skepticism is rather an attitude to life and knowledge than an intellectual capacity following from the strength of mind. One can meet a strong intellect with a conventional mode of thinking as well as a highly skeptical thinker with ordinary intellectual capacities.

be also positive. The central point of any discovery is the new, original, sometimes strange or even crazy idea. A scientist deeply influenced by existing theories would hardly have the courage to suggest a really unordinary conception. The independence of mind combined with skepticism composes the essence of freethinking. Albert Einstein most of all encouraged just the independence and skepticism in the thinking of a scientist. He praised Mach in his *Autobiographical Notes* for these important intellectual qualities. "*I see Mach's greatness in his incorruptible skepticism and independence*", pointed out Einstein.

There is no need to prove the independence of Einstein's thinking. Friedrich Adler wrote that Einstein had "*the most of independent brains*".

Einstein was not merely an independent thinker. Not less important is the fact that he was the most courageous theoretician. One should really be brave to suggest a conception that sounded strange to all contemporary scientists. But one had to be enormously brave to suggest a conception that was in apparent contradiction to well-established facts and observations. That was the case with Copernicus. And that was also the situation with Albert Einstein. Using poet's words, one may characterize Einstein as presenting a union of "*the mildest manners with the bravest mind*".

Einstein was the first physicist to deny radically the "*ghostly existence*" of the ether in a time when the entire physics community was deeply convinced that ether was the necessary media for the very existence of the electromagnetic field.

When in1905 Einstein suggested his conception of light quanta, he had serious reasons to qualify it cautiously as a "*heuristic viewpoint*". By that time, it had been clear to any physicist that the phenomena of diffraction and interference of light could be explained only assuming that light was propagated as a wave. So one had to be extremely courageous to consider light composed of particles. That bald scientist was Einstein. Later, in 1909, he forecast that the apparent contradiction of photon conception and classical wave theory could be solved only through a new synthesis of the wave and corpuscular conceptions. Einstein was sure that the next phase of the development of theoretical physics will bring us a theory of light that can be interpreted as a kind of "*fusion of the wave and emission theories*".[58]

Making this bold assumption, Einstein actually foresaw not only de Broglie principle of wave-particle duality, but also heralded the coming of the quantum mechanics itself. "*The great achievement of Einstein*", noticed Hans Reichenbach, "*consists in that his thinking is free from conventional ideas, that he did not hesitate to disregard the oldest laws of natural science, the laws of geometry, and to set new ones in their place*".[59]

Einstein's independence of thought was unlimited. Even his own great discoveries could not restrain his bold intentions. In 1910, just five years after his historic discovery of light quanta, he wrote to his close friend and colleague Jacob Laub: "*I now have the greatest hopes of solving the radiation problem, actually without light quanta... We must renounce the energy principle in its present form*".[60]

The task to penetrate into the thoughts of the author of an important discovery is always enormously difficult. This task becomes almost unsurpassable when one has to deal with a genius of such unique gifts as Albert Einstein. Cornelius Lanczos clearly re-

[58] Einstein's argument, which he presented in his invited paper at the 1909 Salzburg conference, is of such importance that I would like to present it here in detail. "It is undeniable," explained his position Einstein, "that there is an extensive group of data concerning radiation which show that light has certain fundamental properties that can be understood much more readily from the standpoint of the Newtonian emission theory than from the standpoint of the wave theory. It is my opinion, therefore, that the next phase of the development of the theoretical physics will bring us a theory of light that can be interpreted as a kind of fusion of the wave and emission theories." (Quoted in Ronald W. Clark, *Einstein. The Life and Times.* New York, 1971, p.125.)

[59] Hans Reichenbach, *From Copernicus to Einstein.* New York, Philosophical Library, 1952, p.121.

[60] Carl Seelig, *Albert Einstein: A Documentary Biography.* London, 1956, p.116.

alized the difficulty of his task when he attempted to explain how Einstein could suggest his striking hypothesis of quanta of light. Yet Lanczos undertook this challenging task and convincingly showed that the main factor that helped Einstein to make his great discoveries was his unlimited scientific courage. "*In the case of the light quantum hypothesis*", wrote Lanczos, "*the conclusion was so startling that only an unprejudiced mind of highest unconventionality could accept the result without cringing. The probability expression for the statistical action of light had exactly the same form as if the action of n equal particles were involved. From this Einstein fearlessly drew the conclusion that light actually behaves, as if it were a particle, endowed with the energy $h\nu$. To an ordinary mind this would appear absurd, since the wave nature of light had been so convincingly demonstrated on innumerable occasions. Einstein did not deny the wave nature of light; but he had an uncanny physical intuition which was not afraid of conclusions which were contrary to accepted notions, if undeniable physical observations forced him to accept these conclusions*".[61]

Some historians of science argue that it required Einstein not much intellectual courage to propose strange ideas since he was completely unknown and did not risk his reputation. In general, a prominent scientist, indeed, is definitely handicapped by his high statue in scientific community, while one can readily forgive a young and unknown scientist even his craziest suggestions.[62] But Einstein demonstrated not less courage also in the years of full blossom of his fame. He firmly stood almost alone against all the "*combined forces*" of the twentieth century physicists for over three decades. I mean Einstein's opposition to the so-called Copenhagen interpretation of quantum mechanics. Mainly due to Niels Bohr's active and unceasing argumentation, it was almost unanimously accepted from the early 1930s that atomic phenomena did not follow the principle of strict determinism and were rather statistical in their essence. Einstein opposed this conception during all his active life in science. His aphoristic argument "*God never plays at dice*" became a popular saying even by general public.

