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Perspective

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Science and Arts, Philosophy and Science: Why after All? Why Not?

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Dedicated to the memory of Prof. *Jack D. Dunitz*

This perspective summarizes some interdisciplinary aspects of science and the relation to philosophy, also including the basic motivations and aims as they might be discussed with young scientists starting their careers and presented also in the form of a commencement speech. The contents of this speech were repeatedly discussed also with *Jack Dunitz*, who showed great interest in it, given his broad interests. The speech also referred to an earlier commencement speech by *Jack Dunitz* in 1989. In the introduction of our essay, we mention the early common history of science and humanities under the name of philosophy. This early history can be traced back to ancient Greek philosophy and the 'academy' of *Platon* in Athens with a history of more than 1000 years until closure in 529 AD, in modern times revived as the National Greek Academy in Athens in the 19th and 20th centuries. Other 'academies' in Europe started in the 17th century and had publications under various names involving 'philosophy' with a focus on what we call science (natural science) today. After about 1800 there was increasing fragmentation of the various fields of knowledge and philosophy was considered to be part of the modern 'humanities' quite separate from science, and the natural sciences were fragmented into physics, chemistry, biology *etc*., and even finer subdivisions. The essay also describes an effort at ETH Zurich, reintegrating the various subfields of science and also stressing an education of scientists and engineers in the humanities. The essay concludes with a discussion of several global risks for mankind and a scientific imperative to maintain life on Earth.
The common aspects and the foundations of all sciences as fields of knowledge aiming for an understanding of the world around us and of human beings as part of it are discussed from various perspectives.

Keywords: foundations of science, interdisciplinary aspects of science, natural sciences, philosophy, subfields of science.

1. Introduction

Motto

'When I started my studies one used to study 'the sciences' and not just one of these as is now so commonly done.'

Robert Wilhelm Bunsen

Chemistry as a branch of science is in many ways a highly interdisciplinary enterprise. It is closely related to physics and biology, and some scientists consider these two sciences as particularly interesting special branches of chemistry. Beyond science, chemistry relates also to the arts and to architecture, and some consider synthetic chemistry to be some kind of 'molecular architecture'. Indeed, the beauty of chemical structures as also the beauty of the creations of art and architecture is certainly appreciated by the structural chemist, in particular.[1] Notably also symmetry is a concept connecting these different areas of human endeavor,[1–8] as also often stressed by *Jack Dunitz*.[2] While being part of the laboratory of organic chemistry at ETH Zurich, *Jack* always kept close contact to physical chemistry and viewed his own scientific work as highly 'interdisciplinary science' in a broad sense. The statement of the early physical chemist *Robert W. Bunsen* quoted at the start of this essay also expresses this broad view of chemistry as an interdisciplinary science.[9] When *Bunsen* made this statement (originally in German, freely translated by us here, see [9], as cited in [10]) he commented on the first half of the 19th century.

At that time in fact in the English language one still used philosophy as almost synonymous with what we call now 'science' with the meaning effectively focusing on natural science (physics, chemistry, biology…, then also 'natural philosophy'). This is well reflected in the names of the journals of science, one of the first being the '*Philosophical Transactions of the Royal Society*', by the Academy of Science in London, which took the name 'Royal Society', founded in the 17th century at about the same time as the German Academy of Science Leopoldina was founded (*Deutsche Akademie der Naturforscher*, Leopoldina, named after the Emperor *Leopold*, who granted special privileges such as freedom to publish without censorship) and the French Academy of Sciences (*Académie des Sciences*), which both had similar journals for science with a continuous history of publication until today.[11] These three academies existed without interruption from about 1650 until today, whereas the older Italian Academy of Science, the *Accademia dei Lincei* (founded in 1603 with its most famous member *Galileo Galilei* joining in 1611) had a complex history: it ceased to exist several times, experiencing several revivals, until it was finally established as the current national academy of science in Italy after the Second World War. These academies had no direct commercial purpose but had the goal of promoting and disseminating science in a broad sense. One might note that a commercial journal of science was also founded in 1798, the '*Philosophical Magazine*' focusing on 'natural philosophy' or science in a broad sense with a continuous publication history until today. From this one can trace the common use of the word 'philosophy' for science until 1800 at least. When we use the title Ph.D. (doctor of philosophy) for a degree in science, this reflects still today this former usage of 'philosophy'.

The word philosophy goes back to ancient Greece (a contraction of words with the roots *philein* and *sophia*, loving wisdom or *philos* and *sophia*, the 'friend of wisdom' for the philosopher). The program of Greek philosophy was a systematic rational approach to understanding the world at large, including natural phenomena as well as human activity, social phenomena and politics, often focusing on 'natural philosophy' but by no means restricted to it. There is only a fragmentary written record of pre-*Socrates* philosophy before 400 BC,[12] but *Plato* as a most famous student of *Socrates* founded the 'Academy' of Athens around 385 BC, with its members meeting in the olive groves of the 'hero Akademos', giving the name to this as well as to later academies. *Plato*'s writings have been well preserved in several books,[3] as have also the writings of the younger member of the academy, *Aristotle*, with a strong focus also on natural phenomena. Much later another famous student of the academy of Athens was *Euclid*, providing an example that mathematics was a logical part of philosophical studies. The Academy of Athens had a long, complex history of almost one thousand years until it was closed in 529 AD by the Greek Christian Emperor *Justinian*. It was re-founded in modern times as the Greek Academy of Athens, starting with an effort to generate a building and location for it around 1850

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and officially instituted as the National Greek Academy in 1926. *Figure 1* shows a photograph of the main building of the current Academy of Athens in Greek revival style of the 19th century.

