Hans R. Kricheldorf

Getting It Right in Science and Medicine

Can Science Progress through Errors?

Fallacies and Facts

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For my mother Orlaug Christie v. Aadna

Preface

This book may be understood as a second revised and augmented edition of the German version *Erkenntnisse und Irrtümer in Medizin und Naturwissenschaft* published by Springer Spektrum in 2014.

Hamburg, Germany Hans R. Kricheldorf

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Contents

Part I
Insights and Definitions

Chapter 1
Introduction

> The Ten Commandments of God are so clear because their formulation was not influenced by a commission of experts.
> (Charles de Gaulle)

Comments on and critiques of science have come and continue to come from various groups of authors. For example, journalists and philosophers have developed an increasing tendency during the past 30 years to complain about scientific progress and its technical utilization, mainly considering negative consequences such as the rapid increase in allergies, environmental pollution, climate change, and consumption of landscape. These critics ignore the enormous benefits resulting from scientific discoveries and inventions, for example, with regard to food production and progress in medicine (see Sects. 3.2 and 5.3, and Chap. 6). Their attitude is also hypocritical, because their professional activities rely on scientific and technical innovations. For example, none of the vehicles used for transportation, such as bicycles, cars, trains, buses, steamships, and airplanes, grow in nature, and paper, ballpoints, computers, and printing machines are also the result of scientific discoveries and technical inventions.

Another group of critics, with a tradition of almost 500 years, are theologians, regardless of whether the Bible or the Koran forms their theoretical background. A detailed discussion of the numerous critical comments and arguments written by theologians over a period of 500 years is, of course, beyond the scope of this book. However, one important but rarely discussed point should be mentioned. All monotheistic religions have in common that God/Allah is considered to be the only creator of the universe and of all living organisms, including humankind. If so, scientists studying the properties of nature directly deal with God's/Allah's own work. In contrast, theologians exclusively study manuscripts and printed texts written by men or women, because not a single sentence exists that was written by God/Allah. Most frequently, theologians extract and interpret secondary and tertiary literature. Therefore, carefully interpreted scientific findings offer a closer and more trustworthy look at God's/Allah's work and intention. Certainly,

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individual scientists may lack self-criticism and, thus, may be responsible for overinterpretations of scientific results, but such misbehavior occurs in all areas of human activity, including theology.

This book mainly focuses on discussing the skeptical comments and critiques of science contributed by two other groups of authors, namely historians or philosophers of science and theoretical scientists or experimental scientists. Historians, philosophers, and theoretical scientists like to discuss fundamental structures, limits of cognition, reliability, sense, and justification of scientific research. In numerous contributions to this field, the philosophy and theory of science are discussed without clear definition or description of what the term "science" really means. Does science, for instance, include sociology and anthropology, or even the humanities? Therefore, to avoid misunderstandings the meaning of science, as it is understood in this book, is defined in the first section of Chap. 2.

Typical consequences of insufficient differentiation or lack of definition are comments and conclusions that sound strange when applied to the natural sciences. For example, the British philosopher Stephen Toulmin (1922–2009) wrote in his book *Foresight and Understanding – an Inquiry into the Aim of Science* (p. 62): "Just as the question 'Is this music good of its kind?' is distinct from the question 'Is this good music?' so we find scientists asking both 'Is this event a natural and self-explanatory one of its kind?' and also 'Is this an example of the most natural and self-explanatory sort?'" On pp. 15 and 16, he wrote: "It is, in fact, doubtful whether a final account could ever be given of the aims of science: especially one which was both exhaustive and brief. . . . Science has not one aim but many, and its development has passed through many contrasted stages. . . . There is no universal recipe for all science and all scientists any more than there is for all cakes and all cooks. There is much in science which cannot be created according to set rules and methods at all. . . . Science as a whole – the activity, the aims, its methods and ideas – evolve by variation and selection." The response of the author of this book is given in Sects. 2.1–2.5.

Another example of a funny description of science can be found in the work of the French historian Jacques Barzun (1907–2012). One of his books is entitled *Science: The Glorious Entertainment* and on p. 77 he says about scientists: "What science is in their view amounts to an earthly translation of the kingdom of heaven where fitness and perfection rule and nothing is other than it seems." This and other statements by Barzun are discussed in Sect. 4.1.

One more example of a work that suffers from a lack of definitions and differentiation is the famous book *Against Method* by the Austrian philosopher Paul Feyerabend (1924–1992). Going through the text, the reader must learn step by step that arguments and conclusions have various roots, ranging from astronomy and physics to sociology and historical research. His stance is discussed in Sect. 4.1. Examples extracted from the fourth edition (pp. ixxx) are given below:

> Science is an essentially anarchic enterprise: theoretical anarchism is more humanitarian and more likely to encourage progress than its law-and-order alternative.

