Chapter 2
Frameworks in the Integration of the Sciences

2.1 Introduction

Chapter 1 describes the essential concepts of a few Renaissance philosophers, who were also mathematicians and/or physicists. Galileo Galilee and Isaac Newton were included in this category because their basic works in physics form the fundamental framework of scientific philosophy. These thinkers opened the way to modern sciences and were the predominant philosophers up to the beginning of the twentieth century. Although Henri Bergson does not belong to the Renaissance philosophers, he was an interdisciplinary working mathematician and academic who bridged concepts of mind from the Renaissance to modern science by forging essential steps in the theory of memory. He also provided an ultimate approach to both Albert Einstein's concept of time and Charles Darwin's theory of evolution.

In fact, Chapters 1 and 2 could have been presented as a single chapter, because the topics under evaluation also have a relevant philosophical impact. However, it seemed better to split the fundamental scientific-philosophical approaches into two chapters, with this one describing the important and fundamental discoveries at the end of the nineteenth and beginning of the twentieth centuries that opened the way to modern biology and contemporary physics. René Descartes and Newton's mechanical viewpoint gave way to probabilistic and statistical approaches in the twentieth century. There is a separation between the Newtonian mechanical viewpoint and statistical approaches. Accordingly, what is described in the present chapter leads to a new conceptual framework that is explained in Part IV.

The reader may wonder about the choice of 12–13 important developments by the most recognized scientists. The answer to this question can be found in Chapters 15–20.

E. Başar, *Brain-Body-Mind in the Nebulous Cartesian System: A Holistic Approach by Oscillations*, DOI 10.1007/978-1-4419-6136-5_2,

2.2 Charles Darwin and the Voyage of the Beagle

In the 1830s, Charles Darwin started his famous voyage on the Beagle from England to South America, and thus opened the way to modern biology. Darwin studied medicine and theology, and could be considered a zoologist as well. For two thirds of this 5-year journey, Darwin was on land carefully noting a rich variety of geological features, fossils, and living organisms and collecting an enormous number of specimens, which were sent to Cambridge together with reports about his findings. The voyage of the Beagle summarizes Darwin's findings and provides social, political, and anthropological insights into the wide range of people he met. One of the most important books by Darwin was entitled, *On the Origin of Species by Means of Natural Selection or the Preservation of Favored Races in the Struggle of Life* (usually abbreviated to *The Origin of Species*). Darwin's theory rests on two fundamental ideas:

1. The concept of *heritable variation*, which appears spontaneously and at random in individual members of a population and is immediately transmitted through descent.
2. The idea of *natural selection*, which results from a "struggle for life." Only individuals whose heredity endowment enables them to survive and reproduce in a particular environment can multiply and perpetuate the species.

In the 1970s, Jacques Monod suggested an extension of Darwin's model to cultural evolution and the progression of ideas. Related arguments were also developed by Karl Popper. The proposition separately advanced by these authors is that cultural evolution arises from the externalization of the inner representations of the brain, the sharing of these representations between the brains of individual members of a social group, and ultimately their storage in extracellular memories (Changeux 2004).

The monograph by Monod (also mentioned in Chapter 17) is a brilliant piece of scientific conceptual work. However, Monod did not adequately take into account the work by Bergson, which he criticized as somewhat impulsive and not scientifically grounded. On the contrary, Bergson gave a superb intimation of how to understand the evolution of ideas (see Chapter 17 and 18). Nevertheless, Monod's *The Chance and Necessity* (1970) opened the way to bridge molecular biology and evolution (see also Sect.2.1).

As strongly emphasized in several chapters, Darwinism in the general sense provides an important conceptual method in all sciences. Darwin used comparative physiology to develop his theory on the evolution of species; thus, he went out of the system to become able to understand the system.

Einstein took a similar step by studying gravitation in various galaxies to understand the Earth's gravitational fields. Başar (1976) proposed "going out of the system," a conceptual method to approach physiological functions. The starting point was that to understand the causes of the autoregulation of blood flow in the kidney one has to go out from the specific system under investigation and look into other systems. For example, the coronary system of the heart and the contractile behavior of smooth muscles in the vasculature and peristaltic organs also should be analyzed to learn about the circulation of the kidney. (This is explained in Chapters 4 and 5.) In the brain one cannot perfectly understand the functioning of the hippocampus without establishing comparisons and links to physiology of the reticular formation. In other words, a holistic view is needed, which is why attention has been drawn to the holistic approaches of Darwin and Einstein, who provided magnificent examples and lessons to scientists trying to solve core problems in the natural sciences and physics.

2.3 Norbert Wiener and Cybernetics

Cybernetics is the science of control and communication – the transmission, exchange, and processing of signals in animals and machines (Fig. 2.1). Although Wiener's formulation was based on very little experience in biology, it predicted the course of the development of research in the field of cybernetics. His definition includes everything that the term *cybernetics* encompasses today. Although several research scientists find Wiener's approach somewhat old-fashioned, the intellectual impact of his work had a strong influence on several disciplines and provided a turning point for the establishment of the schools of Ilya Prigogine on dissipative structures and Herman Haken on synergetics. The view of René Thom in catastrophe theory and the general nonlinear approach to sciences have immensely profited from Wiener's vision. The book provided an inspiring framework for thinking broadly in parallel in multidisciplinary fields. One thing is absolutely clear:

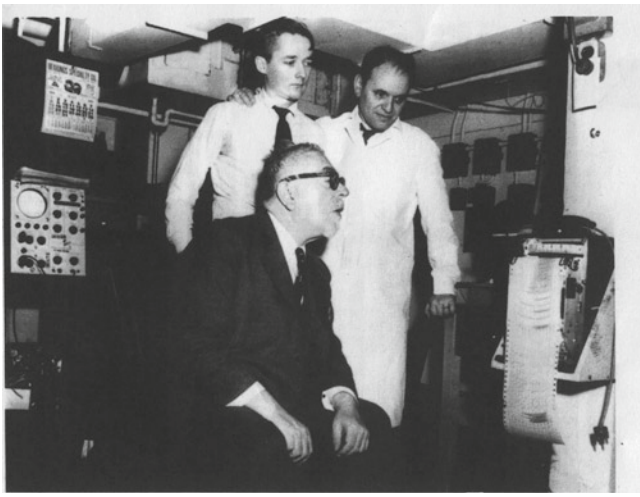


Fig. 2.1 Norbert Wiener (November 26, 1894–March 18, 1964) at work

The research leading to the foundation of *Brain Dynamics*[1] was anchored in the idea of signal processing and communication in the brain.