This building also demonstrates the role of symmetry in the beauty of Greek architecture, which can be related also to the beauty of symmetrical structures generated by molecular architecture,[1,2] and the role of symmetry in understanding the fundamental structure of the laws of nature in Greek philosophy[3] as also in modern physics.[4–6] Obviously, we cannot provide here an adequate history of mankind's philosophy and science, which should include pre-historic documents of human efforts to understand and picture the world, such as the cave paintings going back several tens of thousands of years, relating pre-historical 'science' with art, but with uncertain interpretation, the human religions and mythology as representations of world understanding, early astronomy of the old Babylonian and Egyptian cultures as the discovery of certain regularities in natural phenomena, and, of course, ancient Eastern Philosophy, for which extensive written records exist, with often strong religious links.

What this perspective would attempt here is to show that until about 1800 there was a certain unity in the understanding of philosophy as an approach to rational understanding, which certainly included science with a prominent place. Today we include 'philosophy' as part of the 'humanities', in French '*sciences humaines*', in Italian '*studi umanistici*', and German '*Geisteswissenschaften*' ('sciences of the human spirit'), as opposed to the 'natural sciences' or 'science' in short. Such an opposition seems strangely inappropriate, particularly, when one expresses the opposition by calling the natural sciences 'inhumanities' (or analogously '*sciences inhumaines*', '*geistlose Wissenschaften*') or when claiming that 'humanities are no science', all of which is in fact occasionally done in various ways.

Figure 1. Photograph of the Main Building of the Academy Athens built in the 19th century in Greek revival style, illustrating the role of symmetry in art and architecture (Photo taken 2018 by *Gunther Wichmann* during the European COST conference Molecules in Motion at the Academy).

After about 1800, there was an increasing fragmentation, separating humanities and social sciences from the natural sciences and separating the various branches of science into subfields. Today, one recognizes an ever-increasing specialization of the various areas of scientific investigation into more and more fine-grained sub-fields and 'sub-branches of sub-fields'. In order to counter this tendency, ETH Zurich has introduced the possibility to study 'Interdisciplinary Natural Sciences' in a program which combines physics, chemistry and biology to start with (including mathematics, see *Figures 2* and *3* for a brief summary[13]).

This turned out to become a very successful and lively program of studies which became popular with many of our students. After a difficult period when being incorporated in the Chemistry Department in the early 1990s, it is now comparable in its size to the traditional branches of studies in chemistry and in chemical engineering. I had been responsible (as '*Fachberater und Studiendelegierter*', 'advisor and delegate of studies') for its development for almost two decades, and partly motivated by this function, I gave one of the traditional commencement speeches to finishing doctoral students of all Departments of the ETH in 2004, where a broad audience of students and their relatives had to be addressed. In this commencement speech I tried to convey some of the most important aspects of the common ground for all sciences and, indeed all kinds of rational human investigation in the sense of what was called 'philosophy' when it started 2500 years ago but addressing young students of today. This speech has appeared in print in German in several versions[14–16] but is not available in English. The present short perspective provides a slightly modified and complemented version in English, which thus will make the main ideas and contents now available here to a wider readership. In order to retain some of the liveliness of the original version, *Sections 2* to *6* of the perspective follow the form of the original speech closely. This is complemented with some concluding remarks in *Section 7*.

We should give here some warning that related to its origin, this brief perspective does not intend to deal

