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An Essay

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AN ESSAY

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ABSTRACT

The development of modern science has depended strongly on specific features of the cultures involved; however, its results are widely and transculturally accepted and applied. The science and technology of electricity, for example, emerged as a specific product of post-Renaissance Europe, rooted in the Greek philosophical tradition that encourages explanations of nature in theoretical terms. It did not evolve in China presumably because such encouragement was missing. The transcultural acceptance of modern science and technology is postulated to be due, in part, to the common biological dispositions underlying human cognition, with generalizable capabilities of abstract, symbolic and strategic thought. These faculties of the human mind are main prerequisites for dynamic cultural development and differentiation. They appear to have evolved up to a stage of hunters and gatherers perhaps some 100 000 years ago. However, the extent of the correspondence between some constructions of the human mind and the order of nature, as revealed by science, is a late insight of the last two centuries. Unless we subscribe to extreme forms of constructivism or historical relativism, we may take the success and the formal structure of science as indications of a close, intrinsic relation between the physical and the mental, between the order of nature and the structure of human cognition. At the metatheoretical level, however, modern science is consistent with philosophical and cultural diversity.

SCIENCE, CULTURE AND THE STORY OF ELECTRICITY

A few years ago, there was a remarkable exhibition in Berlin on the history of Chinese technology. I was impressed by the sophistication of mechanical designs and chemical processes on display, most of them more advanced than those seen in Europe before the Renaissance. The invention of gunpowder was said to have originated from the combination of coloured substances representing metaphysical features that in conjunction should have given rise to some ideal property. A particular combination exploded. Eventually, explosive mixtures were utilized for various military as well as non-military purposes.

Tradition and development of technology benefited from practical skills as well as from the mental structuring of knowlegde in China, as it did in Europe. And yet, there were impressive qualitative differences between the highly elaborated tradition of the Chinese and the evolving modern European technology, the most conspicuous being that electricity was virtually absent in Chinese technology, despite its very advanced level in other fields. Was it just because some contingent initiation was effective in Europe that did not occur in China? The answer seems to be “no”. Around 1750, there were contacts between members of the Russian Academy in St. Petersburg, involved in research on electricity, and Jesuits in China who were engaged in science and technology; instruments were transferred to Peking and some studies on electricity were made there. However, the Jesuits found it difficult to motivate Chinese intellectuals to get acquainted with the theoretical background of electricity. Without such acquaintance, experimental demonstrations of electrical phenomena were considered dangerous. It appears that the Chinese interest in the field either could not be raised, or soon faded away, in contrast to the subsequent dramatic developments in Europe. The dynamic scientific and technological developments in post-Renaissance Europe as compared to China may be attributed to different causes depending on the field, but when it comes to electricity the European pursuit of theoretical knowledge based on general physical laws was most likely a decisive factor.

This, I would claim, is at least partially due to the nature of electricity itself: Electric forces are extremely strong, being mainly responsible for the coherence and properties of matter. It is for this very reason that most objects are neutral and electric phenomena, such as lightning or frictional electricity, are rare and marginal in common experience. Therefore, exploration requires basic research driven by theoretical curiosity, and it is this feature that has a specific tradition linked to European culture. 2500 years ago, the pre-Socratic philosophers pursued the rational explanation of nature in abstract theoretical terms. With the rise of monotheistic religions of revelation in the first Millenium, these efforts were discouraged as contributing nothing to salvation; however, in the Middle Ages a positive attitude gradually developed towards scientific thought, especially at the newly founded universities, implicating that a rational understanding of nature by the human mind is in accordance with the will of God. In fact, the ‘book of nature’ was claimed by some to have almost equal status with the Holy Scriptures. In the Renaissance period, the creative power of the individual mind was emphasized and, in modern times, starting with Galilei, Kepler and Newton, the foundations of modern science were laid: just a few general laws of physics were claimed to underlie all events in space and time. In designing the theory of gravitation Newton incorporated celestial mechanics into the set of general physical laws; later, electricity and radiation, the foundations of chemistry and eventually molecular biology were integrated into a framework of a generalized Newtonian type of physics, a physics based on a few forces and a few elegant and formally simple mathematical relations.