In the Introduction to *Cybernetics*, Wiener gives a detailed description of the experiences and thoughts that preceded the founding of *cybernetics*: On the basis of reflections and conversations with scientists in many specialties, especially physicians, it became clear to him, as a mathematician, that control processes take place and information is transmitted and stored in the human organism as well as machines (Hassenstein 1971). Wiener advised scientists working in multidisciplinary areas that a physiologist working with a mathematician would never be able to develop as powerful mathematical techniques as would a mathematician; but a physiologist would at least be able to understand the mathematical tools being jointly applied. Similarly, a mathematician or physicist would never be able to develop a physiological preparation with the skill of a biologist. However, he or she can understand what is going on in the physiological system as well as the main propose of investigating a given function.[2]

Wiener discovered functional similarities between technical processes and living organisms. The new science of cybernetics was intended to create a scientific framework considering it as a separate branch of science with the idea of conforming to the functional principles in technology and biology. Cybernetics was conceived as a common ground on which engineers, biologists, mathematicians, psychologists, etc., could meet and discuss in a common scientific language the problems of control and communication that appear in various forms in their scientific fields.

This means that the concepts of cybernetics should be neutral and abstract; they should contain no specifically technological or biological characteristics that would make them inapplicable to another field. By considering these entire essential proposals it can be seen that the science created by Wiener was a school of thought that was unique at the beginning of the twentieth century and resembled the ancient Greek Academy of Athens. However, the philosophers of Athens and later of Ionia did not have the tools available to Wiener. Unfortunately, Wiener's life was too short for him to realize his applications in biological sciences. However, despite this his predictions have come true about the future governing role of computers. The applications of cybernetics are detailed elsewhere in this book (see especially Chapters 3 and 6).

2.4 Hermann Haken: Synergetics and Laser Theory

A recent important development in the physics-like theories applied to biological systems is framework synergetics. The word *synergetics* is composed of two Greek words and means "working together." Haken (1977) states, "In many disciplines,

[1]Başar 1976, 1980; Freeman 1975.

[2]The author of present book took this advice very strongly into consideration. Although educated as physicist, he learned physiology and also developed several physiological techniques in his laboratories. In this way it was possible for him to become one of the neuroscientists who launched the field of brain dynamics and oscillations.

ranging from astrophysics over biology to sociology, we observe very often that cooperation of many individual parts of a system leads to macroscopic structures of functionings." In its present state, synergetics focuses its attention on those situations in which the functioning structures of the systems undergo changes on a macroscopic scale. In particular, synergetics investigates how the subsystems produce these changes in an entirely self-organized manner. The subsystems are usually discrete, e.g., atoms, cells, or human beings. An important group of phenomena are oscillations (temporal structures) that occur in a self-organized manner. Here a rod of laser-active material with two mirrors at its end faces is pumped energetically from the outside, and the atoms emit light (Fig. 2.2).

The essential feature to be understood is this: If the laser atoms are pumped only weakly by external sources, the laser acts as an ordinary lamp. The atoms, independently of each other, emit wave tracks with random phases. The coherence time of about 10^{-11} s is evident on a microscopic scale. The atoms, visualized as oscillating dipoles, are oscillating at random. If the pump is further increased, suddenly within a very sharp transition region the line width of laser light may become on the order of 1 cycle/s so that the laser is evidently in a new, highly ordered state on a macroscopic scale. The atomic dipoles now oscillate in phase, although they are excited by the pump completely at random. Thus, the atoms show the phenomenon of self-organization. Evidently the macroscopic properties of the laser have changed dramatically in a way reminiscent of the phase transition of the Ferro magnet, for example. The laser analogy and cooperative phenomena at the atomic level are presented here to provide an additional metaphor for the phenomenon of frequency stabilization, i.e., the transition to a highly ordered state on a macroscopic scale as seen in the brain responses (see also Chapter 6).

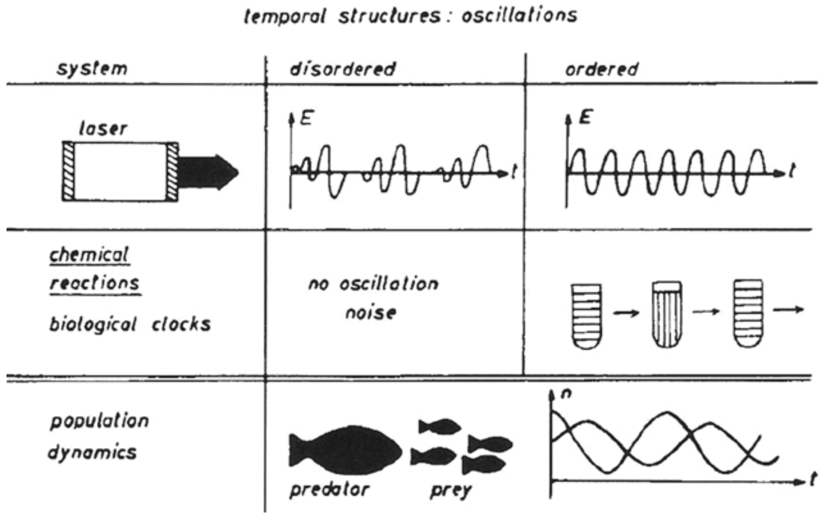


Fig. 2.2 Self-organized oscillations from physics, chemistry, and population dynamics (from Haken 1977)

2.5 René Thom: Catastrophe Theory and Forced Oscillations in the Brain

Eric Christopher Zeeman (1977) discussed the classical oscillators, the Van der Pol oscillator, and especially Duffing's equation in brain modeling in terms of catastrophe theory. Forced oscillations can x + ax = Fc be modeled by Duffing's equation: where $k > 0$ is a small damping term, a small nonlinear term (a = -1/6 for a simple pendulum), and F cos Qt is a small periodic forcing term with frequency fi close to 1, the frequency of the linear oscillator. The amplitude A of the resulting oscillation depends on the parameters, and Fig. 2.3 shows graph A as a function of a and ft (keeping k and F fixed). There are two cusp-catastrophes with a, 0 as conflicting factors. At each cusp the upper and lower sheets represent attractors (stable periodic solutions) whereas the middle sheets represent saddles (unstable periodic solutions). If the frequency of the forcing term is gradually changed to cross one of the cusp lines, starting from the inside and going to the outside of the cusp, then the amplitude A will exhibit a catastrophic jump. There will also be a sudden phase shift at the same time (Zeeman 1977).