> There is no idea, however ancient and absurd, that is not capable of improving our knowledge. The whole history of thought is absorbed into science and is used for improving every single theory. Nor is political interference rejected. It may be needed to overcome the chauvinism of science that resists alternatives to the status quo.
>
> This is shown both by examination of historical episodes and by an abstract analysis of the relationship between idea and reaction. The only principle which does not inhibit progress is: Anything Goes!.

Over the past 200 years, numerous sociologists, but also biologists and philosophers, have attacked reductionist tendencies in science without condemning science as a whole. Depending on the working field, reductionism is a philosophical or scientific position that claims that a complex system is nothing but the sum of its components and that an account of it can be reduced to accounts of its individual constituents. A fundamental criticism of science relies on the assumption that science is per se and automatically reductionist, which is certainly an exaggeration. In Sect. 4.2, the advantages and disadvantages of reductionist concepts in science are commented on in more detail.

Fundamental criticism of the trustworthiness of empirical research was presented by the philosophers Ludwig Wittgenstein (1889–1951) and, above all, Karl Popper (1902–1994). Those theorists, their coworkers, and followers believed that inductive conclusions are not reliable and that any hypothesis or theory may be falsified . Hence, the philosophical approach of this group of skeptic theorists was called falsificationism. Popper also described science as a theory of theories. Sections 2.4 and 3.3 are devoted to the falsification of their critique.

Yet, fundamental criticism concerning the reliability of empirical research and scientific knowledge also comes from experimental scientists, mainly from physicists. The following statement by Max Born (1882–1970), awarded the Nobel Prize for Physics in 1954, is characteristic: “Ideas such as absolute certainty, absolute accuracy, final truth, and so forth are inventions of the human imagination and should be avoided in science.”

However, strange comments on and fundamental criticisms of science were not only uttered by physicists and theorists infected by physics, but also by biologists. For example, the American professor of biology Robert Shapiro says in his book *Origins* (dealing with the origin of life on earth) in a chapter entitled “Science, Realm of Doubt” (p. 33):

> I have chosen this title to make the strongest possible contrast between the common view of science described above and its essence. Science is not a given set of answers, but a system for obtaining answers. The method by which the search is conducted is more important than the nature of solution. Questions need not be answered at all, or answers may be provided and then changed. It does not matter how often or profoundly our view of the universe alters, as long as these changes take place in a way appropriate to science. For the practice of science, like the game of baseball, is covered by definite rules.

This characterization of science needs opposition for two reasons. First, if asking and answering, including repetitive modification of answers (insights), does not have any final target, then science is nothing more than a scholarly but pseudoscientific social game and a gigantic waste of tax revenues. The primary aim is certainly a reliable and as precise as possible description and analysis of natural phenomena. The second aim is the utilization of discoveries and inventions to improve the welfare and prosperity of humankind. Furthermore, Shapiro ignores the roots of science. Since emancipation from apes, humankind has striven to learn more and more about regular processes in nature and to extrapolate experience into the future (see Chap. 3). This capability of the human brain, existing at a lower level in the brains of other mammals, was not designed by evolution to play games, but as a strategy to enable survival for at least a few million years in a world dominated by microbes, arthropods (insects), and natural catastrophes.

Finally, the latest book by the biologist Rupert Sheldrake should be mentioned, which appeared in 2013 under the title *The Science Delusion*. This book contains numerous critical questions, but almost no suggestions of better alternatives. It contains the following statement (p. 6): "In this book I argue that science is being held back by centuries-old assumptions that have hardened into dogmas. The sciences would be better off without them: freer, more interesting, and more fun. The biggest scientific delusion of all is that science already knows the answers. The details still need working out, but, in principle, the fundamental questions are settled."

A similar statement was presented decades ago by the philosopher Ludwig Wittgenstein (1889–1951) in his *Tractatus* (6, 371–372):

> The whole modern conception of the world is founded on the illusion that the so-called laws of nature are the explanations of natural phenomena. Thus, people today stop at the laws of nature, treating them as something inviolable just as God and Fate were treated in past ages.
>
> In fact, both are right and both wrong: though the view of the ancients is clearer insofar as they have a clear and acknowledged terminus, while the modern system tries to make it look as if everything were explained.

These statements have to be qualified as untruth. Wittgenstein's comment is perhaps a reflex on the scientific worldview of the physicists at the end of the nineteenth century (see below and Sect. 2.2). However, every modern scientist endowed with at least a minimum of self-critique knows that the sea of unknown and unexplored facts and theories is many orders of magnitude larger than the nutshell of knowledge in which he moves forward. Complementary to this, the Austrian scientist Adolf Pichler (1817–1900) merits the citation: "Scientific research is always on the move and will never come to an end."

