

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

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:

$$S = (T, R)$$

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 worldview 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 translated 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 unacceptable 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 Beebe, 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

are physical laws.” Further confusion arises from the following statements (p. 14): “More specifically, physical laws occur among only two classes of general propositions: universal propositions and statistical propositions” and “Physical laws, however, are not empirical generalizations, i.e., propositions inductively generated from empirical data” (an opposing view by scientists is discussed in Sect. 2.4).

The debate about the metaphysical meaning of laws of nature mainly concerns two competing theories. The “regularity theory” holds that laws of nature are statements of the uniformities or regularities in the world. They are mere descriptions of natural phenomena and events. The “necessitarian theory” holds that laws of nature are the principles that govern the natural phenomena of the world. That is, the natural world obeys the laws of nature or, in the words of Beebe: “Laws are relations of necessity between universals.” For example Armstrong, Dretske, and Tooley are counted among the advocates of the necessitarian theory. They argue that a physical (also called “nomic” or “nomological”) necessity is inherent in the laws of nature. This physical necessity is a property of nature and, thus, inherent in matter and in the structure of the universe.

Beebe, Bird, and Ellis are representative of philosophers favoring the regularity theory. Beebe entitled an article explaining her concept “The Non-Governing Conceptions of Laws of Nature,” Bird entitled one of his articles “The Ultimate Argument against Armstrong’s Contingent Necessitation View of Laws,” and Ellis declared in his article “Looking for Laws” (p. 338): “The things that exist are thus supposed to determine what the laws of nature are, rather than the laws determine how things should behave.” On p. 439, he states that “laws of nature are descriptive of reality not prescriptive.” For reasons discussed below and in Sects. 2.2, and 2.4, this debate looks artificial and obsolete to scientists. It is partly based on a misleading analogy of laws of nature and the laws existing in a human society. Some philosophers seem to understand the role of the human brain in analogy to that of a dictator or parliament that can modify or change laws at will, and members of the society have to obey them.

A topic that is intensively discussed in this context is the difference between “accidental truth” and a law of nature. In his book *Laws of Nature* Carroll outlines the problem as follows: “The perplexing nature of the problem of laws emerges upon realizing there are laws and accidental properties (phenomena) that appear to be very similar indeed. Suppose that the fastest that any raven has ever traveled is exactly 30 m/s. Then consider this generalization:

1. All ravens have speeds < 31 m/s.
2. All signals have speeds $< 300,000,001$ m/s.

Generalization (1) is true, but not a law. What about (2)? Suppose that this special aspect of reality is correct; it is a law that no signals travel faster than light and the speed of light is slightly less than 300,000,001 m/s. So it is plausible to think that (2) is both true and a law. Now it is extremely difficult to describe precisely the significant difference between (1) and (2).”

For scientists, Carroll’s example is not a theoretical problem but may involve experimental difficulties, because any differentiation between laws and accidental

truths or other speculative regularities and hypotheses requires experimental results. However, Carroll's argumentation about ravens is not well suited for scientific analysis. A more realistic scenario looks like this: A population of ravens in Kent (UK) and another in Cornwall (UK) were studied and no raven travelling at a speed above 30 m/s was found. Certainly, no scientist would conclude that all ravens worldwide and all ravens of all times fly at speeds below 31 m/s. The experimental evidence does not suffice for this conclusion. That all ravens in southern England fly at speeds below 31 m/s is clearly an accidental truth. Now, let the speed limit be raised to 3001 m/s. With such a high limit the statement "all ravens have speeds less than 3001 m/s" may become a law of nature. It is possible to demonstrate that:

1. The lungs (and eyes) of ravens and all other birds cannot resist the air pressure at a speed of 3001 m/s
2. The power of their muscles can never suffice to reach such a high speed

Even easier to prove and to understand is a similar "exclusion law" that purports that no ravens ever fly at temperatures above 500 °C. Regardless of which property or function of a living or non-living object is considered, decisive for identification of a law of nature is the experimental evidence. However, terms such as experiment, measurement, and reproducibility are usually absent from the texts of philosophers.