The description of the mathematics of the catastrophe theory (Thom 1975) is beyond the scope of this book; therefore, a detailed explanation of the graph technique or terminology used by Zeeman is not attempted here. However, it is important to note that according to Zeeman's theory the brain's activity can be modeled by forced nonlinear oscillations. Furthermore, Zeeman's catastrophe model exhibits catastrophic jumps in amplitude at resonant frequencies and sudden phase shifts at the same time. These theoretical statements are most pertinent to the analysis presented in this book because sudden jumps of amplitude and phase shifts are also obtained at resonant frequencies of the brain response.

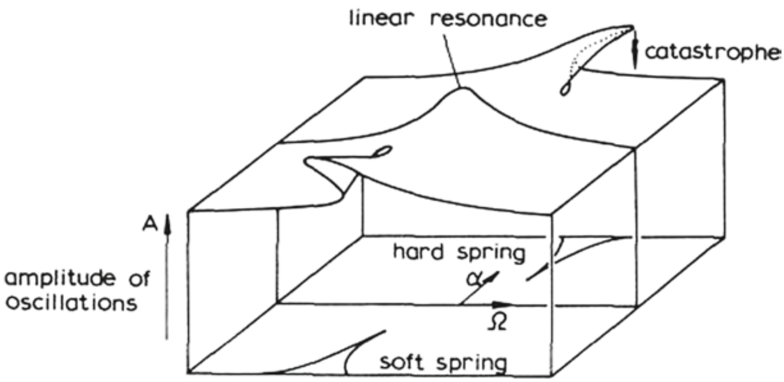


Fig. 2.3 The oscillation of a forced non-linear oscillator bifurcates according to the cusp-catastrophe (from Zeeman 1977)

2.6 Prigogine: Dissipative Structures

The mechanisms of self-organization in the genesis of oscillations through various kinds of interaction in physical, chemical, biological, psychological, and social systems has been deeply explored by Aharon Katzir-Katchalsky et al. (1974) and Ilya Prigogine (1980) in studies of dissipative structures and chaotic state transitions. According to Prigogine's theory, no system is structurally stable; fluctuations lead to instabilities and new types of function and structure. The evolution of a dissipative structure is a self-determining sequence according to Fig. 2.4.

This approach combines both deterministic and probabilistic elements in the time evolution of the macroscopic system.

Freeman's viewpoint (1999) is that complex biochemical feedback pathways within cells support the emergence of oscillations at cycle durations of minutes, hours, and days, and they underline the recurrence patterns of normal cyclical behavior as well as epileptic fits, mood disorders, and other pathologies. Further, large numbers of neurons form macroscopic population under the influence of external and internal stimuli and endogenous neurohormones. Freeman's opinion is that these populations are more closely related to the nerve cell assemblies conceived by Hebb (1949). In these assemblies, relationships of neurons to the mass are explained by Haken's synergetic theory (1977), whereby the microscopic neurons contribute to the macroscopic order and then are "enslaved" by that order, similar to particles in lasers and soap bubbles.

According to Prigogine, "living processes" were in some sense pushed outside nature and physical laws. One was tempted to ascribe an accidental character to a living organism and imagine the origin of life as being the result of a series of highly improbable events. A sharp distinction is made between events and regularities in classical dynamics.

At most, we could use Boltzmann's probabilistic interpretation of the second law of thermodynamics to ascribe a probability to each possible condition. One an initial condition is specified, the system will be led to its most probable state through an irreversible process.

Life, considered to be a result of "improbable" initial conditions is, therefore, compatible with the laws of physics (initial conditions can be arbitrarily chosen), but does not follow from the laws of physics (which do not prescribe the initial conditions). This is the outlook supported, for example, by Monod's well-known book.[3]

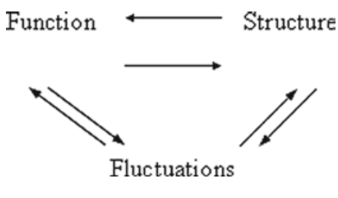


Fig. 2.4 Dissipative structures

[3]Monod (1970), Le Hasard et la Nécessité, Seuil, Paris.

Moreover, the maintenance of life appear, in this view, to correspond to an ongoing struggle of an army of Maxwell demons[4] against the laws of physics to maintain the highly improbable conditions that permit its existence. The results summarized by Prigogine support a different point of view. Far from being outside nature, biological processes follow the laws of physics, appropriate to specific nonlinear interactions and conditions far from equilibrium. Thanks to these specific features, the flow of energy and matter may be used to build and maintain functional and structural order.

The reader is referred also to Chapter 17, in which the possible role of a Maxwell's demon in cognitive processes and creative evolution is detailed.

2.7 The Importance of Einstein's Three Concepts in Brain Research: (1) Synchrony of Clocks, (2) Brownian Motion, and (3) Unconscious Problem Solving

What is a clock? Any physical phenomenon may be used as a clock, provided it exactly repeats as many times as desired. Taking the interval between the beginning and the end of such an event as one unit of time, arbitrary time intervals may be measured by the repetition of this physical process. All clocks, from the simple hourglass to the most refined instruments, are based on this idea. It is, therefore, inconvenient to have only one clock; therefore, if we know how to judge whether two or more clocks show the same time simultaneously and run in the same way, we can imagine as many clocks as we like in a given coordinating system (Einstein and Infeld 1938) (Fig. 2.5). Provided

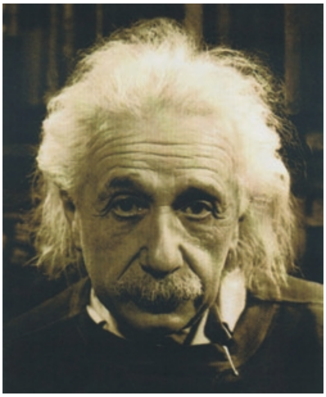


Fig. 2.5 Albert Einstein (March 14, 1879–April 18, 1955)

[4]For the second law of thermodynamics see Chapter 17.