On page 8 of his book *The Science Delusion* Sheldrake also states that medicine and science support the following dogma: "Mechanistic medicine is the only kind that really works." The author of the present book has never met any physician or surgeon who adhered to this dogma. Furthermore, Sheldrake ignores and defames self-understanding and the intentions of psychoanalysis, psychotherapy, and psychosomatic medicine (see Chap. 6).

The numerous partially strange, partially misleading, partially defaming, and partially incorrect comments on science delivered by various groups of authors have stimulated this author to revise and reshape the picture of science from the viewpoint of an experimental chemist. The author's view is based on 50 years of experience in experimental research and it is the view of a non-physicist. This second point deserves explanation.

In 1873 James C. Maxwell published in his textbook *A Treatise on Electricity and Magnetism* mathematical equations explaining the phenomena of electricity and magnetism, including a better understanding of the nature of light. Together with previously achieved results in the areas of mechanics, optics, and the nature of elements the physicists believed at the end of the nineteenth century that they could explain almost all the fundamental principles and properties of the world. They believed that physics is the leading branch of the natural sciences, and they felt called upon to explain to all other scientists and interested laics what the world looks like. The discoveries and calculations of Max Planck and Albert Einstein after the turn of the century required considerable revision of the existing picture of the world, but this revision also stimulated new important discoveries and insights in the fields of astronomy, cosmology, and physics. Hence, physicists kept the tendency to consider physics as the leading science.

Yet, as exemplarily demonstrated in Chaps. 2, 3, 4, and 5 and in Sect. 4.1, conclusions and interpretations based on physics and its history are not necessarily representative for all natural sciences and may even be misleading. Furthermore, the numerous revisions of seemingly established theories, which were necessary in the history of astronomy, cosmology, and physics, made a significant contribution to the fact that philosophers, theoreticians, and physicists themselves became skeptical about the reliability of insights and knowledge elaborated in all scientific disciplines.

From the viewpoint of the author, modern science provides worldwide a steady flow of data every day, which is accompanied on a numerically much, much lower level by a flow of minor and major errors, mistakes, and fallacies. Errors and mistakes are unavoidable, because scientists are not perfect robots. However, it is also characteristic of modern science that it involves a self-healing process. This means that the permanent flow of results and mistakes is accompanied by a flow of revisions of previous errors and mistakes. This automatism arises from the fact that any step into a new field is based on knowledge, methods, and materials acquired by previous research activities. In this way, all previous results are sooner or later reexamined, and errors and mistakes are revised. In other words, ongoing research has a “Janus character” looking into the future and checking the results of the past. As demonstrated in Part II, any revision of a big mistake automatically entails a big step forward.

In summary, this book serves two purposes:

First, it deals with the questions of what is meant by science and whether science can provide trustworthy information and knowledge despite numerous mistakes, errors, and fallacies (Part I).

Second, it illustrates with important examples selected from medicine and various natural sciences, how mistakes and errors were made and revised, thereby also shedding light on the history of science (Part II).

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Chapter 2
What Is the Meaning of Science?

2.1 How Can We Define Science?

> The strongest arguments prove nothing so long as the conclusions are not verified by experience. Experimental science is the queen of sciences and the goal of speculation.
> (Roger Bacon)

In his book *Asimov's New Guide to Science* the Russian author and science fiction expert Isaac Asimov (1920–1992) offered a plausible explanation for the origin of science, a shortened version of which is cited here (1987 edition, pp. 3–5):

> Almost in the beginning was curiosity: Early in the scheme of life, however, independent motion was developed by some organism. It meant a tremendous advance in the control of the environment. A moving organism no longer had to wait in stolid rigidity for food to come its way, but went out after it. Thus adventure entered the world—and curiosity. The individual that hesitated in the competitive hunt for food, that was overly conservative in its investigation, starved. Early on, curiosity concerning the environment was enforced as the price of survival. As organisms grew more intricate, their sense organs multiplied and became both more complex and more delicate. More messages of greater variety were received from and about the external environment. At the same time, there developed (whether as cause or effect we cannot tell) an increasing complexity of the nervous system, the living instrument that interprets and stores the data collected by the sense organs. ... There comes a point, where the capacity to receive, store, and interpret messages from the outside world may outrun sheer necessity. An organism may be sated with food, and there may, at the moment, be no danger in sight. What does it do then? ... If curiosity can, like any other human drive, be put to ignoble use—the prying invasion of privacy that has given the word its cheap and unpleasant connotation—it nevertheless remains one of the noblest properties of the human mind. For its simplest definition is 'the desire to know.' ... Thus, the desire to know leads in successive realms of greater etherealization and more efficient occupation of the mind—from knowledge of accomplishing the useful, to knowledge of accomplishing the esthetic, to 'pure' knowledge.