The motives for the developments of modern science were mixed, as demonstrated by the statutes and practices of the Academies that were main centres of scientific research in the 17th and 18th century. On the one hand, experiments and the acquisition of knowledge were expected to improve technology and economics; however, another main motivation was the prospect of achieving a basic understanding of nature in rational terms by discovering general laws of nature, making it possible to explain specific physical structures, phenomena and processes. Electricity is a particularly impressive example. Though magnets as well as electrostatic effects were known to both ancient Chinese and Greeks, it was only in 18th century Europe that electricity began to receive a great deal of systematic scientific attention. Thorough measurements and analysis led Coulomb, around 1785, to the conclusion that the forces between electric charges follow basically the same type of mathematically simple laws as the forces of gravitation. Chemoelectric effects were found and investigated, allowing from 1800 onwards for the substitution of clumsy machines generating electricity by friction, by batteries making electricity readily available for experimenters. In 1820, Oersted discovered that magnetism was generated by electric currents. In 1831, Faraday reported that electricity was generated by the relative movement of a conductor and a magnet. On the basis of these fundamental results, it was realized that in principle it was possible to build electromagnetic generators of electric currents, and that these currents could be distributed to be used by electromagnetic machines for all types of mechanical work, as well as for other purposes.

Nevertheless, it was half a century before this technology became widely applied. In a first phase, electric technology was confined to such niches as galvanization, electric light by the arch lamp, and, in particular, telegraphy. It is striking that the pioneers of electrical engineering, Edison and Siemens, gained their initial experience in the improvement of telegraphic communication. Around 1867, the dynamo was invented, in which electric currents themselves produce the magnetic field that is required for the generation of electricity. After the incandescent electric lamp had been developed for general use and application, in 1882, the first power plant was established in New York. Such large-scale electric networks for wide distribution of electricity constituted the breakthrough in the use of electric power for multiple purposes, ranging from the generation of light to electric traction.

A somewhat analogous story of immense though retarded technological consequences of theoretical physical insights can be told about electromagnetic waves. Around 1864, the theoretical physicist Maxwell proposed a set of formally beautiful, comprehensive equations for electromagnetic phenomena in terms of electric and magnetic fields. Problems of internal consistency were resolved by the inclusion of a new, particularly important term into the equations. It says, in words, that not only do changing magnetic fields produce electricity; changing electric fields also produce magnetism. This term is of little consequence in conventional electromechanics, because effects would be negligibly small in mechanical devices, but it is of great interest with respect to other phenomena. In particular, the equations suggested the existence of electromagnetic waves of high frequency. In 1888, Hertz experimentally discovered such electromagnetic waves, in full accord with Maxwell’s theory. It turned out that natural light was essentially just such an electromagnetic wave and that artificial waves with many different properties could be produced, which later formed the basis of modern means of communication, including radio and television.

Among the more recent technological developments let me select information processing in computers. Microelectronics also developed following scientific insights - in this case, into solid state physics -, though this was a rather specialized field of science not directly linked to the deepest questions about the physical explanation of nature. Layers of silicium with added small amounts of different atoms were produced and arranged in such a way as to allow for fast electric processing of large amounts of information on a microscale with high efficiency. Similarly, information processing in neural networks is also based on charge separations across small distances, namely membranes of nerve cells, in this case controlled by voltage- as well as ligand-gated channels. Fast modes of processing of electric signals on a microscale are capable of combining efficiency and reliability of information processing, be it in computers or in brains. In both cases, this process depends on highly specific material properties, which are the result of hundreds of millions of years of evolution in the case of neural networks, and very sophisticated technological development in the case of microelectronics. It is by no means obvious from the basic laws of physics that such highly efficient modes of processing information can be materialized at all; this is an insight of the 20th century only, resulting from neural biology, solid state physics and information theory.

SCIENCE-BASED TECHNOLOGY: BEYOND ALGORITHMIC SOLUTIONS

Throughout the development of physics there were close interrelations between science and technology; this is particularly evident in instrumentation. After the physical principles allowing for a new technology were discovered, this was followed by technological development for implementation. However, it would be misleading to subsume this process altogether under ‘applied science’. The basic laws of physics can be taken as algorithms for calculating changes, and thus the behaviour of given material entities, in the course of time; however, they do not permit, by themselves, determining every possible stable or stationary state of material systems and their properties, that is, everything that exists or can be made to exist technologically. Thus, not only science, but science-based technology as well requires, for epistomological reasons, creativity, intuition drawn from various fields, and often luck. The styles of science and technology differ because the areas and contexts in which creativity and invention is necessary are different. In particular, implementation of techniques often requires that adequate materials be found - say, for filaments of the electric light bulb - as well as geometric arrangements of devices, such as the moving and non-moving components of electric dynamos and engines. Last but not least, the solution must be economically feasible. There is no algorithm for such technological design and innovation in the first place - neither for the choice of suitable material compositions, nor of efficient spatial arrangements of components - starting from the basic laws of physics.