Explaining his position Einstein insisted that only those can have a deep insight into foundations of modern physics who have successfully "*wrestled*" with the problematic situations of their age. In this respect, he had sufficient ground to hold to his own viewpoint. "*I am, in fact, firmly convinced that the essentially statistical character of contemporary quantum theory is solely to be ascribed to the fact that this [theory] operates with an incomplete description of physical systems*", declared Albert Einstein his position.[63]

Einstein held his ground firmly to the very last years of his active life in science. "*He spent those years*", recalled Robert Oppenheimer, "*first in trying to prove that the quantum theory had inconsistencies in it... When that did not work, after repeated efforts, Einstein had simply to say that he did not like the theory. He did not like the abandonment of continuity or of causality... He fought with the theory which he had fathered but which he hated*".[64]

By the irony of history, Einstein's main opponent Niels Bohr also came from the ranks

[61] Cornelius Lanczos, *The Einstein Decade.* London, Elek Science, 1974, p.107.

[62] Friedrich Gauss claimed that he had deliberated for a long time over the idea of non-Euclidean geometry. But the famous mathematician never discussed in public his idea. Gauss might believe that the publication of such a strange idea could damage his well-deserved authority.

Mendel presented an opposite case. He was absolutely unknown to scientific circles. So he was not under any kind of pressure elaborating his own viewpoint. "Perhaps he was fortunate," mentioned Loren Eiseley, "so far as his experiment went, in not being a famous man already laboring under a point of view." (Loren Eisley, *Darwin's Century*, p.213.)

[63] Albert Einstein, *Remarks Concerning the Essays Brought Together in This Co-operative Volume.* in: *Albert Einstein: Philosopher Scientist*, volume 2. Ed P. A. Schlipp. La Salle, Illinois, Open Court, 1970 (first edition 1949), p.666.

[64] Quoted in Ronald W. Clark, *Einstein. The Life and Times*, p.534.

of "*real*" geniuses. He began his discussions with Einstein in 1927 at the Fifth Physical Conference of the Solvey Institute and never ceased to prove his point all the following years. And that notwithstanding his deepest admiration regarding Albert Einstein's scientific achievements. Bohr acknowledged the "*indebtedness of our whole generation for the guidance his genius has given us*" and highly evaluated Einstein's scientific heritage as of "*epoch making contributions to the development of natural philosophy*".[65]

Ronald Clark pointed out once that many contemporaries of Einstein "*had sent up sparks of genius during their early years yet failed to set the world ablaze*". Most probably, Einstein set the whole twentieth century science ablaze just due to his unlimited intellectual courage.

I could include into the set of the derivative factors of great discoveries the originality of ideas and strong imagination, too. "*A good deal of his genius lay in the imagination which gave him courage to challenge accepted beliefs*", suggested Ronald Clark in regard of young Albert Einstein.[66], p.32. But in fact, the intellectual courage covers up both these factors since it assumes an extreme originality of thinking as well as unlimited imagination.

The independence of thought was so characteristic and essential for the greatest physicist of our epoch that Abraham Pais believed it could serve as an overall characteristic of his genius. "*If I were asked for a one-sentence biography of Einstein's life*" , wrote Pais, "*I would say, He was the freest man I have ever known*".[67]

[65]Niels Bohr, *Discussions with Einstein on Epistemological Problems in Atomic Physics.* In: Niels Bohr, *Atomic Physics and Human Knowledge.* New York, John Wiley & Sons, 1958, p.32.

Interestingly enough, the positions of the both great physicists can be traced back to Greek philosophers. The founder of atomistic philosophy Leucippus declared, "Nothing happens at random; everything happens out of reason and by necessity". While Tisias and Gorgias insisted the contrary, namely, that probability is "superior to truth".

[66]Ronald Clark, *Einstein. The Life and Times*

[67]Abraham Pais, *"Subtle is the Lord..." The Science and the Life of Albert Einstein.* New York, Clarendon Press, 1982, p. VII.

## Step 18. SOME ADDITIONAL AGENTS OF GENIALITY

***"What mattered was the talk."***

*Ronald Clark*

All the above revealed secrets of Albert Einstein's genius, beginning from his great ambition and ending with the extreme intellectual courage, tell us the psychological features that determined his intellectual potential for great discoveries. Here a question can arise whether did not Einstein have also some secret methods of thinking with the help of which he was able to solve the most difficult problems of theoretical physics? Since I have proved earlier that the hypothetical-deductive method is the universal method of scientific discoveries, my answer to the question can be only negative. Einstein's letters prove that he explored the foundations of physics in full accordance with the method of hypotheses.

Nevertheless I would like to call your attention to three important points in Einstein's method of research. First, Einstein got great advantage in regard of all other physicists at the very start of research. Any scientific research begins with problem formulation. Einstein followed the principle to explore only those problems that were of great significance for the further advancement of physical science. Just the investigation of this type of problems had the potential to bring eventually to great discoveries. For instance, Einstein explained in a letter to Jakob Laub, "*This quantum question is so incredibly important and difficult that everyone should busy themselves with it*".

In his quest for the fundamental laws of nature, Albert Einstein was substantially supported by his approach to scientific knowledge. Einstein learned only basic knowledge. He denied "*cramming*" into one's mind non-essential, superficial information. It enabled Einstein to reach a deep understanding of fundamental theoretical conceptions and reveal the essence of the most difficult problems of theoretical physics.