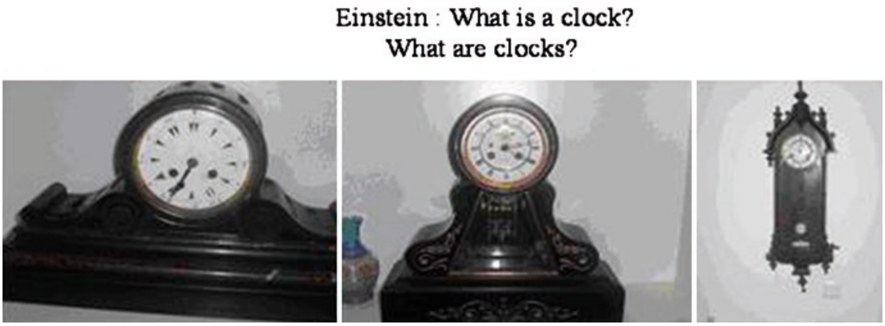


Fig. 2.6 Clocks (from the collection of the Başar family)

the clocks are all at rest relative to the coordinating system, they are "good" clocks and are *synchronized*, meaning that they show the same time simultaneously.

2.7.1 Synchronization of Clocks in the Brain (Synchronization of Oscillations of Neurons and of Neural Populations)

There are two classes of synchronized clocks in the brain: First, synchronous neural oscillators in a given special brain structure (Eckhorn et al. 1988; Singer 1989), and second, large-scale synchrony between distant structures (Başar 2004; Bressler and Tognoli 2006; Varela et al. 2001; von Stein and Sarnthein 2000). The electroencephalogram (EEG) consists of the activity of an ensemble of generators producing oscillatory activity in several frequency ranges. These "brain oscillators" are active in a random way, usually. However, with application of sensory-cognitive stimulation, these generators become coupled and synchronized; they start acting in a coherent way. This synchronization and enhancement of EEG activity produces the "evoked" or "event-related" oscillations that may be phase-locked to the stimulus; or they may be non-phase-locked to the stimulus and thus have an "induced" character (Fig. 2.6).

The compound event-related potential (ERP), which includes the responses of ensembles of neural populations, represents a transition in the brain from a disordered state to an ordered one. The morphology of the ERP waveform is an outcome of the superposition of evoked/event-related oscillations. The "natural frequencies" of the brain that compose these oscillations range from the delta band (0.5–3.5 Hz) to theta (3.5–7 Hz), alpha (8–13 Hz), beta (15–30 Hz), and gamma bands (30–70 Hz). That the oscillations are the basic responses of the brain nowadays finds strong support from a large number of neuroscientists who endeavor to understand the brain and the way it functions in cognition (Bressler and Tognoli 2006; Freeman 2006; Yordanova and Kolev 1998b).

In Haken's *Synergetics* (1977, 2004), the synchrony of oscillators plays a major role in the laser effects used in many applications. In biological systems and especially the brain, on the other hand, the synchronization of clocks plays a crucial role in the realization and control of the integrative functions. Although it is a technical phenomenon in physics, it is an explanatory model in biological systems. Electrocorticograms (EcoG) have a broad-band spectrum; within it, all frequencies are simultaneously present and are separately waxing, waning, and shifting phase (Bullock 1988a, b; Bullock et al. 1990).

There are also clocks that are not synchronized; according to Einstein there are *bad clocks*. Bad clocks are observed in case of pathologies, presented in Chapter 13.

2.7.2 Brownian Motion

Einstein and Infeld (1938) described the tracks of molecules in Brownian motion. However, they did not only describe the tracks, but also analyzed the causes of Brownian motion. In searching for causes of gravitation, Einstein wished to understand the causes of dissipating energy. To establish what is happening in the galactic system, he predicted black holes. Thus he not only used descriptions of the astrophysical events; he also combined the existing knowledge on the motion of stars and considered the laws of physics. With such an approach, he described the nature of stars and the galaxy; thereafter he arrived at the concept of black holes, an existence invisible to conventional observation techniques.

What is Brownian motion? A suspended particle is constantly and randomly bombarded from all sides by the molecules in the liquid. If the particle is very small, the hits it takes from one side will be stronger than the bumps from the other side, which will cause it to jump. These small random jumps make up Brownian motion. The first mathematical theory of Brownian motion was developed by Einstein in 1905 (Einstein and Infeld 1938). Einstein showed that the overall visible motion, averaged over many observations, exactly matches that expected if the little particles were atoms or molecules. Brownian movement exists if the bombarded particles are sufficiently small. It exists because this bombardment, owing to its irregular and haphazard character, is not uniform from all sides and cannot be averaged out. The observed motion is, thus, the result of the unobservable one.

One of the aims of EEG research is try to discover brain functions. Accordingly, the analysis of Brownian motion trajectories initiated by Einstein (Einstein and Infeld 1938) is an excellent theoretical model or metaphor for the brain functions, which is latently present in the puzzling engrams that the EEG-oscillations form. In a number of explanatory formulations (Başar 2006; Begleiter and Porjesz 2006; Bressler and Tognoli 2006; Bullock 2006; Freeman 2006; Galambos 2006), the trajectories of EEG-oscillations are used for discovering their hidden sources (origins). These formulations show the immense usefulness of function-oriented investigation of brain signals for understanding the way the system functions. As Einstein's fundamental model shows, signal analysis alone will never be sufficient.

2.7.3 Unconscious Problem Solving

In describing the way Sir Arthur Conan Doyle's detective Sherlock Holmes solves problems, Einstein pointed out the following:

> The great detective, however, realizes that no further investigation is needed at the moment, and that only pure thinking will show the pattern of relation between the collected facts. So he plays his violin, or lounges in his armchair enjoying a pipe, when suddenly, by Jove, he has it! Not only does he have an explanation for the clues at hand, but he knows that certain other events must have happened. Since he now knows exactly where to look for it, he may go out, if he likes, to collect further confirmation on his theory.

This very important viewpoint is presented in Chapter 20 on unconscious states. Although in the present chapter only the empirically founded facts are analyzed, it is important to emphasize here that Einstein too was interested in the metaphysics of the brain.

2.8 Werner Heisenberg

2.8.1 Microscope Model of Werner Heisenberg

The uncertainty principle in quantum physics was formulated by Werner Heisenberg during the period of the Copenhagen School at the beginning of the twentieth century. To justify the philosophical framework of this principle, Heisenberg developed a model of thought.[5] If one day a microscope with very high resolution could be used, the experimenter would be able to observe the interaction of a gamma ray with an electron in the aperture of the microscope. Heisenberg assumes that at the time the gamma ray, which is used for the illumination of the electrode, would undergo an interaction with the electron, meaning that supplying energy to the electron should change the position of the electron according to the laws of physical motion. When the observer aims to localize the position of the electrode, he or she will certainly fail. The observer would then discern not the exact position of the electron at the moment of collision with the X-ray light, but only the position of the electron following the displacement (Fig. 2.7). No observation is possible without using a gamma light; the exact localization of the electron is impossible by using the light. This model of thought was the subject of discussions after the development of quantum mechanics. Finally, the experimental requirements of Heisenberg were fulfilled and the microscope theory was supported by the experiments of Christopher Foot (1994) and in this way Heisenberg's dream was realized.