Another strange kind of argumentation by philosophers of science is a comparison with "another world." For example, Bird presents in his aforementioned article about Armstrong's necessitarian theory the following comment (p. 147): "For example and in particular, properties [of materials] do not essentially or necessarily have or confer any dispositional character or power. Being made of rubber confers elasticity on an object, but it does not do so necessarily. Being negatively charged confers on objects the power to repel other negatively charged objects, but not necessarily. In other possible worlds rubber objects are not elastic, negatively charged objects attract rather than repel one another." The meaning of "other possible worlds" is not defined. If other inhabitable planets are meant, this argumentation is wrong because it is well known from space research that all the chemical and physical laws discovered on Earth are also valid on other planets. In a certain temperature range, rubber has the same elasticity on Mars as it has on Earth. If a world outside our universe is meant, the above argumentation is sheer non-sense because nobody knows anything about a world outside our universe, and human logic and all scientific methods are confined to the universe we live in.

In summary, the relevance of what philosophers debate about laws of nature is for scientists best expressed in an aphorism of the physicist Richard Feynman (1918–1988, Nobel Prize 1965): "Theory of science is as useful to scientists as ornithology is to birds"! The ravens from the example above will certainly agree.

However, three closely related questions that are of outmost importance for both scientists and theoreticians should be discussed here in more detail:

- What does the term "frame of validity" (introduced in Sect. 2.2) really mean?

- Does a law of nature exist at a certain time, a certain location, and certain temperature when its consequences are not detectable under these conditions?
- Were all laws of nature “born” at the first moment of the Big Bang?

The following, similarly important, questions are discussed in other subchapters:

- Do inductive inferences based on reproducible experimental facts yield trustworthy laws of nature as foundation of the natural sciences? Discussion of this question is given in Sect. 2.4.
- Does scientific research yield absolute truths (in the terminology of philosophers)? This question is discussed in Sect. 2.5.

What does “frame of validity” mean? As outlined in Sect. 2.2, all laws of nature have limits with regard to time, location, and temperature or with regard to two or all three parameters. The frame of validity is therefore a set of parameters (or reaction conditions) that allows the detection of reproducible phenomena obeying the law under consideration. Whether this frame has sharp borderlines or (as usual) consists of a gradual transition to other laws of nature is not relevant for this discussion. It is another logical consequence of this consideration that when the conditions of a scientific inquiry that do not allow for the discovery of a law of nature are shifted in such a way that they overlap with the frame of validity, the existence and effectivity of the law immediately becomes detectable.

A first experimental argument in favor of the above consideration results from the discovery of black holes. The physicists say that most laws of nature identified on the surface of the earth during the past 500 years are at not detectable in a black hole. The experimental verification of this statement is difficult to achieve and thus a fictitious experiment which, in principle, allows for verification on earth should be discussed. Consider a chemical laboratory that can repeatedly be heated to temperatures above 500 °C. In the beginning, a chemist studies the synthesis of penicillin from various starting materials at 20 °C. Afterwards the laboratory is heated to 500 °C. The penicillin and all organic substances the chemist has used are destroyed by thermal degradation, yielding charcoal and various gases. Under these conditions, organic chemistry is no longer feasible and the chemical laws that govern the synthesis and structural analysis of penicillin are not detectable. Now, the laboratory is cooled down to 20 °C. The chemist can enter the laboratory again and repeat the syntheses of penicillin. This process can be repeated again and again provided the laboratory is cleaned after each heating cycle. In other words, when a chemist equipped with a cooled, fire-proof protective suit enters a laboratory at 500 °C and asks nature, whether the molecules A, B, or C are suitable for the synthesis of penicillin, nature does not answer. However, in a second identical laboratory, the temperature of which is fixed at 20 °C, the synthesis of penicillin can be studied at any time and without interruption. Any experiment or study of natural phenomena is a question to nature and it is a fundamental requirement of any scientific inquiry to find the set of parameters (reaction conditions) that allow nature to answer.

The same line of argumentation can be considered from another point of view. At the time when all planets existing in the universe had surface temperatures above

1000 °C, none of the millions of biological and chemical laws that have been discovered on earth or that are foreseeable today (due to the existence of many millions of species of microbes, plants, and animals) were observable and detectable in the universe at that time.