Probably, this kind of selective learning was intuitive, since Einstein regretted sometimes that he was lacking some important knowledge. Recalling the years at the Zurich Polytechnic Institute, Einstein admitted that he "*neglected mathematics to a certain extent*". His professor of mathematics Hermann Minkowski was of the opinion that Einstein "*never bothered about mathematics*". Consequently, Einstein had certain difficulties elaborating his revolutionary theories, especially when he worked out the conception of general relativity. Another case when Einstein felt he was handicapped by the lack of some important information concerns his research in statistical physics. Developing his original statistical conception, Einstein was unaware that J. Willard Gibbs had already solved the problem. During the discussion of his work he admitted, "*Had I been familiar with Gibbs' book at that time, I would not have published those papers at all, but would have limited myself to the discussion of just a few points*".[68]

Einstein disliked learning. He did not read much. Apparently, he was not fond of his work of a lecturing professor as well. Einstein's real destiny was scientific research. Nothing could stop him from exploring the secrets of nature – neither the bitterness of the total neglect, nor the enthusiastic admiration of the educated world. In his inaugural address before the Prussian Academy of Sciences, of which he became a member in 1913, Albert Einstein expressed his gratitude just for the possibility to devote himself to scientific studies.[69]

[68] *The Collected Papers of Albert Einstein*, vol.3, p.251.

[69] "First of all", said Einstein to German academicians, "I have to thank you most heartily for conferring the greatest benefit on me that anybody can confer on a man like myself. By electing me to your academy you have freed me from the distractions and cares of professional life and so made it possible for me

The only thing that could for a moment shift aside his study of science was again the science. I mean Einstein's enormous passion to talk about science, to discuss various topics of science with anyone ready for the task, were it a student having difficulties in his physics course or a world wide famous scientist.

Young Einstein's first opponent was his Uncle Kaiser Koch. Just to him addressed young Einstein his first cogitation on the nature of luminiferous ether. At the Zurich Polytechnic he discussed physical theories with his friends Conrad Habicht and Marcel Grossmann. Given a slightest chance, Einstein would involve people he met into tense discussions of complex problems of physical science. When he took his dissertation to Professor Kleiner, it resulted, quite naturally, in a lengthy discussion of many topics of modern physics.

Einstein's salary at Patent Office was not sufficient to afford decent life conditions to his young family. He decided to get some additional income by private lessons. Maurice Solovine, a student from Romania who had to improve his poor knowledge of physics, became Einstein's first pupil. From the very first meeting, Einstein's lessons turned into exciting discussions of scientific topics. Both the teacher and the pupil were so fond of these talks that they became close friends and continued their meetings till 1903 when Solovine left Bern.

A short while later, Conrad Habicht joined the meetings of this peculiar pair. The three romantic friends got such a profound satisfaction from their regular meetings that they called their small fraternity "*Academy Olympia*". To his last days, Einstein had the warmest memories of their "*academic*" activities. In 1953, the patriarch of the twentieth century science recalled in a letter to Solovine the "*immortal*" Academy, its "*childish joy in clarity and reason*", and wished its members his fidelity and devotion "*to the last enlightened breath*".

Topics of these "*academic*" discussions were of general nature. It was Michelangelo Besso who got the privilege to discuss Einstein's original papers during the process of their elaboration. In a letter to Mileva Marič Einstein characterized Besso as an "*extraordinary fine mind*". Then he mentioned that they talked almost four hours on ether and matter, the definition of absolute rest, the nature of molecular forces etc. – problems that preoccupied Einstein constantly.

Their talks became regular in1904 when Besso, with the help of Einstein, got a position at the Bern Patent Office. Every day the two friends returned home together from the office deeply involved in discussions of Einstein's conceptions. These regular discussions continued up to the beginning of 1905. Einstein once mentioned in a letter to Habicht that after Solovine's departure even talks with Besso had ceased. Most probably, by that time Einstein was bringing to completion his famous papers of 1905 all of them published during the year 1905 in the vol.17 of "*Annalen der Physik*".

Impressed by Einstein's papers, Professor Wilhelm Wien sent Jacob Laub who was taking degree at Leipzig to see who that unknown Einstein was. Coming to Bern and meeting the young scientist Laub was drawn, as everyone else who met Einstein on a professional basis, into an "*obsessional discussion that soon rose and swamped every thing else*".[70] Naturally Laub and Einstein became close friends, continued their discussions for about two years, and even published three joint papers.

When in 1911 Einstein moved to the German University of Prague, a strong friendship struck up between him and George Pick. These days Einstein was busy with his theory of general relativity. He often discussed with Pick his new conception, especially the difficulties he met in building its mathematical apparatus.

to devote myself entirely to scientific studies." (Albert Einstein, *Principles of Theoretical Physics.* in: Albert Einstein, *Ideas and Opinions.* New York, Crown Publishers, 1954, p.220.)

[70]R. Clark, *op. cit.*, p.110.

Did not these endless talks mean merely wasting precious time? What could Einstein get, for instance, from the talks with Solovine whose knowledge of theoretical physics was next to nothing? It is not excluded that talking and discussing science was just a passion for Einstein (as it was certainly for Niels Bohr), and passion does not require reason or rational goal. But this passion appeared to be very useful to Einstein. Factually, Einstein implied in his talks one of the most effective methods of problem solving, which I would like to call "*brainstorming discussion*". Talking to Solovine and explaining to him the perplexing points of physical theories, Einstein could consider problems of theoretical physics from many different standpoints, a circumstance extremely important in fundamental research. On the other hand, talking with Besso and his physicist colleagues, Einstein could check his own ideas and consider possible objections. These two types of discussions could induce also some valuable hints for new approaches and solutions.

It is impossible to assess to any reasonable extent what contribution had these talks made to Einstein's scientific achievements. But one thing is absolutely clear. These talks should be very helpful in developing Einstein's magnificent creation of the Special and General Relativity. Discussions with Besso had been so important to Einstein that he mentioned Besso's contribution to his theory in the final paragraph of his famous paper on relativity. "*I should like to note in conclusion*", wrote Einstein, "*that my friend and colleague M. Besso was my devoted assistant in the elaboration of the questions herein and I am indebted to him for a number of valuable suggestions*".