Technological developments are often strongly influenced by political and psychological factors as well. Electricity is a good choice of topic, but we could just as well have taken organic chemistry or molecular biology. The history of electric technology provides abundant material for studying the conditions underlying the conversion of theoretical knowledge into practical application. There are specific reasons for the success of some countries (United States and Germany in the case of electricity) relative to others (especially England, presumably because, and not although, England was already by far the most developed country industrially in the 19th century). As for obstacles to implementation, the story of electric traction in Germany is an interesting case: the electric street car was invented and first introduced in Berlin around 1880, and yet it took half a century to implement electric traction in the major urban and suburban transport system of this city at large (the “S-Bahn”), partially because of a powerful resistance of the steam engine lobby.

SPECIFIC CULTURAL ROOTS, YET TRANSCULTURAL EFFECTS OF SCIENCE

The historical remarks on the science and technology of electricity were meant to show some features of the relation between basic science and technological innovation: at first, intellectual curiosity is a main motive - the desire to achieve understanding of strange artificial phenomena and to eventually integrate it into the framework of general physical laws. Some of the results then suggest practical applications, but considerable technical development is required for its realization. These features applied to electromagnetic machines and, at a later stage, to electromagnetic waves. Practical implementations of other fields of science, including molecular biology have been more diverse, but show the same general pattern.

The pre-requisites of modern science and the corresponding technological developments appear to have been rather specific features of modern European culture, to be traced back to a specific sequence of intra- and cross-cultural developments in the course of history ranging from ancient Greek and Hebrew ideas through Christian and Islamic cultural traditions. No matter how impressive achievements of other lines of cultural tradition (such as those in East Asia), have been in mechanics, instrumentation, chemistry and manufacture, there have also been developments (such as that of electrodynamics), that are linked specifically, though partially indirectly, to post-Renaissance European culture with its emphasis on basic science directed towards a comprehensive understanding of natural processes in theoretical, and often mathematical terms. Nowadays, electricity is applied worldwide, and the corresponding physics is also taught and understood worldwide. Cultural specificity of origins and transcultural acceptance of results are characteristics of modern science. Let us now consider the possible reasons for these two characteristics.

SCIENCE IS TRANSCULTURALLY ACCEPTABLE BECAUSE BASIC COGNITIVE CAPABILITIES ARE COMMON TO OUR BIOLOGICAL SPECIES

As a starting point, it may be appropriate to draw attention to some of the biological dispositions underlying human cognition. There is genetic evidence suggesting that the current world population may have originated from a small group in Africa that lived some 200 000 to 100 000 years ago; this is not altogether certain, but it looks that way. We do not know whether there was a concomitant upgrading of cognitive capabilities that allowed descendants of this group to replace other branches of *Homo* throughout the world, but I would guess there was. Anyhow, it was the modern species of man that developed art, such as cave paintings more than 30 000 years ago, and that ever since has been developing new cultural features documented by improved tools, by the innovation of agriculture, and, eventually, by the emergence of ‘high’ cultures marking the transition from prehistory into history.

Chimpanzees show rudiments of culture in that they acquire and transfer habits and skills. Early men developed culture with increasing complexity of artifacts until they were substituted by biologically superior humans. At some stages, cultural and genetic changes probably co-evolved. Then, following the advent of biologically modern man, cultural dynamics as such appears as the main factor of further change and development. Cultures, as we know them, are products of dynamic development and differentiation, based predominantly on the relatively fast transfer of information by means of language, rather than on comparatively slow effects of mutation and selection of genes of their human carriers.