The only consistent interpretation of these arguments is the assumption that all laws of nature are permanently present in the universe, but their detectability is limited by a certain set of parameters, their frame of validity. If, as defined above (Sects. 2.1 and 2.2), laws are fundamental and characteristic properties of nature, they were born together with all other fundamental aspects of our world at the very first moment of the Big Bang. In other words, the universe, our world, is characterized by the sum of all laws of nature plus space and time. As a result of the existence of a biosphere on earth (and perhaps on other planets), the current state of the universe represents a preliminary maximum of laws of nature that are detectable. However, the number of laws of nature inherent in the universe is potentially endless and, regardless of how long humankind survives, the limited capacity of the human brain (even when augmented by computers) will never be able to explore all the laws and their complex interactions. Therefore, it is wrong or at least premature to call this concept deterministic. Such a classification would overrate existing scientific knowledge and underestimate the richness and complexity of nature. In the words of R. Feynman: “The imagination of nature is far, far greater than the imagination of men.” However, this concept is consistent with the initially given definition of laws as the language that nature uses for the rational communication with the human brain, which is itself part of this nature. The last words should be left to Max Planck: “Science cannot solve the ultimate mystery of nature and that is because in the last analysis we ourselves are part of nature, and therefore, part of the mystery that we are trying to solve.”

2.4 Critique of Empirical Research as Source of the Laws of Nature

When, after 1933, the Nazis gained increasing influence on the political and social life in Austria, numerous artists, scientists, and philosophers with a Jewish background immigrated to foreign countries, notably to England and the USA. Among them was a small group of philosophers who were later nicknamed the “skeptical philosophers.” The most prominent figures were Ludwig Wittgenstein (1889–1951) and Karl R. Popper (1902–1994). The most severe and most widely known fundamental critique of empirical research originates from Popper and, therefore, this chapter is primarily devoted to an analysis of his arguments. However, concerning his critique of inductive inferences as source of reliable knowledge, he had two forerunners, namely the British philosopher and politician John S. Mills (1806–1873) and Wittgenstein (see Sect. 3.3).

In 1934 Popper published the book *Logik der Forschung* (The Logic of Scientific Discovery), which was translated into English in 1959. The following citations and page numbers concern the 6th edition (1972). At the beginning of the first chapter Popper asks (p. 27): “But what are these methods of empirical research? And what do we call empirical science?” He gives the answers in the subsequent section with a critique entitled “The Problem of Induction” and this critique begins with the following statements:

According to the widely accepted view—to be opposed in this book—the empirical sciences can be characterized by the fact that they use inductive methods, as they are called. According to this view, the logic of scientific discovery would be identical with inductive logic, i.e., with the logical analyses of these inductive methods. It is usual to call an inference ‘inductive’ if it passes from singular statements (sometimes also called particular statements), such as accounts of results of observations or experiments, to universal statements, such as hypotheses or theories.

Now it is far from obvious, from a logical point of view, that we are justified in inferring universal statements from singular ones, no matter how numerous; for any conclusion drawn in this way may always turn out to be false: no matter how many instances of white swans we may have observed, this does not justify the conclusion that all swans are white.

The question whether inductive inferences are justified, or under what conditions, is known as the problem of induction.

In the subsequent sections entitled “Deductive Testing of Theories,” “The Problem of Demarcation,” “Experience as Method,” Scientific Objectivity and Subjective Conviction,” and “Elimination of Psychologism” Popper never comes back to concrete examples illustrating or proving his inferences and statements. Therefore, a discussion of his frequently cited “swan argument” is of particular importance. Popper, like other philosophers, distinguishes between two types of statements: the singular (particular) statement and the universal (general) statement. The singular statement concerns a single observation, such as “the swan in front of me is white.” When all swans an observer comes across are white he achieves a series of identical singular statements and may finally formulate the universal conclusion: all swans are white. Popper points out that this inductive inference is falsified as soon as a colored swan is observed. Popper draws the final conclusion that a series of identical singular statements (observations) never yield reliable universal statements and, therefore, laws of nature can never be reliably determined from reproducible experimental results followed by an inductive inference.