Another partner of Einstein's discussions – George Pick – helped him to find out the mathematical apparatus for the General Relativity, the so-called tensor calculus. In this particular case, the mathematical apparatus had an essential role since Einstein's revolutionary ideas on gravity, and space and time would lack the power to convince physicists if they were not presented in the form of a strict quantitative theory. In fact, the final recognition of the theory of relativity and the worldwide fame to its author came after the confirmation of the quantitative conclusions of Einstein's theory by the observations of 1918 solar eclipse.

Einstein's conception of relativity has an exceptional standing even compared to his own other important contributions to the development of theoretical physics. As we have seen above, the conceptions of Special and General Relativity had been brought to completion with the help of Einstein's method (or rather passion) to talk out his ideas and problems to his friends and colleagues. In the light of this fact, one has to consider a possibility that the most fundamental problems of science are likely to be solved in the atmosphere of collective discussions and friendly talks rather than in the solitude of the research of individual scientists.[71]

Of course, at the basis of scientific progress lie the individual efforts of scientists. Not only great discoveries but also ordinary scientific achievements presume that investigators should completely concentrate on their research problems. Einstein had been no exception. Maurice Solovine recalled Einstein "*wrapped himself completely in his thoughts to the point of oblivion of everything around him*". Another classical picture is that of Einstein in his Bern apartment rocking the cradle of his child and reading a book, but ready to expose the black notebook from his pocket the first quiet moment. Ronald Clark emphasized Einstein's "*ferocious concentration*" on his research and his determination that "*nothing should be allowed to divert him from it*".[72]

But one should not exaggerate the image of Einstein as of "*scientific loner*". This

[71] I have found a supporting remark by G. J. Whitrow. In his book on Albert Einstein he noted, that the form in which he chose to communicate his theories to the scientific world was considerably influenced by the endless discussions he had with Besso. "This shows that, even in the case of the most original scientific geniuses, discussion with others is invaluable," concluded Whitrow. (G. J. Whitrow, *Einstein. The Man and His Achievement.* New York, Dover Publications, 1967, p.18.)

[72] R. Clark, *op. cit.*, p.106.

picture was true for the last decades of his life when all his great discoveries had already been made. Einstein the revolutionary of science was very fond of communicating people and talking out to his colleagues his ideas and problems.

Perhaps, the passion for talking was common to all real geniuses. Socrates admitted having a benevolent habit "*of pouring out himself*" and being ready "*to pay for a listener*". It was not much important to him who was his listener. "*Any one, he be rich or poor, may ask and answer me and listen to my words*", declared the great thinker.

Niels Bohr was very fond of friendly talks too, especially on the central issues of atomic physics. He could talk out his mind to any group of listeners, be it his assistant or a student auditorium. Heisenberg recalled that when he was invited to work in Copenhagen Institute, almost from the first day began regular talks and discussions with Niels Bohr. These everyday meetings were not something exceptional. Bohr actively discussed the research work of all his young colleagues to the extent that there remained little time for his personal research and administrative work.[73]

In his recollections Paul Dirac mentioned Bohr's notorious habit to think aloud. He even believed that Bohr carried on all the gigantic work of his mind by talking aloud.[74] There could be no better proof of Plato's thesis "*Thinking is talking to oneself*". A sage, talking himself out to his listeners, seems to be rather a common experience. By Gene Derwood I met the following lines, "*There must be something wrong with being wise – talking we go, wondering and wandering with woes*".

A really striking case of scientific success by mere talking is that of James Watson and Francis Crick winning Nobel Prize for the discovery of DNA structure. By March 1953, when their paper on the discovery of the double helix structure of DNA was sent to publication, James Watson was only twenty-four years old and Francis Crick thirty-five. And what is really astonishing, by that time Watson had not done yet any worthwhile research, while Crick had just started serious work for his Ph.D. at the famous Cavendish laboratory.

Crick's serious trouble was his inability to concentrate on some central issue of theoretical research. Since he was always involved in talking and discussing completely different issues of science and social life, Watson called him "*talking machine*". Crick talked not only excessively but also louder and faster than anyone else did. And as if this non-interruptible loud talking was not enough, he also used to exercise a Homeric laugh. "*When he laughed*", recalled Watson, "*his location within the Cavendish was obvious*".

By that time an intensive investigation of DNA structure went on mainly in Linus Pauling's laboratory in California and Maurice Wilkins' laboratory in London. The basis of all investigations was Pauling's discovery of the helix structure if DNA. Wilkins' advantage was that he had come to the edge of experimental discovery of the main building blocks of DNA through long and systematic X-ray diffraction studies.

So how could Francis Crick, not speaking of James Watson, jump ahead of these two powerful laboratories? In fact, Crick benefited from his obsessive talking.

Crick talked and discussed problems almost with all Cavendish research teams since anything important immediately attracted his attention. He frequently visited other labs to see which experiments had been done. This general attitude and constant talking sometimes brought very useful results. For instance, the central idea of modern genetic theory – the scheme of gene replication – emerged during a casual talk with an astronomer on the "*perfect cosmological principle*".[75]

[73] Werner Heisenberg, *Erinnerungen an Niels Bohr aus den Jahren 1922-1927.* In: Werner Heisenberg, *Schritte uber Grenzen.* Munchen, 1973, S. 56-57.

[74] Paul Dirac, *Recollections of an Exciting Era.* In: *History of Twentieth Century Physics*: Proceedings of the International School of Physics "Enrico Fermi". Course LVII. New York, Academic Press, 1977, p.133.