Whereas dynamic cultural development itself is not a genetic process, it depends critically on general capabilities, which are, in turn, biological features of the species of modern man and, thus, products of biological evolution. In other words, the capability for culture is encoded in our genes, the individual culture itself is not. An example is the human language faculty: Chimpanzees are able to learn some hundred symbols, but only humans can learn languages at a level encompassing a virtually unlimited manifold of expressions, abstract terms, tenses for past and future, and grammaticalization. Virtually everybody can learn any language. Artificial constructs of communication by sounds do not usually work as natural languages do, and once a given language is learned it is difficult to learn a second one up to the perfection of native speakers. One may infer that the human language faculty is encoded in very abstract terms in our genes as a necessary, though of course not sufficient, condition for the acquisition of language, but the language itself is a product of culture. As an educated guess we might extrapolate these notions on linguistics to the biological basis of human cognitive capabilities in general: they are most probably basically similar in all human societies, to a first approximation. And, therefore, the widespread acceptance of modern science as the relatively most adequate way of explaining nature, I would suggest, is rooted in the common biological features of the human brain throughout mankind that are the evolutionary basis of human cognitive capabilities. At least in principle and in the long run, they allow for reception and comparative assessment of information regardless of its origin.

INTRINSIC LIMITATIONS OF SCIENCE AND THE PERSISTENCE OF CULTURAL PLURALISM

The capabilities of human cognition, which are shared by all mankind, are undoubtedly limited, and it is remarkable to what extent scientific thought itself has revealed its own limitations: It is a law of quantum physics that quantum physics does not allow the accurate prediction of future events in atomic and molecular dimensions. However, it is also a law of quantum physics that the energy state of a stable system can be determined and calculated with unbelievable accuracy. So, to a considerable extent, we know what we know and we know what we don't know. It is a law of mathematics that rich formal systems do not allow the proof of their consistency by their own means. It is at least a fair guess that complete scientific understanding of the mind-brain relation may not be possible in principle. All these limitations are related to self-referential features of analysis: limits of measuring the state of measuring instruments in the case of quantum physics; limits of a logic of logical systems in the case of mathematical undecidability; limits of mental, and thus conscious analysis of consciousness in our attempts to resolve the relations between the mental and the physical. These limitations, in turn, are related to the fact that *any* analysis is from *within* a system of which we, the analysers, are parts rather than detached entities.

At the metatheoretical level, such limitations allow for different philosophical interpretations. One may consider physics, as I prefer to, as a theory of possible knowledge of nature rather than of nature itself - this is the interpretation of Bohr and Heisenberg of quantum indeterminacy - or one may assume, alternatively, that there are still real processes not accessible to us that underlie observations which are subject to uncertainty relations. One may interpret the Goedel type laws of mathematical undecidability as an indication that any formal human thought depends on intuitive presuppositions (an interpretation I definitely prefer) or one may regard them, as some of the professional mathematicians do, just as formal laws applying to formal laws. And one may think of limits of decodability of the mind-brain relation - assuming that they exist - as implying that subjective conscious experience may exceed what is accessible to outward physical analysis of the brain in principle (an interpretation I strongly advocate), or one may still consider mental states as *nothing but* epiphenomena of physical processes in the neural network even if we don’t understand this relationship. These different interpretations, in turn, are related to age-old controversies on the relation of human thought to reality, extending back to the roots of Ancient Greek philosophy. It seems to me that the persistence of these controversies, not only over decades but over more than two thousand years, is *not* due to the failure of the intelligent to convince the less intelligent philosophers; rather it indicates that the world we experience is intrinsically and unavoidably ambiguous with respect to interpretations at the metatheoretical level and will always be so. Different concepts and ideas at this level are compatible with established facts and formal logic rendering modern science as a whole consistent with different, though of course not all, philosophical, cultural and religious interpretations of man and the universe. We realize that there are open questions in these contexts that are expected to remain open even if the “Super-String-Theory of Everything” (TOE) would eventually succeed to everybody’s satisfaction - questions as to why there is something and not nothing; why we can understand, in theoretical terms, so much of the order of the universe in which we are, physically, an almost negligible entity; and how the conditions for the material realization of life, mind and conciousness are linked to the physical order of nature.

This openess at the metatheoretical level is in contrast to what many people used to think, particularly in the 19th century: namely that a uniform scientific world culture would eventually replace diversified less rational metaphysical and religious notions. The choice of the interpretation one prefers, of course, is not ambiguous; nobody would just cast dice on what he or she would most easily accept or believe. It is a matter of temperament, socialization, and art de vivre, and it requires wisdom, not just knowledge. Agnostic and religious world views are expected to co-exist in the long run. It appears that liberal versions of both are consistent with scientific thought, in contrast to narrow fundamentalistic and ideological notions. Moreover, many cultures seem to be endowed with a considerable bandwidth of tolerance towards intrinsic inconsistencies. As a whole, historically different cultures proved remarkably efficient and rather robust in absorbing scientific and technological knowledge by intercultural communication, without loosing their identity distinguishing them from others.