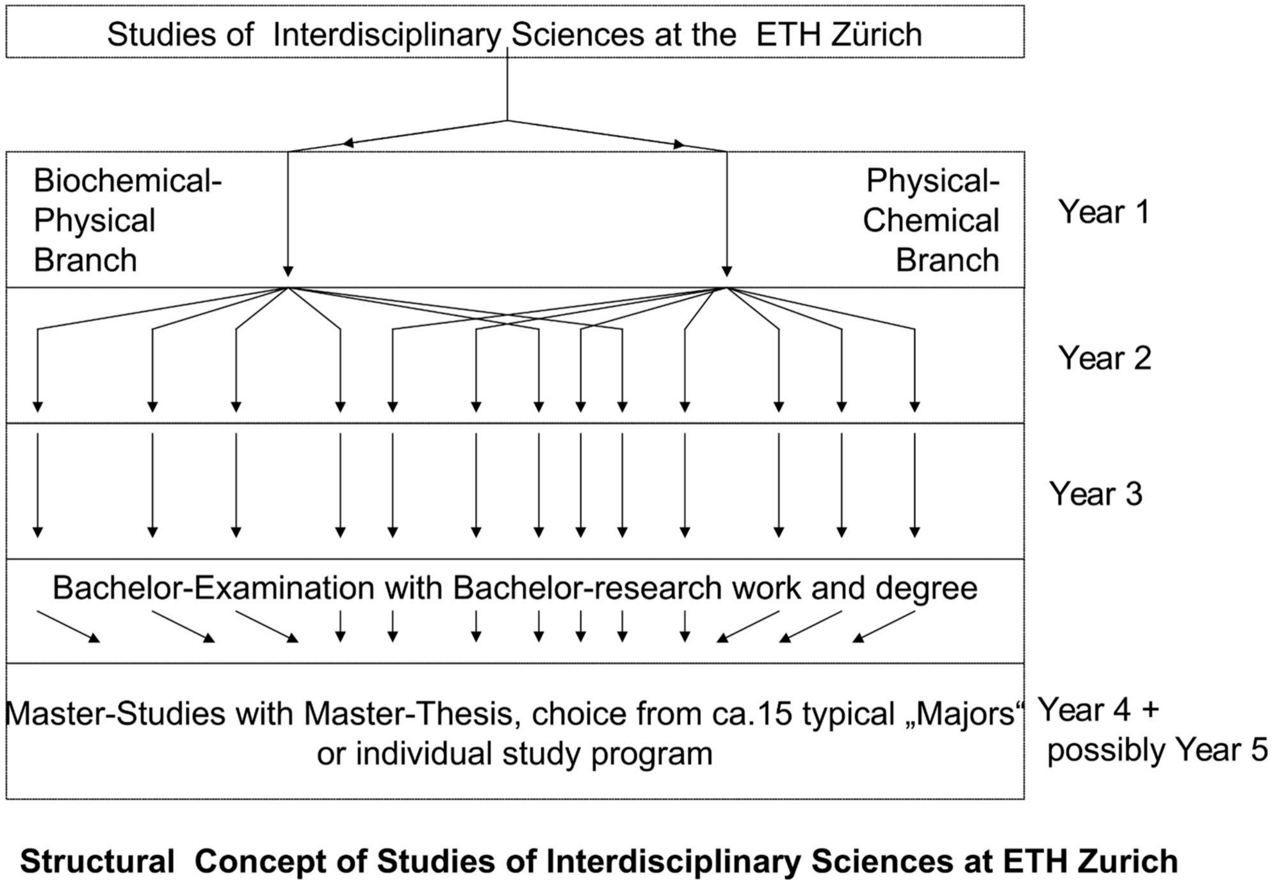

Figure 2. Overview of the program of study followed by students in the interdisciplinary Natural Sciences Program at the ETH Zürich. In the first year of study, the 'basic year', the students choose between the biochemical-physical and the physical-chemical fields of study, both of which have a relatively well-defined program of study for one year each, with little freedom of choice of courses available within the fields of study.[13] This is intended to make it easier for students to begin their studies. Starting with the second year, students can compile a broad program of study, including, in part, groups of required courses, which can be supplemented with individually chosen courses. The options range from a strong biological orientation to a more physical-chemical direction of study, to theoretical physics and high energy physics, whereby an interdisciplinary component continues to be incorporated in the program. The direction of study chosen initially does not yet determine the definitive orientation of study. Both fields of study converge in the master's degree program, with research-oriented specializations with around fifteen different 'majors', which range from 'Chemistry and Physics' through 'Biophysical Chemistry and Organic Chemistry', 'Analytical Chemistry and Physical Chemistry' and 'Biology and Chemistry', to name only a few examples.[13]

with its topic in encyclopedic detail and depth. It rather intends to raise some questions which may stimulate further thinking. We also do not deal with 'Chemistry' in the usual sense in the first place but address chemistry as an interdisciplinary topic and typical for the sciences in general, as indeed some have stated that physics, biology, and even philosophy are interesting branches of that 'interdisciplinary chemistry' a point of view certainly appreciated by *Jack Dunitz*. Before turning to this topic specifically, one should add here that the ETH Zurich as the Swiss Federal Institute for studies in science and engineering at a technical university also makes an effort to provide all students, without exception, with some compulsory instruction in what we today call the 'humanities'. While the extent of this instruction is presumably too small to be very effective, it nevertheless reminds the students of the motto of *Francesco de Sanctis*, one of the founders of the ETH as an institution concentrating on studies in science and technology: *Prima di essere ingegneri, voi siete uomini* (see [17,18]). Some of this effort is hoped to induce students of science to perhaps also take on wider responsibilities in society and politics, where we find so few scientists, unfortunately,[19] although some scientists do have careers as successful politicians as

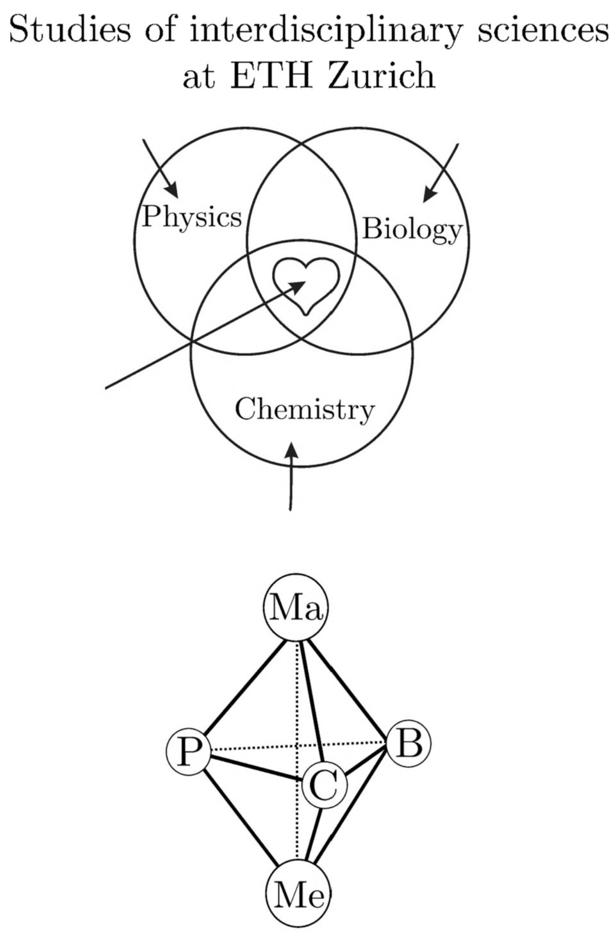

Figure 3. Diagram illustrating the concept of the interdisciplinary sciences program. The three basic sciences, with their overlapping areas, are shown in the plane of the page. When one extends the diagram into the third dimension, this can be extended to a double tetrahedron of five sciences, where Ma stands for mathematics and Me for medicine.

well (see [20,21]). It might be noted that in the USA (*e.g.*, at technical Universities such as MIT *etc.*) science and engineering students have compulsory requirements to take several courses in the 'humanities'. One also finds the concept of a 'college of arts and sciences' or a 'faculty of arts and sciences', where during the first year of studies, students take courses from many disciplines before majoring in one discipline.