Unfortunately, Asimov did not provide a compact definition of science. From this point of view, his book shares the character of many other books, essays, and articles dealing with science, as already mentioned above. The reluctance of many

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authors to define science may have three reasons. First, several authors apparently do not understand the purpose, usefulness, and character of definitions correctly. A typical example is the following comment by Toulmin (on p. 18 of *Foresight and Understanding*): “Definitions are like belts. The shorter they are, the more elastic they have to be. A short belt reveals nothing about its wearer: by stretching, it can be made fit almost anybody. A short definition applied to a heterogeneous set of examples has to be expanded and contacted, qualified and reinterpreted, before it will fit every case.” These words may be enjoyed by philosophers, but from the viewpoint of scientists a definition has neither to fit anybody, nor to accommodate anybody, nor to fit a heterogeneous set of examples. A definition has to provide a description that is as precise as possible of a term or phenomenon, avoiding misunderstandings and avoiding overlapping with terms that may look similar at first glance.

The second reason that certain authors might avoid a definition of science is because they believe that the meaning of science is clear and all readers have the same meaning and definition in mind. However, such a conviction stands in sharp contrast to the numerous different comments published about the nature and aims of science, as exemplarily demonstrated in the introduction to this book (Chap.1). Third, other authors perhaps do not dare to provide a definition because they are afraid of attracting criticism. Yet, if an author is a scientist and not willing to make clear statements, he should perhaps change his profession and turn to politics. The author of this book presents his understanding and definition of science here at the beginning of the text, not because of the assumption that he has found the optimum definition for all time, but to provide a precise basis for consistent discussions.

The term “science” as it is used throughout this book means the sum of all natural sciences, such as astronomy, biology, chemistry, geology, pharmacy, and physics. Because of characteristic differences in their methods of inquiry relative to those of the natural sciences, psychology, sociology, anthropology, and the humanities are not included in the term science as it is used in this book. After this primary definition, a secondary definition may follow:

Science means observation and description of all natural phenomena (including experiments in laboratories) and explanation of these phenomena on the basis of the laws of nature and their interactions.

Fundamental research is, in turn, defined as the search for laws of nature and for a better understanding of their consequences and interactions.

Other descriptions or definitions of science are discussed in Sects. 2.3, 2.4, 4.1, 5.1, and 5.2. To avoid misunderstandings, it should be emphasized at this point that the above definitions are not meant as justification for reductionalism as the sole intellectual strategy in scientific research. Aristotle’s antireductionist conclusion “The whole is more than the sum of its parts” may be a law of nature limited to living organisms (see Sect. 4.2). Furthermore, the human consciousness may formulate questions concerning the entire universe or individual humans (e.g., what is the purpose of life?) that cannot be answered by scientific methods.

Because the above definition of science emphasizes the interaction of laws of nature or, in other words, the simultaneous influence of several laws on one phenomenon, this definition also includes a new branch of science, systems science. Systems science may be understood as a kind of “metascience” of all traditional natural sciences. The American theoretician George J. Klir wrote in the first chapter of his textbook *Facets of Systems Science*: “Systems science is that field of inquiry whose object of study are systems. … To be made operational this definition requires that some broad and generally accepted characterization of a concept of a system is established. … However, when separated from its specific connotations and uses the term system is almost never explicitly defined. … To begin our search for a meaningful definition of the term system from a broad perspective let us consult a standard dictionary. We are likely to find that a system is a set or arrangement of things so related or connected as to form a unity or organic whole (*Webster’s The New World Dictionary*), although different dictionaries may contain stylistic variations of this particular formulation. It follows from this commonsense definition that the term system stands in general for a set of some things and a relation among the things. Formally, we have:

$$\mathrm{S} = (\mathrm{T}, \mathrm{R})$$

whereas S, T, and R denote, respectively, a system of things distinguished within S and a relation (or possibly a set of relations) defined on T. Clearly the thinghood and systemhood properties of S reside in T and R respectively. … For example, a collection of books is not a system, only a set. However, when we organize the books in some way, the collection becomes a system. … From the standpoint of classical science, systems science is clearly cross-disciplinary. … Classical science and systems science may be viewed as complementary dimensions of modern science.”

Characteristic of the basic methodology of scientific research is the search for observations, measurements, and experiments that are reproducible regardless of their location, regardless of time, and regardless of the properties of the researcher (a restriction of this statement is discussed in Sect. 2.2). In this regard, natural sciences differ from all other sciences and research activities.