[5]Works of Bohr, Schrödinger, Pauli, Dirac, Born, and Weizsäcker.

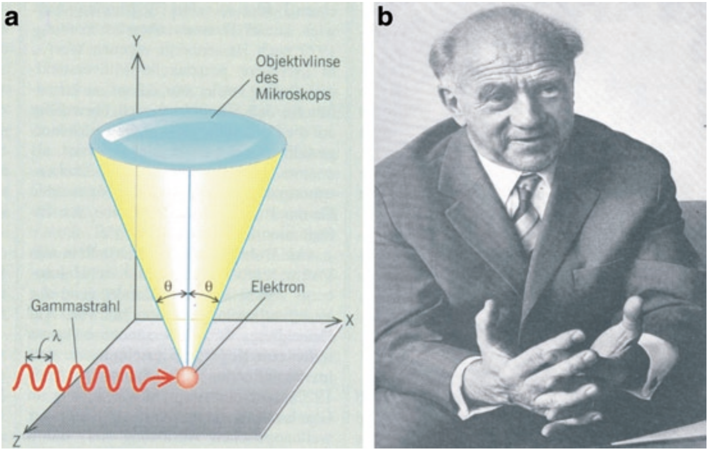
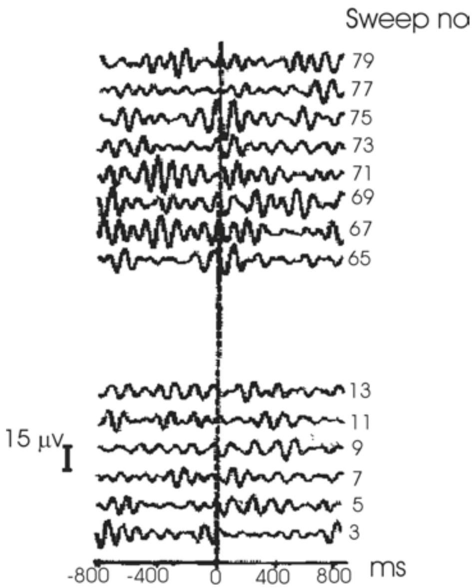


Fig. 2.7 The Gedanken Experiment by Werner Heisenberg: microscope theory

Fig. 2.8 Development of alpha activity on sensory stimulation



Is it possible to translate the uncertainty principle manifested by the microscope thought experiment to brain research? Consider the experimental recording in Fig. 2.8, in which the brain is stimulated by a sequence of peripheral stimulations. The spontaneous activity of the brain incessantly changes. The development of alpha activity with increasing amplitudes has, in turn, an important influence on the alpha responses. The brain is learning and goes from a preliminary state to a learned state. The same situation occurs with the microscope analogy. At the moment of application of the cognitive input, the brain state is changed. Accordingly, it is not possible to determine the exact cognitive response to cognitive inputs or cognitive inputs with emotional components.

The laws of quantum physics are statistical. This means that they are valid not for a single system, but for an aggregation of identical systems. They cannot be confirmed by measurements on one individual, but by a series of repeated measurements from that individual. In Einstein's words, "*Quantum physics formulates laws governing crowds and not individuals. Not properties but probabilities are described.*" (Einstein and Infeld 1938). Laws do not disclose the future of systems, but govern the temporal changes in these probabilities. In quantum physics, laws are valid for a great congregation of individuals. Similarly, laws concerning the brain specifically in cognitive processing are valid not for single neurons, but for neural populations. What applies to quantum mechanics also applies to the dynamics of chaotic systems. In such systems also, not properties but probabilities are described, laws disclose the change of the probabilities over time, and they are valid for congregations of individuals (see also Chapter 16 and 24).

2.9 Boltzmann's Statistical Mechanics

2.9.1 Statistical Mechanics in Biology and Physics from Griffith's Perspective (1971)

Griffith (1971) discussed concepts of *statistical neuron-dynamics* and tried to formulate the similarity between *statistical mechanics* and *neurodynamics* as follows:

The situation is superficially very similar to that which is obtained in statistical mechanics, as it applies to the relation between macroscopic thermodynamic quantities and the underlying microscopic description in terms of the complete specification of the states of all the individual atoms or molecules,… These are, firstly, that we could not, even if we knew all the necessary parameters, actually solve in detail the 10^{10} or more coupled neuronal "equations of motion" necessary to follow the state of the system in detail as a function of time. Secondly, that there exists a simpler "macroscopic" level of description which is really our main ultimate object of interest so that we do not wish, even if we could, to follow the "microscopic" state in detail but merely wish to use it to understand the time development of the macroscopic state. One most important aspect of this is that we only wish to specify, at the macroscopic level, the initial conditions of any calculation we may make. This leads immediately to the problem of whether the fundamental assumptions of equal a priori probabilities and random a priori phases hold for nerve cell aggregates, and, if not, whether we can find anything to replace them (Griffith 1971).

Griffith's remarks are more important today than they were 30 years ago because new trends or avenues in brain research clearly indicated the need to introduce new frameworks to analyze the integrative brain function by introducing *cell aggregates instead of single cells.*

2.9.2 Global Neurodynamics: The View of Rosen (1969)

A similar problem statement was created by Rosen (1969) asking the following question: "*What is the role of statistical mechanics in gas dynamics?*" The gas laws that describe gas dynamics are based on the ensemble of molecules in an isolated system. One does not describe gas dynamics with the dynamics of single molecules in an isolated system. However, after the laws are experimentally determined, one tries to correlate the macro-system laws with dynamics in the micro-level, i.e., with gas molecules. In other words, the laws of gas dynamics were determined before these laws were exactly correlated with molecular properties. This is a complementary explanation to Griffith's problem.

Başar (1980, 1998) commented on the questions of Rosen and Griffith as follows:

> In the analysis of brain waves we are certainly interested to discover the particular properties of individual neurons and their relation to the gross activity. To further examine the problem of the correlation between single unit activity (micro-activity) and gross activity (macro-activity).

Rosen (1969) explained the concepts of statistical mechanics and physics and their relation to Neurobiology as follows:

> What is the micro-description? We know, that here, the fundamental state variables are the displacements and momenta of the individual particles which make up our system. According to Newtonian dynamics, the kinetic properties of the system are given by the equations of motion of the system, which express the momenta as functions of the state variables.