However, the swan argument combines a correct with an incorrect inference, because Popper does not differentiate between the properties of a living or non-living object, which are variable without affecting the definition of the object, and properties that are constituents of their definition. The color of swans is not relevant for the definition of swans (*cygninae*). In the case of swans and many other animals, races exist that display a variation in color as an evolutionary consequence of their adaption to different environments. Therefore, it is true that even the largest number of white swans does not guarantee that all swans observed in the past, today, or in the future will be white (dark colored swans were indeed discovered in Australia).

For comparison, the following universal statement should be examined. All swans (like other birds) have wings equipped with feathers and their nerve signals propagate via a sodium (Na^+)–potassium (K^+) exchange across the nerve membranes. Where the nerves are interrupted by synapses, the nerve signals propagate via neurotransmitter molecules. Imagine that a kind of bird is discovered that at a distance looks like a swan, but closer inspection shows that it has wings covered by hair or the propagation of nerve signal involves other chemical mechanisms. The discovery of such a bird does not falsify the above universal statement, because such a bird does not obey the definition of swans.

An analogous example is from the domain of plants: All oak trees (*Quercus rubra* and *Quercus petraea*) produce acorns that after falling to earth serve as seeds for new oak trees. Their green leaves produce glucose via photosynthesis and the glucose serves as starting material for the synthesis of cellulose. Suppose that trees are found that look like oaks but do not produce acorns and their leaves do not produce glucose via photosynthesis. The discovery of such trees does not falsify the above universal statement, because they are outside the definition of oak trees.

Finally, a third example from the domain of non-living objects: All rubies are red gemstones consisting of aluminum oxide (Al_2O_3) colored by traces of the element chromium. Other red minerals having a different chemical composition, or aluminum oxide crystal having another color (e.g., corundum or sapphire) do not obey the definition of ruby.

Considering that millions of plant and animal species exist on earth, many millions of universal statements could be formulated that represent at least partial definitions of living organisms, and many more such statements can be made about non-living objects. Together with the structural formulas of chemical compounds (see Sect. 2.4) all these descriptions and definitions represent the largest body of reliable knowledge in science. In other words, the swan argument is wrong whenever it is used as a critique of inductive inferences and empirical research.

Popper also wrote on p. 28: “Thus to ask whether there are natural laws known to be true appears to be only another way of asking whether inductive inferences are logically justified.” The answer is: Yes, they are justified and laws of nature may represent an absolute truth, as demonstrated in Chap. 3.

Based on his misinterpretation of the swan argument and its underlying logic, Popper continues on p. 40: “Now in my view there is no such thing as induction. Thus inference of theories from singular statements which are verified by experience (whatever that means) is logically inadmissible.” On p. 28, he states: “Now this principle of induction cannot be a purely logical truth like a tautology of an analytical statement. Indeed, if there were such a thing as a logical principle of induction, there would be no problem of induction; for in this case all inductive inferences would have to be regarded as purely logical or tautological transformations like inferences in deductive logic. Thus the principle of induction must be a synthetic statement, that is, a statement whose negation is not self-contradicting but logically possible.”

These statements provoke the following questions: What does the negation of the law of the lever look like and what is its logic justification? Furthermore, any baby must start breathing immediately after the navel cord is cut. What does the

negation of this natural law look like and what is the logical justification in this case?

On p. 59 Popper says: “The experimental sciences are systems of theories. The logic of scientific knowledge can, therefore, be described as a theory of theories. Scientific theories are universal statements. Like all linguistic representations they are systems of signs and symbols.” This description of empirical sciences is not agreeable. First of all, empirical science begins with accumulation of observations or experimental data. If, for certain observations or data, reproducibility irrespective of time and location can be attested, the observer can continue on two tracks:

- I. The observer recognizes in his consciousness or subconsciousness a law of nature and extrapolates the reproducibility into the future to profit from reliable predictions. This process does not require the design of hypotheses.
- II. The observer develops a hypothesis that combines two aspects: (A) an explanation based on comparisons with other observations (experimental data) and/or with existing theories; and (B) prediction of new experiments to test the hypothesis, which after confirmation achieves the status of an established theory.