Interestingly, there does not seem to be a similar effort towards some compulsory education in science for students of law, economy, political sciences *etc.*, the 'humanities' at universities, although this might be highly desirable, quite generally and, in particular, when these students take on great responsibilities in society and politics later in their lives. Indeed, in the 'culture of the humanities' one often finds a certain disdain of the natural sciences as 'non culture' (a fairly typical example is to be found in the very popular book by *Schwanitz*[22]). This disdain and separation of cultures was also addressed in the widely cited Rede lecture of *C. P. Snow* on the 'two cultures'.[23] The reverse disdain can also be found sometimes.[24] However, we shall try to point out here that there exists among some scientists and philosophers a culture of unity between science and philosophy, art and literature, and a good example can certainly be found with the 'chemical' and 'non-chemical' writings of *Roald Hoffmann*.[25–27]

However, this essay shall address finishing students in science and engineering here and now in the first place in the form of a commencement speech.

2. The Natural Sciences: Why at All? Why Not?

Today we're celebrating the conferral of your doctoral degrees, which you are receiving as a result of a great achievement, as a result of a great deal of long, hard work on a difficult project. You have solved a scientific or technical problem which had not been solved before. Through your work you have created new knowledge! I extend to you my sincere congratulations on this. My congratulations also go out to your parents and partners who have supported and helped you during your education and the phase during which the most strenuous part of your research work took place. They are rightly invited today as your guests for this celebration.

The completion of such a work is a time to pause and reflect upon why one has taken on this work and put in this effort in the first place, and perhaps will continue to do so in the future in a different form.

About two thirds of you have worked on a topic of mathematical or scientific nature, while about one third of you have worked in the areas of engineering and architecture. With my choice of topics today I hope to speak to all of you, because the boundaries between the fields of study cannot be clearly defined: not even the border between the natural sciences and the humanities.

Sciences – Why at All? Why Not?

The answers to these questions were expressed by the Greek natural philosopher *Democritus* two and a half thousand years ago, or have at least been attributed to him:

βουλεται μαλλον μιαν ευρειν αιτιολογιαν η την περσων οι βασιλειαν γενεσθαι

The scientist (philosopher) would rather obtain a single fundamental understanding than become king of the Persians.

(freely translated by us here from *Democritus of Abdera*, *ca.* 470–380 BCE, see also [12,28])

A more literal translation would be, 'he would rather wish to find a single fundamental cause (for some phenomena) than to be conferred (or obtain) the kingship of the Persians (or that the kingship of the Persians would be generated for him).' The words in this sentence are particularly interesting because almost all of them are found in modern language as foreign words. βουλομαι ('I will') is connected to βουλημα, 'the will', and βουλιμια, 'ravenous hunger'. We recognize the word 'bulimia' in connection with this. μια ('the only one') is in use as the female name *Mia*, although this is also understood as a shortened form of *Maria*. ευρειν, 'to find', is known by all from 'Eureka' of *Archimedes*, 'I have found it'. αιτιολογια, 'causes or origins' is found in etiology, the science of finding the origin of diseases: in Latin *rerum cognoscere causas*, 'to know the causes'. The proper name Persian is used unchanged. We recognize βασιλεια, the position or power of a king or his reign, from 'Basilica' (the royal hall) and finally γενεσθαι, 'to become', in genesis or in 'genetic'. One actually doesn't need to know any Greek words to at least guess the general meaning of the sentence, and everyone has learned the Greek letters in science and mathematics. The short translation in English is found in [28]. A statement to the same effect can be found in a speech of *Cyril N. Hinshelwood* (1947) about knowledge as value: 'And to this knowledge they (the scientists) attach an absolute value, that of truth and beauty. The vision of Nature yields the secret of power and wealth, and for this it may be sought by many. But it is revealed only to those who seek it for itself'.

With this, we have perhaps said almost everything which needs to be said about this topic. I should, however, entertain you for about twenty minutes, and so for this reason, I shall discuss this in a bit more detail and provide you with a more complete translation, complemented with a few additional remarks. It is clear that we must translate the reference to the rule of the Persians appropriately: the last kingdom of the Persians was destroyed at the time of the Shah in 1979, but at the time of *Democritus*, the kings of the Persians, *Xerxes*, *Artaxerxes* and *Darius* the second, were the picture of absolute, almost God-like power and unlimited wealth. 'President of the United States' would be the closest modern equivalent, but this would be only a weak reflection of the glory of the Persian rulers. One single, large or perhaps not so large fundamental understanding, perhaps out of your doctoral thesis work, is worth more than the power and wealth of the rulers of the world. Why study science at all? The answer lies in knowledge gained and discoveries made. Why not study science? The answer is not power and wealth: this is what *Democritus* tells us.

What, however, do we mean when we speak of the natural sciences and their fundamental discoveries and insights? We shall discuss a few topics which pertain to this:

1) What are the natural sciences?
2) What are the subjective reasons for studying them?
3) What are the objective reasons for studying them, and what is the role of the natural sciences as they pertain to society and mankind?
4) What is the relationship of the natural sciences to the humanities? Are there border crossings in the basic knowledge of the natural sciences in the direction of the humanities?
5) At the end we'll return to the statement of *Democritus* and the questions, 'Why at all?' and 'Why not?'

3. What Are the Natural Sciences and Why Does One Study Them?

The first three points lead us to a 'classical' formulation of the theme of this perspective.

'What are the natural sciences and why does one study them?'

All too often this question or similar questions have been the topic of academic speeches. The formulation goes back to a 'classic', the inaugural lecture of *Friedrich Schiller* as professor of philosophy in Jena in the remarkable year of 1789, 'What does it mean and to what end does one study universal history?' ('*Was heisst und zu welchem Ende studiert man Universalgeschichte*' an academic inaugural speech on the occasion of the opening of his lectures), delivered by *Friedrich Schiller*, Professor of Philosophy in Jena, 2nd Edition, Jena 1790, cited in.[29] *Schiller* has been taken to task on this because of poor grammar – but he had poetic license. The title of his talk sounds better than the seemingly grammatically correct alternative (at least in the original German version)!