[75] James D. Watson. *The Double Helix*, p.84.

Through talking and jumping into each one's business Crick eventually appeared in a very advantageous position. His quick mind immediately appreciated the bright perspectives of molecular model building approach used by Linus Pauling. But Pauling, as a very strong rival, was denied the newest diffraction data of Maurice Wilkins' laboratory. Wilkins had to keep his data away from anyone else and especially from Crick, knowing his obsession to talk to everyone and about everything. But Crick and Watson found finally an unordinary way to the newest results of Wilkins' research group.[76]

This way Crick got a decisive advantage over the two main research groups. He used Pauling's method of molecular modeling and could guide his research with the help of the newest experimental results of Wilkins' group. No wonder that his solution of the mystery of DNA structure was brilliant and rapid. Yet one should bear in mind that the passion for talking served the fertile soil out of which grew this grand achievement.[77]

### Step 19. BECOMING A QUASI-GENIUS

***"Blessed is he who has found his work."***

*Thomas Carlyle*

Revealing the secret of geniality, I am ready to teach educated men to get a chance for a great discovery.

First, I am going to prove that the above revealed intellectual capacities, which helped Albert Einstein to become the greatest scientist of our epoch, are *necessary* to make a great discovery and *sufficient* for getting a chance to make a great discovery.

I start by proving the necessity. To reach this goal, I have to prove that great ambition, passionate love of science and freethinking are necessary factors of a great scientific discovery. Without great ambition no one would have the courage to undertake the research of a fundamental problem of science. That is the first precondition for any significant discovery. Great discoveries are produced by intensive and persistent exploration of fundamental super-difficult scientific problems. Such an exploration can accomplish only a scientist driven by a passion for fundamental theoretical research, an investigator in a state of holy obsession in regard of fundamental problems of science, a thinker in deep and passionate love with science. A radically new, revolutionary idea can visit only a mind brave and courageous, free of traditional taboos and independent of any opinion – even of those sanctified by the history of science.

The above revealed "*secret*" qualities of geniuses are determined by their task to make a revolutionary discovery. Any epochal discovery presupposes solving a fundamental problem. In the case of greatest discoveries, one has to solve a super-difficult fundamental scientific problem. And to explore such a problem, it is absolutely necessary to have great ambition. On the other hand, super-difficult problems require complete mobilization of explorer's intellectual powers and the ability to perform hard and unceasing

[76] Max Perutz, a department chief at the Cavendish, was appointed member of a committee that coordinated biophysics research. So he regularly got reports with comprehensive summaries of accomplishments of Maurice Wilkins' laboratory. "The report was not confidential and so Max saw no reason not to give it to Francis and me," tells James Watson in his book. (James D. Watson, *The Double Helix*, p.115.)

[77] But what could be James Watson's contribution to this discovery? Watson confessed in his book that he had neither abilities nor capacities of carrying any serious research work. Actually, he was not engaged in a direct DNA research either. So how he could appear so helpful in the discovery of DNA structure that he eventually was rewarded the Nobel Prize? There was a remarkable point that the Nobel committee could never overlook in any circumstances. Watson managed to be the first to send a letter to a California research group about his and Crick's idea of the double helix structure of DNA.

research. In its turn, this may be accomplished only with the help of passion supported by all-absorbing love for science. And lastly, greatest discoveries grow from the seeds of revolutionary ideas. To be revolutionary, one has to be brave and courageous, absolutely independent and completely free in his thinking.

This set of mental qualities – great ambition, passionate love of science and obsession with its basic problems, intellectual courage and complete independence of thought – contains the real secret of geniality. If one lacks any of these necessary qualities, hardly he would have any chance to make a revolutionary discovery. So, one must admit that the intellectual capacities revealed above in regard of Albert Einstein's great scientific achievements are the necessary preconditions of great theoretical discoveries.

Now let us turn to the second part of my thesis. Consider an investigator in possession of the above-discussed intellectual capacities that we presented as the intellectual basis of geniality. Since these intellectual capacities are proved to be the set of the necessary preconditions of great discoveries, there will be no factor barring for this investigator the way to a great scientific achievement. In other words, an educated man with the above mentioned intellectual qualities will have a chance to make a great scientific discovery.

In general, when all necessary conditions of a phenomenon are met, there remains no factor that may prevent its birth. This means that the appearance of a phenomenon should be considered as a possibility if its necessary conditions are presently given. Likewise, when an explorer acquires all the intellectual qualities composing the secret of geniality he gets a chance to make a revolutionary discovery since there remains no factor barring him from a great idea. Of course, the question how significant will be the chance for a great discovery remains open.

Now, to the main point of this discussion. It is not difficult to see that none of the above revealed components of geniality requires any special type of intellectual capacities. Any educated man, if properly instructed, can easily pretend that he has great ambitions and passion for fundamental theoretical research and is continuously obsessed with basic problems of science. It will not be also difficult to him to hold a position of a skeptical thinker, doubting each one theoretical principle and scientific law and feeling himself independent of modern conceptions as well as of opinions of great names of science.

So my discovery is that any educated man can get a chance for a great scientific discovery if he learns the above revealed secret of geniality and behaves himself according to the above listed characteristics of real geniuses. Of course, behaving like a genius, one will get only some chance to make a great discovery. The probability of making a discovery will depend upon the intensity and persistency of his efforts to exercise the undertaken obligation of behaving like a genius.

Consider now a scientist or any other educated person who advances in his research applying in full extent all the above mentioned factors of geniality. Such a person, apparently, will behave himself just *like* a real genius of science. Though the above revealed characteristic features of a real genius are not inborn to that person, yet he will acquire all the necessary characteristics of behavior of a real genius. These two points – the close similarity of the behavior and the fact that geniality is not inborn to that person – provide sufficient ground to call such a person a "*quasi-genius*".