Hence, the development of a theory and its comparison with other theories is the last step of research activities. Proceeding according to (I) is typical for children and for early humankind (Neolithic and before). Yet, even the brains of higher animals behave in this way, as illustrated below, and other mammals certainly do not formulate hypotheses nor use signs and symbols.

However, even in modern science such behavior may make sense. Consider a chemist who has developed a new cheap synthesis for an antibiotic. Prior to technical production, optimization of the yield is required to reduce the costs and to improve the purity of the product. The optimization is usually achieved by systematic variation of those parameters that have a significant influence on the yield, such as reaction time, temperature, and concentration. The dependence of the yield on each parameter represents a law of nature. The reproducibility of the optimized procedure serves, in turn, as basis for the technical production (see Sect. 3.2). The successful technical production confirms every day the reproducibility and predictability of the empirical research underlying the production.

This entire process from the first synthesis to the technical production does not require a hypothesis or theory about the reaction mechanism of the involved molecules, although such a hypothesis might be helpful and desirable. In summary, Popper’s definition of empirical science is one-sided and misleading and his wrong understanding of science culminates in the statement “science is a theory of theories”. This statement is characteristic for a physic-infected theoretician with little knowledge of the scientific fundament of the human civilization (Chapter 3.2), of chemistry in general (Chapter 9) and of the progress of medicine (Chapters 6 and 7).

Popper’s belief that inductive inferences do not yield reliable universal statements and insights in laws of nature has led him to construct a theory of science focused on the aspect of falsifiability of hypotheses and theories. A statement is called falsifiable if it is possible to find an observation or logical argument that

proves the statement to be false. Popper used the falsifiability of hypotheses and theories for the demarcation between science and non-science. His concept was labeled “falsificationism” and he and his followers were nicknamed falsificationists. He explained his concept and its deviation from positivism as follows (p. 40): “The criterion of demarcation inherent in inductive logic—that is, the positive dogma of meaning—is equivalent to the requirement that all statements of empirical science (or all meaningful statements) must be capable of being finally decided with respect to their truth and falsity; we shall say that they must be conclusively decidable. This means that their form must be such that to verify them and to falsify them must both be logically possible. Thus [the Austrian philosopher] Schick says, ‘a genuine statement must be capable of conclusive verification’ and [the Austrian physicist] Waismann says still more clearly, ‘If there is no possible way to determine whether a statement is true, then that statement has no meaning whatsoever. For the meaning of a statement is the method of its verification.’ Now in my view there is no such thing as induction. Thus inference to theories from singular statements which are verified by experience (whatever that means) is logically inadmissible. Theories are, therefore, never empirically verifiable. . . . These considerations suggest that not the verifiability but the falsifiability of a system is to be taken as criterion of demarcation.”

Finally he says: “My proposal is based upon an asymmetry between verifiability and falsifiability, an asymmetry which results from the logical form of universal statements. For these are never derivable from singular statements but can be contradicted by singular statements.”

This latter statement underlines Popper’s misunderstanding of inductive conclusions and is here confronted with non-falsifiable universal statements from biology, physiology, chemistry, and astronomy:

- All men must die. This law is a special case of a more universal law saying that the individuals of all species, whose reproduction is exclusively based on sexual acts, must eventually die. For a falsification of this law, an individual (human or other mammalian) would need to be found that lives for eternity.
- All humans (*Homo sapiens*) produce enzymes for the digestion of starch (rice, corn, wheat, potatoes), but not for the digestion of cellulose (cotton, wood), although both types of biopolymers consist of glucose units. Any individual whose digestion works differently is outside the definition of *Homo sapiens*.
- The human brainstem regulates breathing so that the pH in the cerebrospinal liquid does not exceed the limits of 7.35 and 7.45. At higher or lower pH values the nerves are rapidly damaged, with lethal consequences. A living organism working at a significantly higher or lower pH does not have a human brain.
- The sun and other stars of similar mass have a well-defined *vita*. Their birth begins with the contraction of a cloud of hydrogen atoms, they pass a maximum of radiation in the form of a red giant, a maximum of temperature in the form of a white dwarf, and they finally cool down asymptotically approaching the temperature of the environment. To falsify this law, one would need to find a star that maintains a significantly higher level of radiation or temperature than its environment for all eternity.