Although the individual branches of traditional science, such as biology and physics, apply the same fundamental methodology (as defined above) they differ in certain formal aspects, and for a proper understanding of Part I of this work it is useful to keep these differences in mind.

Importance for the Scientific View of Life and the Universe

As a result of their different working fields, the various branches of science made and continue to make considerably different contributions to the scientific world-view and to the self-understanding of humankind. Nowadays and in the near future, the most important contributions come from theoretical physics in combination with nuclear physics, from astronomy, from the theory of evolution in combination with genetics, and from cerebral research. Since the redefinition of the elements and the elimination of vitalism in the middle of the nineteenth century, chemistry has not made an important contribution (if molecular genetics is attributed to biology). However, in the future chemistry has a chance to deliver an extraordinarily important contribution, namely if it can prove or disprove that life on earth can spontaneously emerge from dead matter.

Importance for Everyday Life
Concerning the level of modern civilization and any progress made in medicine, chemistry has provided more important contributions than any other branch of science. For instance, with the exception of raw wood and stone, virtually all other materials are produced by chemical processes. More than 90 % of the food supply of the western civilization depends on the availability of fertilizers, antibiotics, and agrochemicals such as insecticides and fungicides. Furthermore, more than 90 % of all remedies and medicaments are produced by pharmaceutical companies. Moreover, the availability of electricity and all vehicles, from bicycles to airplanes, is based on the production of metals and polymers (e.g., plastics and elastomers; see Sects. 9.4 and 9.5) by chemical companies (see also Sect. 3.2 and Chap. 6).

Degree of Abstraction
The degree of abstraction is highest for physics, in general, and for theoretical physics, in particular. Working fields that are concerned with the description of natural phenomena, such as landscapes, sediments, habitats, and herds of animals, represent the lowest level of abstraction. This differentiation does not involve any value judgment. All branches of science began with observations and descriptions of natural phenomena, and astronomy demonstrates that observation and description are still an important kind of research activity in modern science.

Extent of Experimental Research in Laboratories Chemistry and physics form together one pole, because more than 95 %, perhaps even more than 99 %, of all empirical data result from experimental work in laboratories. Those working fields of biology, geology, and meteorology concerned with description of natural phenomena represent the opposite pole.

Frequency of Experiments
In this dimension, certain working fields of physics represent one pole and chemistry the opposite pole. This classification deserves an explanation. Physicists working with particle accelerators can typically perform 10–50 new experiments per year. A small group of physicists working on fundamental research with laser light can often only perform between two and ten new experiments per year, when a new apparatus or method is developed. As an example of a medium-sized working group of chemists at a university, the author presents his own group. This group usually comprises between 12 and 17 coworkers consisting of master students, Ph. D. students, postdocs, one or two technicians, and one assistant professor. Almost all experiments are conducted in standard glassware or simple reactors and most chemicals are available from chemical companies. On this basis, 500–800 experiments are performed every year, and each experiment entails at least two

measurements with the purpose of elucidating whether the experiment is successful or not.

These numbers are by no means extreme; this means that a research group of chemists can usually conduct 20–100 times more experiments per year than physicists working with particle accelerators or developing new, complex instruments and methods. These numbers do not imply any judgment about the value and importance of the working groups or experiments. However, a scientist who can perform or supervise several hundreds of experiments per year has two advantages. First, it is easier and usually much cheaper to check the reproducibility of important experiments. Second, the scientist is in a better position to observe routine aspects of scientific research. This means that it is easier to observe how and why errors and mistakes arise again and again, and it is easier to observe the self-healing mechanism as a consequence of ongoing research.

Finally, a much shorter differentiation between biology, chemistry, and physics, as found in the "Handy Guide to Modern Science" (see Internet), should be mentioned:

1. If it's green or wiggles, it's biology.
2. If it stinks, it's chemistry.
3. If it doesn't work, it's physics.

2.2 What Is a Law of Nature?

Laws have two sources, humans themselves and nature. Leaders of clans, kings and emperors, or democratic institutions such as parliaments enact laws to regulate the social life of people living together in small or large societies. Nature (in this book meaning the universe or the entire creation) presents all its structures and activities in the form of laws to those willing to find correlations between, and explanations for, natural phenomena and experiments in laboratories. Definitions of the term "law of nature" are usually absent from textbooks of biology, chemistry, and physics. *Encyclopedia Americana* offers the following definition:

> A scientific law is a general statement that purports to describe some general fact or regularity of the universe. For example, Newton's law of gravitation asserts that every pair of bodies exerts a mutual attraction directly proportional to the product of their masses and inversely proportional to the square of the distance between them. Any such regularity may be termed law of nature.