So: What are the natural sciences?

Simply said, the natural sciences are physics, chemistry, biology and more… but what are these? A few of you are perhaps familiar with the student saying as a rhyme in German:

‚Chemie ist wenn es stinkt und kracht
Physik ist's, wenn die Sonne lacht
Und Bio wenn man Kinder macht'

('Chemistry is when it stinks and explodes, physics is when the sun smiles, and biology is when babies are made.')

Seriously and apart from every schoolbook definition, where are the boundaries between these natural sciences to be found? Actually, there is really just one natural science, just like there is only one ocean. However, it can sometimes be useful to draw approximate boundaries, as in the case of the oceans, like the boundaries drawn between the Atlantic, Pacific and Indian oceans, completely open boundaries. These boundaries are used for delineation and organization of study, teaching, and research. They are not to be taken seriously and are to be crossed whenever necessary. In your research, you've certainly done this often too, and in studies at the ETH, we are particularly familiar with this in connection with the Interdisciplinary Natural Sciences course program of study. Here, physics, chemistry and biology are taught and studied across disciplinary 'boundaries' from the start. If you, as parents, would like to send further children to study at the ETH, you might want to keep this course of study in mind as a possibility for your children. It is a very demanding and valuable study of the natural sciences (see *Figures 2* and *3*).

Our science is concerned with the understanding of all of nature, and this is actually everything which makes up our world, perhaps with the possible exception of the human mind or spirit, which is supposed to be the subject of the humanities.

The objective of understanding all of nature is also evident in the early titles of the textbooks of natural philosophy of the Greeks, 'περι φυσεως πρωτον' ('The First Book of Nature' by *Democritus*) or 'περι φυσεως η περι του οντος' ('About nature, or that, which is').

Ultimately, then, this pertains to our understanding of the world. What, however, are the subjective and objective reasons for this? It would seem that bacteria, earthworms, chickens and perhaps many people can live perfectly well without such a need to understand the world around them. Beer and football might be enough. Why, however, do many people pursue the study of the natural sciences?

4. Subjective Reasons for Science

The first answer lies in the joy of the search for scientific understanding. We hunger for knowledge as we hunger for food. Just as a good meal brings us joy, we rejoice in the satisfaction of our hunger for understanding: this makes us happy. We recognize the same in the words of the beautiful poem by *Rose Ausländer*,[30] as cited here in imperfect translation from [18] (*Du bist / unwiderstehlich / Wahrheit / Ich erkenne dich / und nenne dich / Glück*).

You are
irresistible
truth
I see you
and name you
bliss.

Here she provides an answer to the question of the Roman Sceptic Pilatus, who was confronted with the divine Truth and asked, 'τι εστιν αληθεια': 'What is truth?' In an earlier commencement speech *Jack Dunitz*[31] pointed out the importance of this primary subjective motivation: many secondary reasons can be added to this. One would like to do something good for other people, or one would like to rule over them with greater power. Perhaps one would like to earn a living, or perhaps simply be awarded a doctorate.

5. Objective Reasons and Role in Society and Humanity

The primary subjective reason for the happiness gained through knowledge won leads us to speculate about possible objective reasons. From the point of view of biological evolution, it could be argued that mankind's thirst for knowledge could have evolved in man because of an advantage in natural selection. The advantages associated with it benefit the individual less than they benefit the society as a whole. In the end, the quest for knowledge can be important for the survival of mankind. Science is to be found at the beginning of almost every activity in today's society. To state this is to state the obvious. Less well known is the role of fundamental research: an initially minimal investment in fundamental research produces benefits of immeasurable value. *Viktor Weisskopf* has estimated that all fundamental research conducted since *Democritus* and Archimedes through 1970 cost approximately 30 billion dollars (cited in [32]). This research has laid the foundation for almost all present economic activity, from food production to the production of music CD's (compact disks) and smart phones. Even a small war costs more and produces nothing but misery.

According to another estimate, approximately 20% of the gross national product of the USA is based on the discovery of *Schrödinger*'s equation and quantum mechanics (*Eqn. 1*).[43]

$$\mathrm{i}\frac{h}{2\pi}\frac{\partial\Psi}{\partial t} = \hat{H}\Psi \tag{1}$$

There is more information in this equation than there is in a thousand pictures, and more economic power than is possessed by the largest business empire. Considering some undesirable side effects of modern technology some would then say that we already have more than enough of this kind of knowledge, and that it presents only a *danger for mankind*. I disagree. Rather, my argument is that the dangers for mankind are more likely those which result from uncontrolled human activities which take place in the absence of scientific understanding. The survival of mankind will depend on whether mankind's scientific knowledge advances quickly enough to keep pace with the effects of changes in and threats to the environment due to human activity. The climate issue is without a doubt a central concern, but there exist other known and also hidden and to date unidentified dangers which must be taken into account as well. Sufficient understanding to structure a future-oriented management of our environment is still lacking, and in the areas in which we know what should be done, mankind does nothing! (see [17,18,20,21,32–34]). It is often mistakenly assumed that having only incomplete scientific knowledge makes it impossible to decide what to do. The climate problem is a good example of this. We do not currently know with certainty precisely how the earth's climate will change as a result of anthropogenic CO_2 emissions. It is, however, not necessary to know this in order to make reasonable decisions. It has been known for a long time that the proven anthropogenic increase in CO_2 concentration is associated with very high risks of dangerous changes in the earth's climate. As in Russian roulette, in which the risk of death is only 1/6 (and in individual cases, the result is not predictable in an honest game), the knowledge of the risk should be sufficient to dissuade reasonable people from getting involved in this sort of game. Easily implemented methods for reducing CO_2 emissions have been known for a long time. One must only subject fossil fuels to increasingly high taxes at the 'source' or the point of import. This can be done gradually, systematically increasing the tax each year until the goal of reducing CO_2 emissions is reached. This would have the advantage, by the way, of keeping the money in the consumer countries and not letting it flow out into the producing regions, which is potentially very problematic. All of this has been known for several decades, but nothing has been done (effectively not even today, although recently there has been a lot of talk about it. The 'climate roulette' is more similar to an inverted Russian roulette with the risks for a bad outcome being nearer to 5/6, see [34]).