Another type of critique of Popper's falsification theory was contributed by the theoretician and historian Thomas Kuhn. In his famous book *The Structure of Scientific Revolution* (for review see Chap. 5) he wrote (p. 146/147): "A very different approach to his whole network of problems [is verification of a theory possible?] has been developed by Karl Popper who denies the existence of any verification procedure at all. Instead he emphasizes the importance of falsification, i.e., of the test that, because its outcome is negative, necessitates the rejection of an established theory. . . . But falsification though it surely occurs, does not happen with, or simply because of, the emergence of anomaly or falsifying instance. Instead it is a subsequent and separate process that might equally well be called verification since it consists in the triumph of a new paradigm over the old one."

Unfortunately, Popper cannot answer the question: What does science mean if a reliable determination of natural laws is not feasible? If science is merely an enterprise yielding falsifiable theories, it is nothing more than an intellectual game. Further arguments in favor of an empiricist view of science are presented in Sects. 3.1, 3.2, and 3.3 and below.

2.5 Is There an Absolute Truth in Science?

Truth is a term that is very much liked by poets, theologians, and philosophers, including philosophers of science, whereas scientists usually prefer to talk or write about reliable knowledge, consistent interpretation, correct information, unequivocal evidence, definite proof, etc. Regardless of this difference, the question of whether scientific research can provide reliable knowledge/absolute truth or not needs to be answered. In this connection, Max Born's statement, cited in Chap. 1, should be recalled: "Ideas such as absolute certainty, absolute accuracy and final truth are inventions of the human imagination and should be avoided in science." A similar statement was given by the physicist and Nobel Prize laureate Werner Heisenberg (1901–1976): "Therefore, it will never be possible by pure reason to arrive at some absolute truth." These statements are not acceptable for at least two reasons. First, they are a kind of oxymoron, because they negate themselves. If absolute truth does not exist, this conclusion necessarily implies that it is itself not an absolute truth and Born's and Heisenberg's statements are a pseudo-insight; this is not helpful for a correct understanding of natural sciences.

Over the past 100 years, philosophers of science have extensively discussed whether scientific theories may represent an absolute truth, or a gradual approach to truth, or a truth-likely interpretation of scientific results. Almost all these discussions suffer from the following deficits:

- Almost all philosophers of science lack any personal experience of experimental research.
- They rarely cite concrete examples illustrating and proving their concepts and conclusions. If they cite scientific results and theories they allude to the history

of astronomy and physics, assuming that this history is representative of any kind of natural science and of any kind of research.

- Their texts suggest that they do not have any knowledge of chemistry, geology, physiology, etc.
- Two terms that are of outmost importance for a proper understanding of science, namely “law of nature” and “reproducibility” (of experiments or observations) are not usually found in their texts.

Hence, experimental scientists have the impression that those philosophers discuss a *Fata Morgana* of science but not real science. In the words of the theoretical physicist R. Feynman in *The Pleasure of Finding Things Out*, published in 1999 (p. 173): “And so what science is, is not what the philosophers have said it is and certainly not what the teacher editions say it is.”

However, exceptions, such as the Canadian philosopher Ian Hacking, are exempt from this critique. In 1983, Hacking wrote in his book *Representing and Intervening* (p. 149): “Philosophers of science constantly discuss theories and representations of reality but say almost nothing about experiment, technology, or the use of knowledge to alter the world.” Furthermore, the American philosopher Moti Mizrahi in a recent article (2013) entitled “What is Scientific Progress? Lessons from Scientific Practice” demonstrated by means of two discoveries in the field of physiology that the understanding of science as it is presented by most philosophers, is too narrow and one-sided. The historic examples cited by Mizrahi are the discovery of blood groups by Karl Landsteiner (1836–1943, Nobel Prize in 1930) and the work of Ivan P. Pavlov (1849–1936) on the physiology of digestion (Nobel Prize in 1904).