In a sense, quasi-geniuses are "*artificial products*". They are not born with the set of characteristic features of real geniuses, but with the help of my discovery of the secret of geniality they are able to proceed in their research as if they were real geniuses.

Here I have to introduce an essential correction. Quasi-geniuses should hold to my following advice. They must exercise their function of a real genius only on part-time terms. I have mentioned above that there is no guarantee that a given super-difficult problem will be solved by an explorer if he were even a real genius. So if one decides to become a "*full-time*" genius and investigates only fundamental, super-difficult problems, he, of course, will get a chance to make a great discovery. Yet the probability will be much greater that he would not succeed to solve any of the fundamental problems he intended to explore. Young students must remember George Polya's warning: "*Waiting for ideas is gambling*".

A "*full-time*" genius risks losing all his life in a hard research of super-difficult problems not getting any positive result. I understand well the feelings of Wolfgang Bolyai when he learned that his son Janos decided to study one of the most difficult problems in the field of geometry – the problem of Euclid's fifth postulate. "*You must not attempt this approach to parallels*", Wolfgang Bolyai heartily asked his son. "*I know this way to its very end. I have traversed this bottomless night, which extinguished all light and joy of my life. I entreat you, leave this science of parallels alone. You should detest it just as much as lewd intercourse; it can deprive you of all your leisure, your health, your rest, and the whole happiness of your life. This abysmal darkness might perhaps devour a thousand towering Newtons*".

To avoid such a disaster, a "*quasi-genius*" must devote part of his efforts to the investigation of the ordinary problems of science or to any other ordinary activity. That will enable him to achieve normal goals of life, get scientific degrees and make a respectful career not losing the chance for a great discovery. So, a quasi-genius should act as "*part-time genius*".

Facing a super-difficult problem, all scientists are equal. A super-difficult problem, by its definition, can be solved only with the help of an extremely remote analogy, a crazy idea. But there is no logical way leading to such a solution. Exploring a super-difficult problem, scientists have no idea what kind of analogy can be helpful to solve it. They cannot even be sure in which direction one has to search for plausible ideas. Success comes only due to unceasing search of new ideas supported, necessarily, by a good piece of luck. Even in theoretical research, solutions of difficult problems come to light with the help of a lucky chance. Nevertheless, a lucky chance is not an independent factor. Good luck is realized probability. Luck and success depend upon the intensity of efforts in the search of solutions.

Great discoveries grow up in the land of difficult problems, while *greatest* discoveries are brought about from the land of *super-difficult* problems. Talents rule the land of difficult problems and gather the harvest of great discoveries. But in the land of super-difficult problems all scientists are equal. Moreover, I will now prove that talented scientists are definitely handicapped in regard of super-difficult problems.

First, a talent is highly successful in solving difficult problems of contemporary science. He makes many "*ordinary discoveries*" just in the framework of normal science feeling no need for the revolutionary reconstruction of existing classical theories. Second, a talented scientist is well aware of the enormous danger of being involved in the research of super-difficult problems that can absorb his life's efforts without any tangible result. Third, possessing highest scientific intuition, a talented scientist is well prepared to distinguish super-difficult problems from the solvable ones. It permits him to avoid the adventurous research of questions for which there is negligible chance to reach a satisfactory answer in a foreseeable future. Fourth, a talent is an early fruit. He gains position and reputation very early, often during his first years in science. So a talent would never permit himself to risk his high reputation suggesting revolutionary ideas which would always sound suspicious to his solid colleagues.

Actually, talents are not ambitious. They never require an inner conviction of possessing a potential for great discoveries. Talented scientists just make discoveries. Talents can manage without any special passion for science and scientific research. They get everything so easily that scientific research appears to them an amusing playground, a kind of continuous fiesta. For instance, neither Clerk Maxwell nor Richard Feynman had been ambitious since it was quite clear to their friends and teachers that they had the most brilliant brains for theoretical research. Talents are never involved in talks and discussions since they understand everything to the extreme clarity and have no desire to prove to anybody the correctness of their interpretations.

Thus, talented scientists lack the most important characteristic features of potential geniuses. That means that a talent is seriously handicapped in regard of the greatest discoveries.

One more point which keeps a talented scientist at a distance from revolutionary ideas. Talented scientists have the best understanding of the problems under research. But the higher is the level of understanding of a scientist, the more strict and definite is for him the boundary that separates the land of possible solutions from that of absolutely wrong ideas. But in the case of super-difficult problems, revolutionary ideas are often found among those ones, which seem apparently absurd. So the advantage of the best understanding often closes the gate of the kingdom of greatest discoveries. *Talent is ability, genius – intention.* The extreme intellectual power of a talent is a result of an unceasing exercise based on exceptional inborn capacities. The extreme ambition and obsession of a genius, most probably, are inborn, too. But the ambition to be a genius can be formed also by intention. In this sense, it is never late to make a decision to become a "*quasi-genius*".

Actually, a real genius puts on risk his whole life devoting it to obsessional investigation of super-difficult problems for the sake of a minute chance of making an epochal discovery. And though their life full of unreserved love to science always fascinated me, I would not like seeing any of my young readers involved in such a gamble. My final advice is as follows: be more reasonable and behave yourself as a "*quasi-genius*", undertaking the task of revolutionary discoveries only on a "*part-time*" basis.