The basic postulates of "Newtonian Dynamics" are the following point: Knowing the state variables at one instant and the equations of motion, we are supposed to be able to answer any meaningful question that can be asked about the system at any level. Statistical mechanics however, identifies a macro-state with a class of underlying microstates, and then expresses the global state variables as averages of appropriately chosen micro-observables over the corresponding class of microstates.

2.10 Santiago Ramon Y Cajal

In the twentieth century a great amount of research suggests that it is possible to understand the functioning of the brain once there is sufficient explanation for the specific functions of individual nerve cells and their connections. The transformation of neural information and its storage as memory involve only nerve cells and their interconnections.

However, at the end of the nineteenth century it was generally believed that the brain is made up of a continuous net of nerve tissue, a "reticular network" or "syncytium." The first morphological studies of the nervous system were done by the Spanish anatomist Santiago Ramon y Cajal. He proposed that the functions of the brain could be understood by analyzing the functional architecture of the nervous system. Applying Golgi's silver staining technique to the study of nerve tissue, he observed that only some cells are stained in their entirety. This led to his formulation of the "neuron doctrine," which states that the brain is made up of discrete units rather than a continuous net of nerve tissue or "syncytium," as was originally thought. He proposed that nerve impulses travel from the dendrites of a neuron to its cell body and then along the axon to the dendrites of the neighboring neuron. This flow of information would be a finite process.

The neuron is a transmitter, because it converts the conducted electrical signals into chemical messages and then conveys or "transmits" them from one neuron to a neighboring neuron. Neurons are connected at specialized contact points called *synapses*. English physiologist Charles Sherrington (1861–1952) worked out the details of the reflex arc in the spinal cord of mammals (*The Integrative Action of the Nervous System* 1906). Although the book of Sherrington was republished in 1948, it is noteworthy that he did not include memory and cognitive functions in the integrated action of the nervous system.

2.11 Hans Berger and Electroencephalography

Hans Berger's discovery of EEG dominates several parts of the book. Here, we add only the handwriting of Hans Berger related to encephalography. Figure 2.10 is self-explanatory (Fig. 2.9).

Fig. 2.9 Ramon y Cajal

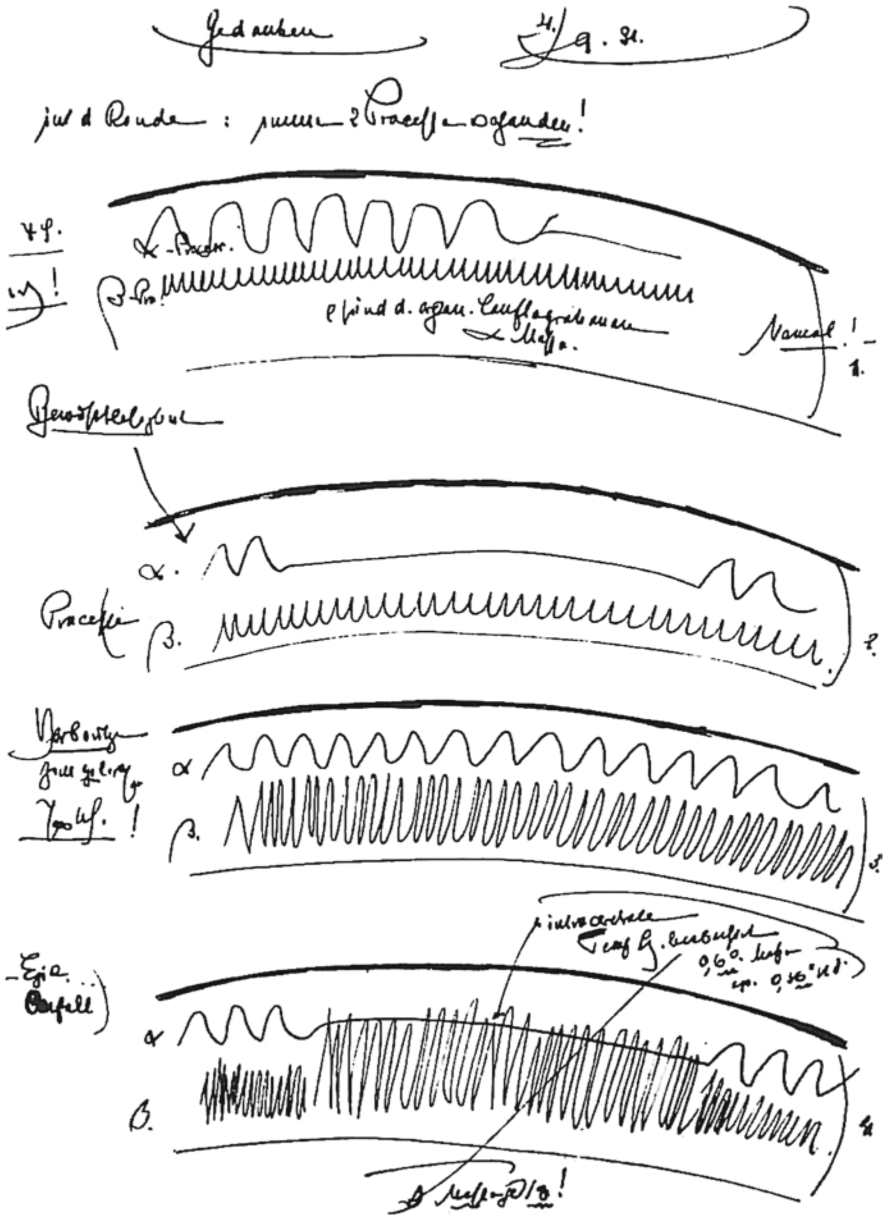


Fig. 2.10 Facsimile page from Berger's protocol giving his concept of the alpha- and beta-wave processes in normal and certain pathological conditions. Berger's handwriting is a mixture of normal German and a special form of shorthand. In English translation: "Thoughts 21/9/31. In the cortex: Always 2 processes present! (1) ψϕ. Psychophysical, Alpha-process. Nutrition! Beta-process. That is the organ. Conflagration of Mosso. Normal! (2). Unconsciousness. Process Alpha. Beta. (3). Preparation for epileptic seizure. Aura! Alpha. Beta. (4). Epileptic seizure. Alpha. Beta. Intracerebral temperature increase measured 0.6°, Mosso 0.36° in the human. According to Mosso, not always, however." (from Jung. Jenenser EEG symposium, 30 Jahre Elektro-enzephalografie, p. 47, 1963. Courtesy of VEB Verlag Volk und Gesundheit)

2.12 Hebb, Hayek, and Helmholtz

In the first half of the twentieth century two important books introduced outstanding holistic and dynamic approaches to brain functioning, Donald Hebb's book (1949) related to the organization of behavior inspired several neuroscientists in search of the "Hebb neuron." Speculations on the existence of the Hebb neuron and Hebb's theory are explained in Chapters 7 and 8. According to Hebb, the functioning of the brain after learning is a different brain compared with the same brain before the learning process.