The titles of articles and books cited below should illustrate the problems and questions frequently discussed in philosophical treatises (the meaning of truth in science is, of course, also debated in other publications):

- *Likelihood of Truth*, Oddie G (1986), D. Reidel, Dordrecht
- *Truthlikeness*, Niiniluoto I (1987), D. Reidel, Dordrecht
- *Realism and Truth*, Devitt M (1991), Blackwell, Oxford
- “Approximate Truth and Scientific Realism,” Weston T (1992) *Philosophy of Science* 59:52
- *How Science Tracks Truth*, Psillos S (1994), Routledge, London
- *Science, Truth and Democracy*, Kitcher P (2001), Oxford University Press
- “Revising Beliefs Towards Truth,” Niiniluoto I (2011), *Erkenntnis* 75:165
- “Progress as Approximation to Truth: A Defense of the Verisimilitudinarian Approach,” Cevolani G, Tambolo L (2013), *Erkenntnis* 78:921

According to a citation in the *Stanford Encyclopedia of Philosophy*, the American philosopher Larry Laudan (born 1941) reached the conclusion that “knowing the truth is an utopian task.” This statement is almost identical to those of Born and Heisenberg and it deserves the same critique. However, any use or discussion of the term “truth in science” has to consider that truth frequently has a religious or other transcendent connotation. Such a connotation renders the term “truth” useless for a

reasonable and consistent debate about the structure, properties, and goals of science. The text below and the discussion of progress in Sect. 5.3 are based on an equivalence of truth and reliable knowledge (information, data, experimental facts).

The examples of problems discussed by philosophers of science should now be confronted with two aspects of scientific practice. The first aspect concerns the lowest level of scientific activity, a behavior any individual learns in the earliest stage of life and a behavior that humankind has practiced since its emancipation from apes. This activity is the observation of natural phenomena, their classification, and their extrapolation into the future. Natural phenomena are classified even in the subconscious into perfectly regular, more or less regular, and irregular events. The discovery of perfectly regular phenomena stimulates, in turn, an extrapolation into the future, either to avoid risks or to achieve an advantage, such as more or better food. The success of the extrapolation to the future is a consequence of the fact that the results of laws of nature must be reproducible irrespective of location and time (as long as their frame of validity exists). For instance, when a baby learns to stand and to walk upright, it is permanently confronted with the reproducible influence of gravity everywhere on the surface of the earth and at any time.

The discovery of a law of nature and the extrapolation of its effects on the time scale may be called inductive inference, but it does not necessarily involve the formulation of a hypothesis (and even less of a theory).

When a baby learns to cope with the problems of gravity it automatically assumes that gravity will persist in the future, otherwise a cumbersome time-consuming learning process would not make sense. The baby certainly does not develop a hypothesis about gravity, law of the lever, and the kinetics of motion. The same line of argumentation holds for the exploration of laws of nature by early humanity, as illustrated in Sect. 3.1.

The ability to discover and utilize laws of nature without elaborating hypotheses and theories is not confined to the human brain, it can also be observed for animals, because it is a fundamental principle of life. For instance, the brown bears living along the coast of British Columbia and Alaska gather in fall every year along the rivers that empty into the Pacific Ocean. They wait for the salmon coming up the river, because they need this calorie-rich food to survive the winter. Over a period of many thousands of years, the bears have learned to profit from this predictable event, but they have certainly not developed a theory about the yearly migration of salmon. In summary, any definition of science focused on the elaboration of theories and their qualities, such as absolute truth or truthlikeness, is too narrow, one-sided, and may be misleading.

The second argument against a theory-laden view of science and against a fundamental lack of truth in scientific results comes from standard chemical research. Since the beginning of modern organic chemistry in the early nineteenth century a fundamental goal of chemists, decisive for the progress of chemistry, was and still is the elucidation of the chemical structure of all pure compounds. This kind of analytical work was difficult in the nineteenth century, in as much as a precise and generally accepted formula language was lacking before 1874. Yet,