Although this definition is in principle correct and useful, it has two weak points. First, it suggests a confusion of regularity or rule, on the one hand, and law, on the other hand, a point discussed in more detail in Sect. 3.4. Second, it is focused on the universe and gives an example concerning a physical property of the universe. Yet, it is not clear to what extent the properties of living organisms are included. In this book, a law of nature is understood as a property of nature, including any kind of living or non-living object. Laws of nature are responsible for the reproducibility of phenomena, which within a certain frame of validity (see Sect. 2.3) are independent of time, location, and the properties of the researcher.

However, the German philosopher Emanuel Kant (1724–1994) and later other philosophers held that laws of nature are a property of the human brain and not of nature itself. Yet, this view is neither progressive nor helpful, because it ignores the fact that the human brain is itself part of nature. Philosophers have the tendency to believe that their brain came from somewhere outside the universe. However, the human brain is the result of a long evolution of the central nervous system, which exists in all higher animals. There are no facts indicating that evolution had the goal of producing philosophers. Evolution of the central nervous system had the purpose of supporting the survival of new species in their struggle for life and broadening the diversification of species. With the modern human brain, evolution has surprisingly developed an organ which allows nature to reflect itself. Therefore, the author prefers to say that laws are the language that nature uses for rational communication with the human brain. A quite similar view has already been formulated by the physicist and Nobel Prize laureate Werner Heisenberg (1901–1976): "Natural science does not simply describe and explain nature, it is part of the interplay between nature and ourselves."

Problems with the proper understanding of the term "law of nature" arose and still arise from the fact that the physicists of the nineteenth century overloaded this term with attributes that in the aftermath were all found to be incorrect or misleading. The physicist Erwin Schrödinger (1887–1967, Nobel Prize 1933) began his frequently cited and published inaugural speech at the Technical University of Zürich in 1922 with the following statement (p. 10 of the German edition translared by the author): "Laws of nature are obviously nothing more than a sufficiently confirmed regularity of phenomena. ... Physical research has unambiguously demonstrated over the past four or five decades that, at least in an overwhelming number of phenomena, the regularity and constancy of which have founded the postulate of causality, the common roots of their strict regularity are accidental events. ... Each physical phenomenon, for which strict regularity is observed, is based on the actions and motions of many thousands, mostly billions, of atoms and molecules. ... The simplest and most transparent example for a statistical understanding of laws of nature is the properties of gases, the discovery of which also marks the historic origin of statistical laws in science." In the subsequent text (pp. 11 and 12) Schrödinger discusses the kinetic theory of gases in detail and continues on p. 13: "I would be able to contribute and explain still a much larger number of experimentally and theoretically exactly studied phenomena, for example, that the uniform blue color of the sky results from random variation of the air density. Another example is the strictly regular decay of radioactive substances, which results from irregular decay of radioactive atoms, whereby it seems a matter of chance, which atom will decay soon, or tomorrow, or within 1 year."

Schrödinger certainly delivered a correct description of most, if not of all physical laws However, a law of nature is not a property of physicists. Schrödinger, like other physicists (see below), did not take into account that conclusions and interpretations elaborated in physics are not automatically valid in all branches of science. For instance, the many thousands of biochemical and physiological reactions underlying the biological functions of all living organisms are not based on random motions or statistical reactions of molecules. The contrary is true. The generation of a biological function or signal (e.g., synthesis of an enzyme within seconds) requires trillions and quadrillions of almost parallel reactions, whereby molecules of identical structure perform exactly the same reaction. Furthermore, all the different molecules that contribute to a single process generating a biological function or physiological signal react in a cooperative mode and never at random. The transformation of photons into signals of the optical nerve, partially described in Sect. 10.5, is a typical example of such a chain of coordinated reactions. At this point, but also with respect to the following text, the professor of evolutionary biology, Ernst Mayr (1904–2005) needs to be quoted: “Biology is not a second physics.”

In the second half of the twentieth century and in the twenty-first century, the term “law of nature” has attracted much criticism, partially from philosophers (see Sects. 2.3 and 2.4), partially from theorists or historians (see Chap. 5), and partially from physicists. Most of this criticism is stimulated by the fact that the physicists of the nineteenth century overloaded this term with attributes typical for their physical world view. This historical scenario has two main roots. First, physics, above all astronomy, may be considered to be the oldest branch of modern science, and as a result of the influence of mathematics, it soon reached a high level of abstraction. Second, the physicists believed at the end of the nineteenth century that almost all fundamental and important laws of nature were known. This scientific world view is illustrated by the answer of Professor Jolly, physicist at the University of München, when the young Max Planck asked him in 1874 whether it makes sense to study physics (Max Planck was an excellent musician and considered studying classical music). Jolly answered no, “because in this branch of science almost all important aspects are explored and only a few minor problems are still open.” In other words, the physicists, but not only physicists, at that time considered physics to be the leading and representative branch of science (see Sect. 4.1). This mentality entailed at least three important fallacies, which are discussed next.