SCIENCE IS A CONSTRUCTION OF THE HUMAN MIND, AND YET IT PROVIDES VALID INSIGHTS INTO NATURE AND ITS ORDER.

Recognizing that human cognition has limits, we may nevertheless ask why it extends as far as has been revealed by the history of modern science. How could evolution lead to cognitive capabilities of human brains, making them capable of such abstract theoretical constructs and mathematical deductions as are required, for instance, to design and understand formally beautiful physical laws, such as Maxwell's equations of electrodynamics? Clearly, there was no obvious selective advantage for such sophisticated capabilities when the features of the human brain evolved biologically up to the stage of hunters and gatherers. The direct selective advantage for such skills, however, was not necessary according to evolutionary theory. What was essential was the evolution of – presumably few but fairly general – basic capabilities of the human brain allowing the introduction or upgrading of symbolic thought and meta-levels of abstraction. These features could have been advantageous for social life, technical performance and rituals even at the stage of hunters and gatherers, as suggested, for instance, by abstract symbols in cave paintings some thirtythousand years old. Most likely, these cognitive faculties included mental preconditions for the abstraction 'number' and set the stage for the human mind to arrive at, teach and elaborate abstractions at various levels and meta-levels in the course of history, independent of further genetic evolution. Thus, socio-cultural development of mathematics including that of the sophisticated mathematical physics of modern science could proceed. This is not an unreasonable assumption, but it helps to explain the scope of human mathematical capabilities only if we realize in the first place that numbers, their applications and their formal arithmetic processing are themselves highly generalizable inventions.

In fact, it is the general, unspecialized capabilities that are most characteristic of the human species: language capable of transferring an immense variety of information at different levels of abstraction; and strategic thinking extending into a far distant future with different scenarios within which the thinking person itself is represented. New general capabilities often have potential applications that are no longer related to the causes of their origin. This is obvious for some fundamental technological innovations, for example, in the case of the invention of the wheel and the discovery of basic features of electromagnetism. Similarly, this extension in range of applicability may also hold for the biological evolution of general brain capabilities. For such reasons, the potential of human cognitive faculties may exceed, by far, those that can readily be explained on the basis of selection pressures up to the stage of hunters and gatherers when, most likely, the biological features underlying higher brain capabilities were encoded in the human genome.

While thoughts along these lines may help us understand why humans are capable of, say, mathematics, they do not explain why conceptualization making use of higher brain capabilities can lead to a far-reaching understanding of nature as documented by modern science. The considerable (though not unlimited) correspondence of certain (though, of course, not all) mental constructs with the order of nature was postulated by the early pre-Socratic Greek philosophers and has been elaborated to a surprising extent by modern science. Philosophically, this convergence may lend support to some sort of objective idealism: science is a construction of the human mind. However, the constructs are not arbitrary. The decision as to whether a construct does or does not hold is reached by the answers of nature to our questions by means of observation, experiment and systematic thought. The correspondence of some of the mental constructs selected in this way with the order of nature is not trivial; it is itself an insight supported by the history of science.

This interpretation and its variants are consistent with a sensible criterion for selecting a philosophical interpretation from those that seem consistent with facts and logic, namely the contribution to the art of living: objective idealism connects us mentally with the world experienced around us, and this has been a deeply rooted cultural motive throughout history. Admittedly, my argument cannot do full justice to the open philosophical questions about the use of the terms ‘convergence’ and ‘correspondence’ I made by relying on their understanding according to common sense. The somewhat old-fashioned flavour of objective idealism is, perhaps, not a valid argument against it, since most philosophical interpretations have been recycled in the course of history, including radical scepticism, which can be traced back to Gorgias in the fifth century B.C. It seems that within the humanities, some of the current intellectual fashions are rather close to extreme forms of scepticism, such as radical constructivism and historical relativism, claiming that there is no such thing as scientific truth, that progress in science is an illusion, and that scientific ideas are all artificial constructs depending on transient cultural situations, and bound to be substituted by others in the course of time. Scientific notions are said to make sense, if at all, only *within* specific cultural and historical contexts in which they are put forward. In my view, it is a good mental excercise to engage in discussions with proponents of such radical scepticism. It sharpens the mind, but it is rewarding only as long as the said proponents do not consider themselves intrinsically superior and more enlightened than ‘naive’ practising scientists and normal people.