## Step 20. MAKING THE CHANCE FOR GENIALITY GREATER

***"What is all knowledge too but recorded experience."***

*Thomas Carlyle*

A quasi-genius as well as any other explorer undertaking the investigation of a super-difficult problem should be ready finding himself eventually into an impasse. The feeling of a deadlock overwhelms a scientist when he gets convinced that all his usual methods of solution appeared unproductive in the case of the given problem. And, as we know, a super-difficult problem cannot be resolved with the help of usual methods and ordinary ideas.

If human beings were logical creatures and their brains operated like computers, then no investigator would have a feeling that he is in a deadlock. Analysis-synthesis-verification cycles would repeat one another, again and again generating new hypotheses and their modifications and testing them. Thus the process of scientific investigation should keep going on until a satisfactory hypothesis would be produced. Anyway, in the logic of research, there had to be no place for an impasse.

But we, human beings, are chiefly psychological creatures. Each one of us has his own boundaries that separate the field of reasonable ideas from the unreasonable ones. A scientist has also his personal set of methods that proved to be useful in his particular professional activities. Apart from paradigms of science which shape the world vision of the epoch, each scientist has his personal set of concepts and methods that proved their efficiency during numerous investigations. The more experienced and successful is a scientist, the more rigid are the boundaries built by the efficient ways of gaining knowledge. This set of general paradigms and personal methods are the mighty weapon, the real *organon* that insures scientist's productive research and his success in normal science.

These paradigms and methods are formed in the field of normal science and prove their efficiency in regard of ordinary problems. But when scientists meet an unordinary problem, when the phenomenon under research belongs to an entirely new level of reality, paradigms and methods of normal science do not work. Moreover, the authority of paradigms and stereotypes becomes a serious obstacle in the research and understanding of extraordinary phenomena.

Stereotypes restrict scientist's field of vision. They keep scientists within the strict framework of old theories and forbid thinking of unreasonable (but potentially revolutionary) ideas and hypotheses.

So meeting a super-difficult problem and exhausting for its solution the domain of ideas permitted by the scope of general knowledge and personal methods, a scientist comes to the conclusion that the problem is unsolvable, for his epoch or at least for him personally. This is the way that brings scientists to the dreadful feeling of a deadlock and impasse.

To make his chance for success greater, a quasi-genius should apply all the methods designed to overcome an impasse. Some of them I have already mentioned above discussing specific features of Albert Einstein's way of thinking discussed.[78]

As it was mentioned above, an impasse is formed by the walls that separate reasonable ideas from the unreasonable ones. So the first thing in fighting an impasse is to weaken these walls, to make breaches in them, to shift them aside or move further away. Here most helpful appears the skeptical attitude to the basic scientific knowledge on which the walls of an impasse are built.

The other important factor is the quality and amount of available knowledge. The more systematic, extended and elaborated is one's knowledge of a theoretical conception, the stronger are the walls of the impasse he has to overcome. Conversely, the less extended and detailed is one's knowledge of a basic theory, the bigger is the probability to find ideas to overcome the impasse in this field.

An impasse, by its nature, is a psychological phenomenon. As we have just mentioned above, an explorer feels himself driven into impasse when he becomes convinced that he had already tried *all* the possible approaches to the problem. But how can one be sure that he had examined all possible approaches? In fact, any explorer considers only reasonable ideas and approaches. The sat of reasonable ideas is determined by explorer's knowledge of the subject of research. It is the critical judgment of the explorer that forbids him to consider apparently unreasonable and absurd ideas. Basic theoretical conceptions and paradigms are the glasses through which the critical mind looks at the relevant ideas.

In view of this specific pattern of problem solving, one should admit that the most extreme way for overcoming an impasse is to forbid any critical judgment of ideas during the attempts to generate new solutions. This is just the essence of Alex Osborn's method of "*brainstorming*". Albert Einstein can be considered as one of Osborn's forerunners in practical use of collective idea generation. He liked to discuss his ideas and problems with his friend M. Besso. He was eager to discuss general problems of theoretical physics with any one interested in the subject. There is much evidence how gentle and considerate was Einstein in regard of his opponents during scientific discussions. This attitude should pay back. Explaining a fundamental problem to different listeners, Einstein had to use various, often unusual approaches and analogies. And this is one of the most effective

[78] See also the scope of these methods in Robert Djidjian, *Twenty Rules for Talented Thinking*, Tel-Aviv, Raemim, 1998, chapters 13 and 14.

means of overcoming an impasse.

As it was mentioned above, the basis of critical judgment of ideas is formed by means of fundamental concepts and conceptions. So, one can critically analyze the fundamental concepts themselves thus opening ways for new understanding of the problematic situation, shifting and pushing aside some boundaries of the kingdom of reasonable ideas. I would like to call this critical revision of fundamental concepts – *basic analysis*.

To carry on the analysis of a basic concept is a very difficult task since one has to judge critically a fundamental idea with the help of which the theory of the given field of science is built. Aristotle was famous for his thorough analysis of fundamental concepts. Many chapters of *Metaphysics* explicate the meanings of such basic concepts as essence, being, time, space, change, motion, matter, cause, etc. Basic analysis was characteristic for Einstein's way of thinking, too. In fact, his conception of the Special Relativity was elaborated through the detailed analysis of the concept of simultaneity.

The result was so much impressive that after the publication of his famous paper many physicists became convinced that no one did understand relativity as deep as did it Einstein. Recalling the years of formation of the Special Relativity, Max Born emphasized that though European physicists read and discussed works of Lorentz, Poincaré and Fitzgerald, it was Einstein who "*disclosed the epistemological root of the problem*" and thus fully deserved that the principle of relativity became connected to his name.[79]

It is quite easy advising to be skeptical and critical in regard of basic scientific knowledge. But it is very hard to exercise such an advice. How can one be critical in regard of concepts that he learned from his school years, when any statement written in a handbook and presented by a teacher was conceived as the absolute truth. How can one be critical in regard of a basic scientific conception that he admired from his youth? Is anyone able to doubt that forces of interaction appear of same intensity in identical conditions and that charges create fields of force in the surrounding space, etc, etc.?