First, the physicists considered that only physical laws were fundamental laws of nature. The numerous laws found by biologist, chemists, geologists, and other scientists were called biological, chemical, or geological laws. They were at best third-rate laws of nature. From Hermann Helmholtz (1821–1894) the following statement is known: “The final aim of all kinds of science is to find mechanical explanations.” Even after 1900, Sir Ernest Rutherford (see Sect. 10.2) remarked that “All science is either physics or stamp collection.”

Presumably, not all physicists shared this short-sighted and arrogant view. Nonetheless, these comments are certainly representative of the mentality of physicists at the end of the nineteenth century. This narrow-minded view of science prevented physicists from becoming aware of the following issues.

Second, for physicists of the nineteenth century, correct understanding of the laws of nature included necessarily a mathematical formula. Forerunners of this mentality were Thales of Miletus (624–546 B.C.) and Galileo Galilei (1564–1642). Galilei published in 1623 in his book *Il Saggiatore* the following statement (equivalent translation): “Mathematics (he was focused on geometry) is the alphabet God used to write the book of the universe." In 1786, the philosopher Emanuel Kant (1724–1804) wrote in his work *Metaphysische Anfangsgründe der Naturwissenschaft* (Metaphysical Foundations of Natural Science) the following insight: "I declare any philosophy or theory of science contains only that much science as it contains mathematics."

In his latest book *Gottes Würfel* (The Dice of God) the German professor of physics Helmut Satz says on p. 205: "It is frequently said that mathematics is the language of physics when God wants to talk to man. This may be, although God is certainly polyglot and capable of sending a message via music or poetry. Nevertheless, it is hard to ignore that he finally returns to mathematics again and again. Otherwise it is hard to understand, why the arrangement of blossoms on all flowers follows a series of numbers, first elaborated by the mathematician Leonardo da Pisa, better known as Fibonacci, to describe the growing of a colony of rabbits."

This statement, although not quite correct (what is true for sunflowers is not true for all flowers) is certainly much more pleasing and flexible than Kant's view of science.

Nonetheless, even Satz's comment is too one-sided. The physicists ignore for instance, that chemistry has developed its own formula language, and in this language both sides of an equation are connected by two reaction arrows and not by a sign of equality. The chemical formula language was developed in the nineteenth century and completed by a publication of the Dutch chemist Hendrik van t'Hoff (1852–1908) in 1874. For this achievement and other discoveries he was awarded the first Nobel Prize in Chemistry in 1901. It is also worth noting here that the formula language of chemistry was not only decisive for progress in modern chemistry and pharmacy, it also supported and supports progress in all other natural sciences and in medicine, because disciplines exist in all branches of science where the structure and reactivity of molecules play a significant role.

Furthermore, physicists and other scientists tend to ignore the fact that fundamental laws of nature can be formulated using words or tables without any need for mathematical or chemical equations. Examples from chemistry are Mendeleev's Periodic Table (see Sect. 9.1) and the law of neutralization. This law says that mixing of equivalent amounts of acid and base (more precisely, equal numbers of acidic protons and hydroxide ions) yields water and salts. A fundamental insight of biology says that the individuals of all vertebrate species must die. A fundamental principle geologists have to learn is the finding that the spatial arrangement of sediments or layers of rocks is directly correlated with the timely sequence of the events that produced those layers (see Sect. 10.6).

It is of course indisputable that mathematics has provided and continues to provide the most efficient mental tools for the progress of modern science and the mental basis for all technical applications of scientific discoveries. However, Kant's extreme stance considering mathematics as an indispensable and decisive constituent of the definition of science is inacceptable and must be rejected. If Kant was right, the immensely important discoveries and insights of Louis Pasteur, Eduard Buchner, Charles Darwin, Alfred R. Wallace, and Barbara McClintock (see Chap. 8) were all outside science—an absurd vision. Finally, a prominent critique of too much mathematics in science should be cited. Albert Einstein (1879–1955) confessed: “Since the mathematicians have invaded my theory of relativity, I don’t understand it myself anymore.”