Against radical versions of relativism, I would argue that the historical development of science, despite all the errors, dead ends and false trails, has left behind an ever-increasing body of persisting knowledge, of real scientific facts. After all, the earth is not a disk but a sphere, though only to a first approximation. There are atoms and molecules, stars and galaxies. DNA is genetic material. The diversity of the forms of life evolved. Neural networks process information. More often than not, a core of scientific insights retains validity even when conceptual frameworks are expanded and changed, and theories (such as Newtonian physics) are recognized as approximations that apply to limited domains. The progression of knowledge, often denied nowadays, is only obvious if we look back in history, not by analysing short periods at high resolution but by considering the long-term development of science - just as the River Mosel looks locally (at high resolution) as if it is going everywhere or nowhere, whereas the large-scale (low-resolution) bird's eye view shows us that it is definitely flowing north-east, downward, and into the River Rhine. In such contexts, paying attention to too much detail does not lead to adequate conclusions, but rather tends to obstruct them.

As already mentioned, claims of truth for scientific insights do not contradict the ambiguity of the metatheoretical interpretation of the body of available knowledge; rather there is a spectrum of choices that are consistent with empirical insights and logical thought. In my view, adequate choices may be facilitated by two basic presuppositions sustained by modern science: First, strict physicalism, because the general laws of physics have turned out to be valid for all events in space and time so far as we can judge. Second, an epistomological scepticism that is supported by science itself, and by decision theory, leading us to recognize that there are limits to human thoughts and knowledge, as suggested by the uncertainty relations of physics and the undecidability theorems of mathematics. There are limits to the limits, however; they do not lend support to *unqualified* scepticism. On the contrary, there is still a very large and important set of scientific questions that have definite scientific answers.

If we decide to deny any truth, even approximation to truth in science, we artificially and, I think unreasonably, exclude some of the most interesting questions the story of science raises with respect to human self-understanding, namely in what way, to what extent and why there is such a considerable correspondence between some of the human mental constructs on the one hand, and the order of nature surrounding us and including us, on the other.

IN FAVOUR OF OBJECTIVE IDEALISM: SOME REMARKS ON $E=mc^2$

Let me illustrate and summarize some of the last points by a well known example: the Einstein formula.

> “Gentlemen, the ideas about space and time I am going to explain to you are based on experimental physics. This is their strength. Their tendency is radical. From this hour onward space as well as time taken by themselves are bound to completely sink into the shadows and only some sort of union of both should retain autonomy.”

This is Minkowski’s famous introduction to his lecture at the 18th assembly of German scientists and physicians in Cologne on September 21, 1908. A few years earlier, Einstein had published the theory of relativity, and Minkowski had given it the mathematical form of perfect symmetry of physical laws with respect to space and a time coordinate - time multiplied by the velocity of light and the imaginary square root i of “minus one”. A byproduct of this formalism, impressive by the beautiful symmetry of equations, is the formula $E = mc^2$ which had already been derived earlier by Einstein. The theory of relativity is strongly confirmed by experimental evidence, in contrast to many other formalisms which are just as beautiful - for example, Kepler’s postulated “harmonic” relationships between distances of planets from the sun based on mathematical features of ideal Platonic bodies. The theory of relativity is a highly abstract construct of the human mind - just think of beautiful formal symmetry and the use of the imaginary number i - and yet it corresponds to real spatio-temporal facts and rules about nature. We would lose much of the fascination of science as well as our orientation in real life if we tried to deny remarkable correspondences between such theoretical constructs, on the one hand, and a reality that exists without us, on the other, by claiming that all of it is just arbitrary mental construction and nothing else, not only the formalism, but also the alleged correspondence with reality. It seems, at least to me, that the notion implicitly underlying the thinking of most practising scientists is still the philosophically most adequate interpretation: physics is considered a construct of the human mind *and* an approach to partial but true insights about nature and its order. And this then leaves us, but also allows us, to discuss challenging though not undisputed interpretations at the metatheoretical level, such as Schelling’s philosophical notions proposed around 1800, on the hidden unity of the ideal and the real aspects of the universe; and Minkowski’s concepts, of 1908, on the hidden unity of space and time.