6. Science, the Humanities, and Society

This leads us to the *second problem*. We really don't know how people and human society function. The answer to questions like this should probably *come from the humanities and social sciences*, but they do not tell us much useful about this. Perhaps a new dialogue between the humanities and the sciences would be necessary here. After all, man himself is also a part of nature, and not only as a higher animal, but also as a thinking being. In this sense, a drawing of perhaps artificial borders between the humanities and the natural sciences does not seem to make sense, and border crossings in both directions seem important.

The obituary for the musician and industrialist *Paul Sacher*, published twenty years ago in the *Neue Zürcher Zeitung* (NZZ), struck me at the time as being so remarkable that I kept it: 'He regarded science not only as a source of useful solutions of practical human problems, he also respected it, like art, literature and music, as one of the humanities.'

The complete quote is from the NZZ on May 25, 1999 and was published as an obituary by Biozentrum Basel, which received substantial support over the course of many years at the urging of Prof. *Sacher*.

'Basel, 25. Mai 1999

In deep mourning we take our leave of *Paul Sacher* Prof. Dr. h.c. mult., the good friend and kind supporter of our institute. He regarded science not only as a source of useful solutions to practical human problems, but also respected it as a humanity like art, literature, and music.

The many hundreds of former and present members and visitors of our institute as well as the members of the International Board of scientific advisors and the Swiss board of consultants of our institute will always remember him with great respect.

Biozentrum Basel'

(Quoted in the original German version and discussed in [35], see also [36], translated here).

I would like to somewhat provocatively expand upon this statement: *Science is not only also a part of the humanities, it includes the humanities and social science of the future.*

Let us consider an ancient and central question of human intellectual history: *How does a human decision come about, and how can the decision be justified?* Is the decision free and unpredictable, or predictable and automatic? There is a neurobiological school of thought of *Gerhard Roth* and others[37,38] which holds the view that *free will is an illusion* because the predictability of human action is supposedly proven by neurobiological experiments. A more detailed analysis[28,39–41] indicates that to reach a definitive conclusion on this matter, one must follow the processes in the brain all the way down to the molecular level. In the process of seeing, as is well known, a simple molecular rearrangement between the *cis*-isomer and the *trans*-isomer of an organic molecule is at the beginning of perception.

cis→*trans*

Figure 4 shows this process in somewhat more detail.

It is conceivable, albeit so far pure hypothesis, that the thought processes are similarly triggered at the molecular level as well. I shall call this *the first hypothesis of a future molecular psychology*. It has been shown in our research on molecular dynamics that there are two types, as shown schematically in *Figures 5* and *6*.

One is quantum statistically indeterminate, which could provide a justification of an objective free will through non-predictability: the other is *quasi*-classically determinate, which could support the *Roth* claim of predictability of acts of will. We are still far removed from being able to provide an answer to these questions about thought processes at the molecular level. A more extensive analysis[28] shows, however, that the common concept of subjective free will, that is, the influence of a higher-level 'self' on the decision processes, is incompatible with the principles of

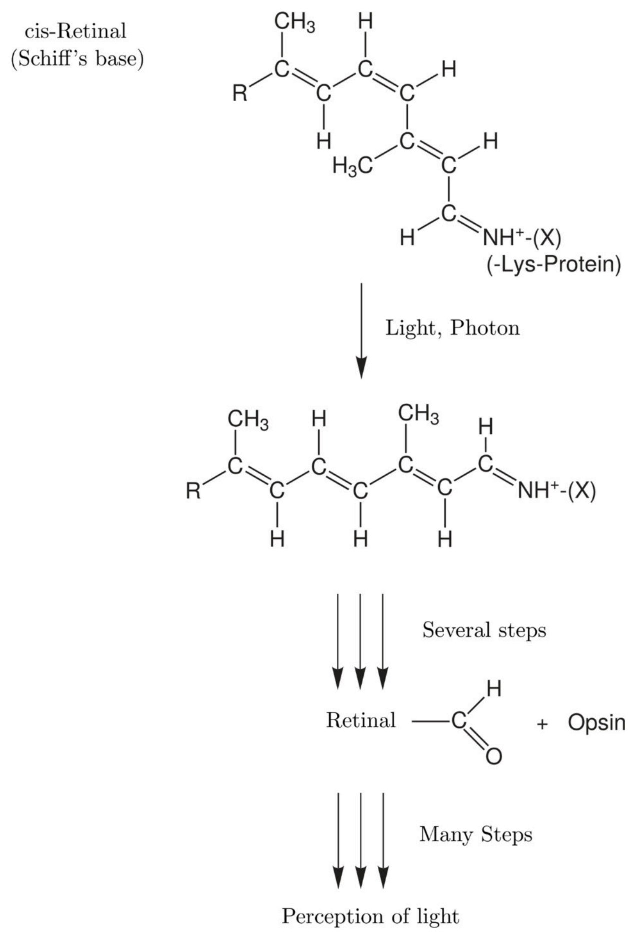

Figure 4. The primary step of the process of vision consists of a molecular *cis*–*trans* isomerization from *cis*-retinal to *trans*-retinal in the form of the *Schiff* base as discussed in [28,35].