Even if one agrees to be critical considering the basic concepts of science, it will be of little use in his practice of research. Factually, one can hardly be critical in regard of a theory that he has conceived from his youth as a specimen of true knowledge.

By contrast, experienced scientists are usually very critical to any new theory. Scientists' strong judgment notices the smallest discrepancies in the newly developed conceptions. A mature explorer conceives any new hypothesis or theory utmost critically.

But it is hardly a good policy to seat and wait for new theories to criticize them. It will be much more effective if one goes to learn an entirely new field of science. Being already an experienced and successful researcher, he will be critical to any fundamental principle of this new field. And it is very probable that he will perceive skeptically even the most fundamental conceptions of this field.

Summing up, we can state that one will significantly increase his chance for great discoveries if he changes his specialty, or more correctly, if he begins learning an entirely new science. It is quite evident that if one starts to study a new field of natural phenomena, being already an experienced explorer in some field of science, the critical approach to all theories in this new field of research is granted to him.

Here are some historic confirmations. Andre-Mary Ampere was already chosen to the French Academy of Sciences for his work in mathematics and chemistry when he started to explore electromagnetic phenomena. Michael Faraday was chosen to the Royal Society of London for his works in chemistry, too. Only later he turned to the study of electromagnetism.

No doubt, both Ampere and Faraday, being already experienced scientist, could have only critical attitude to all theoretical conceptions of electricity and magnetism of their day. That circumstance should have been very helpful in the elaboration of their original

[79] Max Born, *Physics in my generation.* New York, Pergamon Press, 1956, p.109.

conceptions. To stress the significance of such a transfer of the activity of a scientist into entirely new field of research, I would like to label the advantage one gains by radically changing the field of his research as "*the critical vision of an unprejudiced eye*".[80]

Greatest discoveries, by definition, emerge from solutions of super-difficult problems. Nevertheless, *one has negligible chance to make a great discovery if he tries to solve a super-difficult problem.* I devised this paradox to emphasize that one should avoid exploring super-difficult problems as such. Instead, it is much more effective to investigate some particular cases of a given super-difficult problem. Apparently, the best way is to start by investigating the simplest cases. Reaching a particular solution, one can proceed to its generalizations and ascend to a fundamental revolutionary principle.

Let us label this way of increasing the chance for a great discovery as the "*method of particular problems*". There are many striking examples of such an approach in the history of science. Gregor Mendel explored not the general problem of inheritance, but rather the laws of plant hybridization. Werner Heisenberg solved first a particular problem of radiation dispersion. Only his colleagues found out that Heisenberg's method can lead to the fundamental principle of new quantum mechanics. Max Planck introduced the idea of quanta of energy just as a possible way to build a correct formula of the density of energy distribution in radiation spectra. Albert Einstein suggested the idea of photons only as a heuristic means to account for the strange features of photoelectric phenomena. To use the method of particular problems one should realize that for the substitution of the initial problem by its much simpler particular instance one has to reformulate the original problem.

Studying the history of science is the best school to learn the ways of great discoveries. As Richard Feynman put it, guessing nature's laws is an art, which can be learned looking at the history of science in order "*to see how the other guys did it*".

For human mind the best teachers are examples, and the history of science provides many excellent examples of great discoveries. Learning the history of science, one realizes what a variety of approaches and principles were there considered for the explanation of the phenomena under investigation. This circumstance, on the one hand, demonstrates to students that by a persistent search one gets a possibility to reveal even the most deeply hidden secrets of nature. On the other hand, it shows what a variety of remote analogies and crazy ideas can be used in quest of fundamental principles and laws of science. Last but not least, learning the history of science, students become used to the idea that any successful scientific theory can be revised and substituted by a more adequate one. This experience is very helpful in developing a skeptical perception of theoretical conceptions and principles, a vital factor in the quest of revolutionary ideas.

Unfortunately, the history of science provides little information regarding the particular steps that led explorers to their great discoveries. Great scientists seldom wrote autobiographies. And when they did so, their autobiographies afford few facts concerning the ways by which they succeeded to uncover the secrets of nature.

Moreover, when you meet in a great scientist's autobiography an occasional remark that tells important particularities concerning the ways of his great discovery, you cannot completely rely on that evidence. As a rule, famous scientists write their memoirs at a venerable age when one is practically unable to reconstruct the details of the chain of thoughts that had brought to his great discovery. And what is even more limiting, it is a very difficult task for a scientist to reconstruct this chain of thoughts even immediately

[80] The critical perception by an experienced scientist of a new field of knowledge, undoubtedly, is a very positive factor in the research of basic problems. But, of course, this advantage does not guarantee that a scientist turning to the new field of research will make great discoveries. For instance, Richard Feynman turned to the study of biology at the age of forty, but did not succeed to make any major contribution to the field. Possibly, the motivation of the Nobel Prize winner for fundamental research in biology was not strong enough.

after the moment of the great discovery. That is why the typical answer of famous scientists to the question about the ways of their great discoveries is that the great idea had visited him suddenly, unexpectedly, in an amazing instant of illumination.

Learning all the knowledge presented in the previous chapters on the ways of scientific revolutions and "*secrets*" of geniuses of science is indispensable if one intends to increase his chance for a great discovery. Yet one of the most important preconditions is to get used to revolutionary ideas and ways they can be dealt with. This you can learn reading and rereading the appendix of this book.

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