NOTES:

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It would have been very difficult to include adequate references for the different broad aspects combined in this essay. Some aspects are covered in the reference section of my book on "Science and the image of man" on which my article is partially based ("Im Spiegel der Natur erkennen wir uns selbst - Wissenschaft und Menschenbild", Rowohlt Reinbek 1998, pp. 289-312).

The story of gun powder in China mentioned on the first page of this article is treated in much detail in Joseph Needham's "Science and Civilization in China", Vol. V,7, Cambridge University Press 1986. Thang alchemists searched for elixiers of life and material immortality. Their jars must have contained, among other substances, those required for gun powder. In their treatises dated by historians as early as the 9th century, there were warnings not to mix salpeter, sulfur and honey, because, with such mixtures, "hands and faces were burnt, and eventually the whole house burnt down".

With regard to the history of science and technology of electricity in Europe, and its virtual absence in China, see A. Kloss "Von der Electricität zur Elektrizität", Birkhäuser Basel Boston Stuttgart 1987. In this book the author mentions, on p. 41, Richmann's contacts with Jesuits in Peking on electricity in the middle of the 18th century. The relation to the Academy of St. Petersburg is documented by P.A. Gaubil, "Correspondence de Peking 1722-1759" (pp. 617, 810, 811), Libraire Droz, Genève (1970). In a letter to Kratzenstein and Richmann of April 30, 1755 (not yet knowing that Richmann died by lightning while doing experiments on atmospheric electricity in 1753), Gaubil wrote: "... in current circumstances it is not appropriate to demonstrate experiments on electricity in front of Chinese intellectuals and dignitaries; this matter is not without danger and disadvantages for us. Before that, the Chinese ought to learn about the facts and causes in this matter, and this is not easy. Pater Josephus Amiot, fellow of the local

French College, thought and performed ingeniously in his way of doing experiments. Now he does something else...".

The reasons for the "blockades" of Chinese technology in modern times are a matter of controversies (see B. Gille's book on "The history of techniques", Vol. 1, "Techniques and Civilizations", Blocked technical systems - Chinese Techniques, pp. 38-407, especially p. 406/407, Gordon and Beed Scientific pulishers, New York 1986). While Needham emphasizes that the West benefited from a capitalist, manufacturing and mercantile economy, other authors insist that almost every element regarded by historians as a mayor contribution to the industrial revolution in North Western Europe was also present in China. Only the Galilean-Newtonian science was missing.

Basic science motivated by philosophical questions about nature is crucially involved in the development not only of electricity, but also of other fields of technology, such as organic chemistry and genetic engineering. In the 19th century, the development of organic chemistry was stimulated by increasing evidence of how molecules were made up of atoms and of the role of multivalent chemical bonds between atoms, including carbon and nitrogen atoms. The notion that organic chemical substances and reactions have a key role in the understanding of basic life processes which may, in principle, be reproduced and analysed in the test tube has been gaining weight ever since. The synthesis of urea by Wöhler (1828) was hailed as a breakthrough. Thereafter, many biological substances were synthesized by chemical reactions. At the beginning of the 20th century, atomic physics revealed that electric forces were the main determinants of atoms and their properties. To advance understanding of them, quantum mechanics was developed introducing new concepts into the fundamental laws of physics, but the basic forces responsible for atomic and molecular structures, even in the framework of the new quantum mechanics, were and still are attraction and repulsion between charged particles, nuclei and electrons, according to Coulomb's law. Quantum physics led to the understanding not only of atoms, but also of chemical bonds linking atoms into molecules, including organic molecules, which play essential parts in biological processes of reproduction and evolution.

Modern genetic engineering is based on the insights into the structure and function of the heriditary substance DNA. The construction of the DNA model, the double helix, required detailed knowledge of dimensions and angles of chemical bonds, which could only be understood in terms of quantum physics. The model was confirmed by the use of X-ray diffraction. It led to a fundamental understanding of the molecular basis of biological reproduction, heredity and evolution, and all this occurred to a large extent between 1952 and 1963.

Again, it took a while before practical applications were envisaged. These came about only after further research into more specific problems: How does the DNA helix unwind during replication, how do the mechanisms ascertain that chains made up of hundreds of millions nucleotides can be copied reliably with very few errors, if any, and how is chromosomal DNA broken and recombined? The enzymes involved in cutting, re-uniting, transcription, copying and repairing nucleic acid molecules then provided essential tools for artificial construction of DNA sequences, and this was one of the main origins of modern genetic engineering.

Alfred Gierer, February 25, 2000