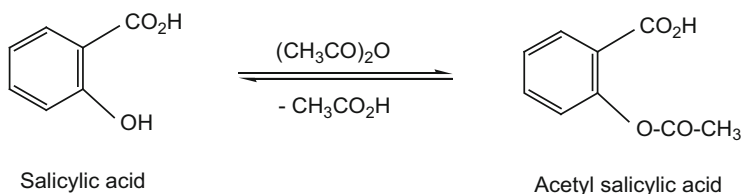


Fig. 2.1 Synthesis of aspirin from salicylic acid

today numerous analytical methods are available and allow rapid and unequivocal determination of chemical structures. Such analytical methods include elemental analyses (qualitative and quantitative determination of the elements that constitute a compound), UV-, IR- and Raman spectroscopy, several variants of nuclear magnetic resonance (NMR) spectroscopy, different mass spectrometry techniques (e. g., classical mass spectrometry, fast-atom-bombardment (FAB), and MALDI-TOF mass spectrometry), various types of chromatography, electron microscopy, and X-ray scattering. For the structural analysis of relatively simple molecules such as aspirin (Fig. 2.1) or procaine (see Fig. 7.1 in Sect. 7.3) the combination of four or five methods is usually sufficient. The structure of a compound is also confirmed by its synthesis from well-established precursor molecules. After confirmation by two or more different laboratories, the chemical structure of a molecule is a piece of reliable knowledge or absolute truth. The understanding of a synthetic procedure, such as the conversion of salicylic acid into aspirin (Fig. 2.1), is an additional piece of truth.

To illustrate the importance of this argument for the proper understanding of science, the following points need to be taken into account:

- The reliable knowledge of chemical structures is decisive for successful research in molecular biology, physiology, pharmacy, organic, inorganic and polymer chemistry, and in mineralogy.
- The rapid progress of human civilization over the past 150 years is based on the knowledge of chemical structures and chemical reactions (see Sect. 3.2). The production of local anesthetics (Sect. 7.3), medicaments, dyestuffs, and numerous polymers (see Sects. 9.4 and 9.5) serves as evidence.
- Pharmaceutical companies only produce and commercialize medicaments of well-known chemical structure (over the past 120 years nearly ten billion aspirin tablets were produced).
- Up to the year 2010 more than ten million chemicals of known structure were synthesized.

Of course, in several cases the initial structural analyses contained errors that were later revised. From this point of view chemical research is not different from research in other disciplines of science. Nonetheless, a body of far more than ten million “pieces of absolute truth” has been accumulated by chemists over the past 200 years. This is the second, the experimental, argument against the statements of Born, Heisenberg, and Laudan.

The third argument and the final answer to Laudan's statement is the fundamental law that all men must die. This is an absolute truth and its hypothetical falsification, an eternal life of skeptical philosophers or antiscientists, is a utopia.

2.6 Law of Nature Versus Model

The defamation of inductive inferences by Popper, Wittgenstein, and their followers; the negation of truth in science by Born, Laudan, and other skeptic philosophers; and the dramatic paradigm changes that took place in physics have stimulated some physicists to draw an extreme conclusion. The German physicist Thomas Millack declares in his 2009 book *Naturwissenschaft und Glaube im Gespräch* (Science and Religion in Dialogue) that he and other physicists prefer to use the term "model" to the term "law of nature." A model is an intellectual method, like hypothesis and theory, providing a preliminary explanation of complex natural phenomena that are influenced by numerous laws of nature and their interactions. Models need further modifications and improvements. Yet, what is the goal of these improvements, if not an as perfect as possible explanation of natural phenomena in terms of laws? Substitution of the term law of nature by model is a confusion of two dimensions because it puts an intellectual method on par with the properties of nature.

The substitution of law of nature by model is not only an issue for discussion among philosophers of science, it also has interesting and sometimes even amusing consequences for the conversation between scientists and among laics. Consider a child that is attempting to learn to stand upright and to walk. Does the child optimize its response to laws of nature, such as gravity or the law of the lever, or does it play with a model? When a motorcyclist has an accident because he ignored the fact that the stopping distance increases with the square of his speed, did he ignore a law of nature or a model? Finally it is instructive to look at the events following the birth of a human being. Immediately after the navel cord has been cut, a baby must start breathing, otherwise it will die within a shorter time than its birth required. Is this need to breathe a law of nature or a model?

This chapter should be closed with a modified aphorism of the German physicist Georg C. Lichtenberg (1742–1799), an aphorism he originally dedicated to chemists: "He who knows nothing but physics, does not even understand physics."

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