Third, the physicists of the nineteenth century assumed that their laws of nature were effective and valid at any time and everywhere in the universe. This characterization has rightly been attacked by physicists of the twentieth and twenty-first century, but without considering that the target of their critique is the mental heritage of their scientific ancestors and was not held by all scientists. Biologists, chemists, and geologists were already conscious in the nineteenth century that the validity of their laws was confined by a narrow frame of temperatures. In the second half of the nineteenth century, chemists had begun to explore the thermal stability of organic chemicals and to study the chemical structures of degradation products. They found that all the organic molecules under investigation decomposed at temperatures in the range of 250–350 °C. Nowadays, it is known that the upper limit for the survival of complex organic compounds is around 500 °C. Inorganic materials such as salts and minerals may show, in rare cases, a short-term stability up to 3500 °C. At higher temperatures chemical bonds cannot exist anymore. In contrast, almost all biologically active molecules decompose in the temperature range of 150–250 °C. Furthermore, all chemical reactions have a low temperature limit. When all translational and vibrational motions are frozen, chemical reactions can no longer take place.

The recent critique of physicists concerning the term law of nature, as defined by the physicists of the nineteenth century, only repeats what other scientists had learned from the laws of other natural sciences more than a century before.

The validity of all laws of nature has limits. Any law of nature is only effective and detectable within a certain frame of validity. For instance, most laws of nature that are effective in the biosphere of earth are not effective in the center of a black hole. Whether, and to what extent, the frame of validity of a certain law of nature is explored depends on the interest, money, time, and human resources available for this purpose in the international community of scientists.

Finally, it is worth mentioning that the terms “law of nature” and “natural law,” which sound similar at first glance, have quite differing meanings. Natural law means a kind of philosophy that certain rights or values are inherent in human nature. According to the *Internet Encyclopedia of Philosophy* the term natural law is ambiguous and refers to a type of moral theory as well as to a type of legal theory. The core claims of the two kinds of theory are logically independent, but both theories intersect. Certain writers still contribute to a confusion of both terms in the twenty-first century. For instance, the American historian Perez Zagorin (1920–2009) published in 2009 a book entitled *Hobbes and the Law of Nature*. Three sections or chapters have the following titles: “Law of Nature,” “Enter the Law of Nature,” and “The Sovereign and the Law of Nature.” However, the entire content of this book is devoted to history and the meaning of natural law and has nothing to do with science.

A complementary example is an article by the English philosopher William Kneale (1906–1990) entitled *Natural Laws and Contrary-to-Fact Conditionals*, which exclusively deals with laws of nature. This problem is characteristic of the English language and of the Anglo-Saxon understanding of laws.

2.3 More About Laws of Nature

After World War II the paradigm changes in physics initiated by Max Planck, Albert Einstein, Louis de Broglie, Werner Heisenberg, and others stimulated (mainly among Anglo-Saxon philosophers of science) a vivid discussion about the meaning and role of laws of nature. Books or articles by the American philosophers Peter Achinstein, John W. Carroll, Frederick Dretske, Gilbert Harman, and Nelson Goodman; the Australian philosophers David Armstrong, Brian Ellis, and John L. Mackie; the British philosophers A. J. Ayer, Helen Beebee, Alexander Bird, William Kneale, and Stephen Mumford; the Canadian philosopher Norman Schwartz; and the German philosopher Carl G. Hempel should be mentioned as representative examples (see Bibliography). The problems and topics discussed by those philosophers concern metaphysical aspects and not real science. For example, Armstrong's introduction to his book *What is a Law of Nature?* begins with the sentence: "The question 'what is a law of nature?' is a central question for the philosophy of science. But its importance goes beyond this relatively restricted context to embrace general epistemology and metaphysics." Ellis says in the beginning of a review article that "Stephen Mumford's book *Laws in Nature* is an important contribution to metaphysics." Nonetheless, a few characteristic topics that merit a short comment should be mentioned here.

Philosophers of science have developed their own terminology, which has little in common with the terminology of scientists. For example, Armstrong distinguishes between spatio-temporally limited laws, infinitely qualified laws, instantiated and uninstantiated laws, disjunctive laws, bridge laws, functional laws, probabilistic laws, and iron and oaken laws. Schwartz presents a further classification in the preface of his book *The Concept of Physical Law*: "In the following pages you will find nothing about the taxonomy of laws, for example the distinction between causal laws, laws of concomitance, laws of dynamics, and functional laws. Similarly, you will find nothing about empirical laws and theoretical laws and nothing about the difference between low-level and high-level laws, nothing about basic laws and derived laws. You will find nothing about the difference between those laws whose non-logical and non-mathematical terms refer only to observables and those laws that contain some descriptive terms that refer to unobservable (or theoretical) entities."

Schwartz also explains: "I prefer the term 'physical law' to either 'law of nature' or 'natural law' so as to avoid any seeming connection with the doctrine of 'natural law' in all." This substitution obscures the fact that laws of nature are properties of nature as defined in Sects. 2.1 and 2.2, and it is not clear whether the term physical law includes biological and chemical laws. On p. 4 he declares: "Scientific laws are conceptually distinct from physical laws. Only the barest handful of scientific laws