Although Friedrich Hayek developed his theory of "theoretical psychology" almost 20 years before the publication of Hebb's book, Hayek's book was published much later (1952). The chain of ideas developed in this theory is highly pertinent to the dynamic nature of the living brain. Hayek states:

> We shall see that the mental and the physical word are in the sense two different orders in which the same element can be arranged; though ultimately we shall recognize the mental order as part of the physical order.

Hayek argues that it is the whole history of the organism that determines its action. New factors contribute to this determination on later occasions that were not present at first. This idea is much better explained in the following sentence: "We shall find out that the same set of external stimuli will not always produce the same responses, but also that altogether new responses will occur" (compare also Fig. 2.8). Here is a dynamic interpretation of brain responsiveness similar to the statement made by the Ionian philosopher Heraclites: "One never can step twice into the same river." One of Hayek's most important statements is related to perception and memory in that they are inseparable functions. This view later received excellent support from Fuster, Baddeley, Desimone, and Başar. Therefore, perception is always an interpretation, the placing of something into one of several classes of objects. An event of an entirely new kind, which has never occurred before and sets up impulses that arrive in the brain for the first time could not be perceived at all.

Here it is important to emphasize the parallels with the theories of Hebb and Hayek. The brain that is learning or is targeted by several stimuli; accordingly it will be changed both physiologically and anatomically. According to Hebb, there are changes in the connectivity of neurons in the learning brain, thus changing both the anatomical structure as well as the electrical activity. Hebb and Hayek both discussed the dynamic brain.

Although neither of these scientists mentioned structural and entropy changes during learning, it is clear that the concept of altered entropy exists in both scientists' theories. This central question is discussed in Chapter 17. Although theoreticians such as Prigogine and Wiener took advantage of Hayek and Hebb's biological models, they did not find an important bridge between neural connectivity and changes in the entropy of the learning brain. Chapter 7 attempts to create this bridge.

Hayek asks, "What is mind?" and he discusses the relation between mind and body or mental and physical events. The difficulty of any fruitful discussion of the body-mind problem consists largely in differentiating what part of our knowledge can properly be described as knowledge of mental events, as distinguished from our knowledge of physical events. After discussing physical events, the physiological responses to physical events, Hayek comes to the following definition: What we call "mind" is a particular order of a set of events taking place in some organism and some manner related but not identical to the physical order of events in the environment.

Hayek considers the nervous system an instrument of classification. He classifies emotion as a special type of disposition for a type of action, which in the first instance is not necessitated by a primary change in the state of the organism, but which consists of complexes of responses appropriate to a variety of environmental conditions. Fear, anger, sorrow, and joy are attitudes toward the environment, and particularly toward fellow members of the same species. This means that a great variety of external events, and also some condition of the organism itself, may evoke one of several patterns of attitudes or dispositions that will affect the perception of, and the responses to, any external event. Emotions may thus be described as "affective qualities similar to the sensory qualities and forming part of the same comprehensive order of mental qualities."

According to Hayek, the term *experience* is related to memory; however, it is a plastic memory. If stimuli are applied to the central nervous system, then this system gains a type of experience. However, when the same stimuli occur again, they have special significance for the organism, even though not having any meaning for the individual. Hayek proposes that we must distinguish between two different kinds of physiological "memory" or traces left behind by the action of any stimulus. One is the semi-permanent change in the structure of connections or paths, which determines the courses through which any change of impulses can run (similar to Hebb's principle). The other is the pattern of active impulses proceeding at any moment as results of a stimulus received in the recent past, and perceived also as merely part of continuous flow of impulses of central origin, which never cease altogether, even when no external stimuli are received. At this point the reader is referred to Chapters 7 and 8, which discuss memory.

Hayek's most important conclusion on the evaluation of impulses from the organism is that it is the whole story of the organism that determines its action. New factors contribute to this determination on the later occasion that were not present on the first: "We shall find not only the same set of external stimuli will not always produce the same responses, but also that altogether new responses will occur." This is similar to the coordinated movement of the organism, which is not determined by the movement of an individual muscle, but to the whole complex of body muscles.

Chapters 15 and 16 introduce the Brain S-matrix, which takes into account the whole history of the organism. Hayek does not comment on the S-matrix, but this concept includes the application of the S-matrix, which includes the history of whole brain-body organism.

Hayek explains perception as an interpretation or the placing of something into one or several classes of objects. An entirely new kind of event, which has never

Fig. 2.11 Hayek (May 8, 1899–March 23, 1992)

occurred before, and which sets up impulses that arrive in the brain for the first time could not be perceived at all. This explanation is in accordance with Helmholtz’s opinion with regard to perception.

Helmholtz puts the emphasis on the effect of experience in determining sensory qualities, and he goes far beyond ascribing to experience the creation of their spatial order. It is today widely recognized that “the manner in which we see things of the external world is sometimes affected by experience to an overwhelming extent” and that “it is often difficult to decide, which of our visual experiences are determined immediately by sensation and which, on the contrary, are determined by experience and practice.” His conception of the “unconscious inference” by which stimuli that do not lead to conscious experience and yet are utilized in the perception of a complex position comes very close to the theory developed here.

Chapters 7 and 8 contain descriptions of the phyletic memory, which is very well described by Fuster (1995a) and later by Başar (2004): every sensation, even the “purest” must therefore be regarded as an interpretation of an event in the light of the past experience of the individual or the species.

Hayek’s conclusion is that the mind must remain forever in a realm of its own, in which we can now only directly experience it, but which we shall never be able fully to explain or “reduce” to something else. Even though we may indicate that the mental event of the kind that we experience can be produced by the same forces that operate in the rest of nature, we shall never be able to say which particular physical events “correspond” to a particular mental event (In Fig. 3 is a picture of Hayek).