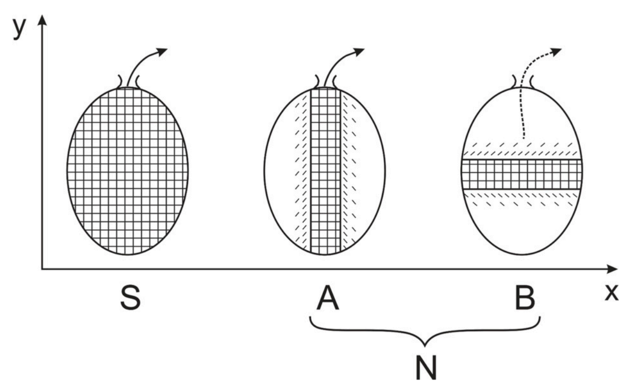

Figure 5. 'Bathtub' diagram explaining molecular deterministic and molecular quantum statistically indeterminate behavior of the kinetics of chemical processes. Diagram of equipotential lines and probability density distributions in a model of two coupled vibrations of a molecule as discussed in [35]. With statistical dynamics, the motion in the plane fills the whole energetically available space equally, like water in a bathtub. In this case the outflow of water from the bathtub (representing the chemical reaction) occurs continuously, statistically at quasi-equilibrium. With deterministic dynamics, the probability of the motion in the plane remains localized in a limited space as if there were 'hidden walls' in a bathtub localizing the water in a reduced space (schematic). In this case the outflow ('the reaction') occurs in a non-statistical way depending deterministically on conditions. In case A the outflow from the hole occurs quickly, whereas in case B it occurs slowly or not at all.

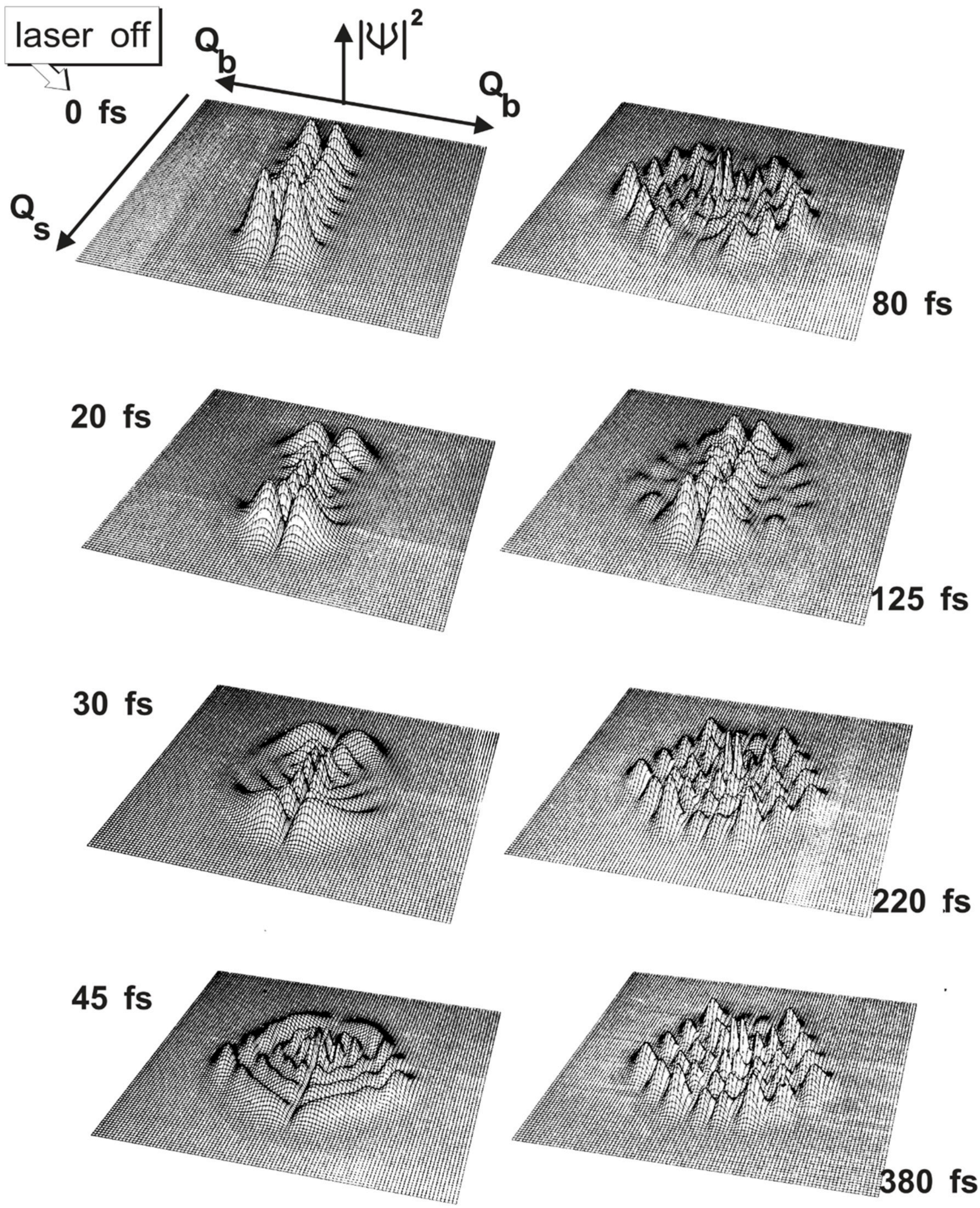

Figure 6. Wave packet motion of the probability density for the molecular structure in CHF_3 after vibrational excitation with six quanta of the CH stretching vibration coupled to a bending vibration. One can map the 'waves' of this probability distribution onto the diagram shown in *Figure 5* to recognize the transition from an initially non-statistically localized probability density in the direction of the CH stretching vibration to a delocalized, quantum statistically indeterminate distribution over the CH stretching vibration and CH bending vibration (see [35] and [42] for a detailed discussion). Further literature on the fundamentals of the spectroscopic methods used to obtain such results can be found in ([4,35,43], see also the very recent review in [8]).

molecular quantum physics.[4,28,42,43] If we would like to retain *subjective free will* as a hypothesis, we must postulate a new physics for the processes in the brain. At present we know so little about this that we can use freedom of decision and action as a *working hypothesis for our lives*, in accordance with the beautiful poem by *Robert Lee Frost*, from which I cite here only the last verse[44]

I shall be telling this with a sigh
Somewhere ages and ages hence:
Two roads diverged in a wood, and I –
I took the one less travelled by,
And that has made all the difference.

It does make a difference how we decide to act. We are not robots and do have a choice. Merit and guilt have meaning; this at least is one valid hypothesis,[28] but other possibilities cannot be excluded at present. Your lifetime could perhaps be the one during which the natural sciences provide an answer to these basic questions of human existence. I hope that you will always make the right decisions along your way.

According to a tradition in my family, you're going to need to make the two most important decisions in your life in the near future, if you have not made them already:

1) The choice of your future profession.
2) The choice of your spouse,

although today this might be expressed as choosing a life partner or even a life stage partner. There is a small parlor game about the second choice which consists of counting out the cherry pits after eating a fruit dessert and summarizes ten possible motives behind this choice. This can be formulated similarly for each gender. The counting rhymes are proper rhymes in the German original,[14,15] translated freely here:

The first one does it for the money,
The second sees a pretty face,
The third because of 'good advice',
The fourth because of Mama's saying,
The fifth feels that it is high time,
The sixth feels rather too alone,
The seventh shows true love,
The eighth shows goodness of heart,
The ninth and the tenth they are so dumb that they themselves just don't know why.

If you ask me in conclusion, *'Why science?' then my answer is: Because the sciences promise us an understanding of the foundation of our world and our place in it. When you ask why we need this, then I answer, 'Why not?'* I sum up the 'Why?' and 'Why not?' for you as follows (*Figure 7*), partly by way of example and partly in a joking manner, in the hope that you will take it to heart.

7. Concluding Remarks on a Scientific Imperative

In discussing the role of science for human life and in society we are often confronted with the statement: Science has the role of telling us objective facts and the laws how nature functions, but it does not tell us how to act and decide in a given situation. For answers to such questions and in particular ethical questions we need the humanities or religion. Of course, the answer from the monotheistic religions is simple: Just follow the instructions as they are given by God in the 'holy books'. The philosopher *Kant*, who was a philosopher of the 'old style' including also studies in astronomy and natural science, tried to give a rational answer to the question of ethical human behavior with his 'categorical imperative' giving a general law for proper ethical human behavior.[45] And others have given similar or different answers to the questions on ethical human behavior. Without discussing the question, which of the rules given by *Kant* or others is best, we note that none of the rational philosophical answers contains adequate motivation

Why the natural sciences?
To experience the joys of discovery and understanding
To contribute to mankind's knowledge
To understand the world and mankind directly and indirectly as a contribution to the improvement of the living conditions of humanity
To survive

Why not?
Not to hurt other people
Not to best someone else in a competition
Not to exercise power
Not to become wealthy

It's better to solve a single research problem and communicate one's results
…than to become President of the US
…than to possess the riches and power of Bill Gates
…than to build one big bomb
…than to have 10 publications in *Science*
…than to be at the top of the list of world's most-cited papers
…than to appear on television 100 times
…than to receive a doctorate
…than to hold a commencement speech for new Ph.D.s

Figure 7. Why the natural sciences? Why not?

why one should follow them. Again, the monotheistic (and similarly other) religions provide that motivation: If you do not follow the commandments, you will not please God and will eventually be punished.

When scientists address the question of rules for decisions and action, they are often told that they should be silent about it. They rather should provide a 'value-free' assessment of facts, causes and predictable consequences and leave the advice for decision on action to others.

However, this is like telling medical doctors that they should restrict their attention to finding a proper diagnosis and leave decisions and actions on therapy to others. This does not seem to make good sense. We have in the past identified three major 'mental diseases of mankind', which constitute major global risks.[34,46,47]

1) Addiction to MAD = Mutually Assured Destruction by nuclear weapons, with this very telling acronym as abbreviation.

2) Addiction to atmospheric pollution with carbon dioxide and other greenhouse gases causing enormous and uncontrolled climate risks.

3) Addiction to ever increasing bureaucracy including today artificial intelligence (or artificial madness) in modern times leading to risks of present and future robotocracy.

In contrast to global risks arising from cosmic catastrophes, which we cannot control, these three major global risks are man-made and thus can, in principle, be avoided. Science and humanities can in a combined effort provide the necessary diagnosis and therapy if the diagnosis is understood and accepted and therapy is allowed for. Indeed, there is a scientific imperative for action, necessary for the survival of civilization, mankind and perhaps even life on this planet. We do not know whether life in the universe is frequent and abundant, or whether it is rare,[48,49] perhaps even unique in its 'intelligent' (or perhaps not quite so intelligent) variant on Earth,[48,50] but we do know about its fragility. Proper action is needed for survival, lack of proper action will be punished by death of civilization, death of intelligent life and perhaps life on this planet. The risk of destruction arising under point *1*) above is immediate and requires immediate action by destruction of nuclear arsenals. The risks under point *2*) above lead to destruction on time scales of decades and centuries, but clearly must be addressed today. The risk under point *3*) might not be taken seriously by many, but it is real[18,51] and leads to a slow decay and death of civilization and mankind by the slow processes of 'mental asphyxiation'. It is human and scientific responsibility to avoid these three major global risks. And if some sceptic asks 'Why?', the answer again is: Why not?

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Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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