2.13 Jacques Monod: “The Chance and the Necessity” (1971)

Monod actually begins by showing that the difference between natural and artificial things is illusory, as natural things are also built for a purpose. Living beings are characterized by three properties: teleonomy (organisms are endowed with a purpose that is inherent in their structure and determines their behavior); autonomous morphogenesis (the structure of a living organism is a result of interactions within the organism itself); and reproductive invariance (the source of information expressed in a living organism is another structurally identical object; it is the information corresponding to its own structure).

From his analysis of how DNA and proteins work, Monod concludes that humans are the product of *chance*, *an accident in the universe*. The paradox of DNA is that a mono-dimensional structure such as the *genome* could specify the function of a three-dimensional structure such as the body. The function of a protein is underspecified in the code; it is the environment that determines a unique interpretation. There is no causal connection between the syntactic (genetic) information and the semantic (phenotypic) information that results from it. Then the growth of our body, the spontaneous and autonomous morphogenesis, rests on the properties of proteins. Monod concludes that life was born by accident, and then evolved by natural selection, as discovered by Darwin. Biological information is inherently determined by chance. The concept developed by Monod is discussed in detail in Chapter 17.

2.14 Otto Loewi and the Discovery of Acetylcholine

One of the most important developments at the beginning of twentieth century is the experiment of Loewi leading to discovery of acetylcholine. The role of transmitters in the understanding of the mind is crucial, and what Loewi has achieved is one of the most important discoveries in brain research (Fig. 2.12).

In his most famous experiment, Otto Loewi took fluid from one frog heart and applied it to another, slowing the second heart and showing that synaptic signaling used chemical messengers. He called the chemical Vagusstoff. It was later found that this chemical corresponded to acetylcholine. We return to this important discovery in Chapters 3, 13, 22, and 24.

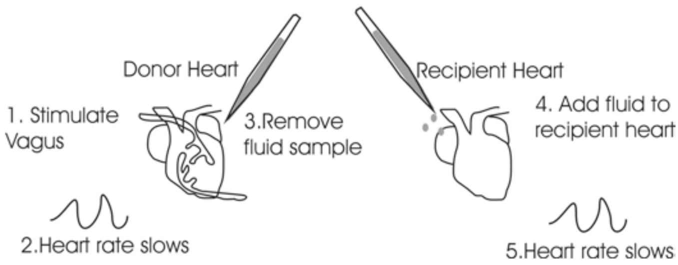


Fig. 2.12 Experiment of Otto Loewi

2.15 A Synthesis from the Concepts of Wiener, Prigogine, Thom, and Haken

These four philosopher-scientists strongly emphasized some common features in interdisciplinary sciences. They carefully analyzed the following ideas: the concepts of order and disorder, the second law of thermodynamics, entropy, and nonlinear phenomena. The energy input in lasers induces the transition of oscillating atoms from a disordered to an ordered state similar to the brain oscillations on sensory stimulation. Prigogine stated that according to the second law of thermodynamics, the emergence of ordered states in the creation of life is improbable. Wiener already mentioned the role of a Maxwell Demon in living processes. As seen in Chapter 17, Monod also emphasized the importance of the Maxwell Demon in the creation of life. These frameworks also have a common general frame. All of these scientists started from physical, mathematical, or chemical metaphors by trying to identify common abstract mechanisms or symbols to create new interdisciplinary sciences. Unfortunately, none of these frameworks have their origin in biological empiricism. One essential biological framework is Darwin's evolution theory, in which "natural selection" plays a major role. However, in turn a selection needs a type of transition for moving a new order. Wiener, Prigogine, Thom, and Haken also mention the importance of non-linear phenomena; and deterministic chaos is related to this. According to these philosopher-scientists, new branches of sciences must deal with the second law of thermodynamics, equilibrium, feedback mechanisms, and communication and information processes.

With a profound approach to the phenomena analyzed in these frameworks and by amalgamating these trends with Bergson's concept of creative evolution processes, we will develop the idea of launching a new framework, or a new Cartesian system. The scope of the present book and the aim in launching a new Cartesian system consists of a synthesis of the excellent ideas governing these described frameworks in the twentieth century. The present author has worked with these four frameworks, so as to launch the EEG-brain dynamics[6] concept, which is now the prevailing approach in publications from a number of neuroscience laboratories. Therefore, the aim here is not to deny the importance of existing frameworks, but to enlarge them and also incorporate the philosophical schools following Renaissance, quantum physics, and the new results in chaotic brain dynamics. The Cartesian system of the twenty-first century is not intended to discover final solutions, but to raise questions that could be answered with the help of many experiments and scientists. This system will provide a working branch, as in Wiener's cybernetics, and have the additional possible advantage of collecting experiences from existing frameworks.

Figure 2.13 illustrates, globally, the evolution of philosophy and sciences from old Athens and the Renaissance to the development of physics and the new contemporary unifying schools. In the twentieth century cybernetics, quantum

[6]Definition of dynamics.

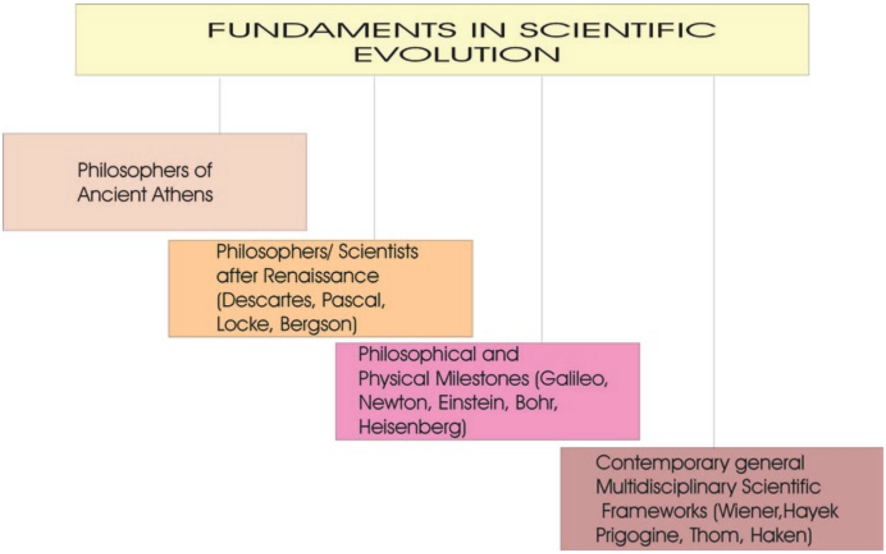


Fig. 2.13 Some fundamental approaches during the evolution of science (compare with Fig. 26.1)

theory, chaos theory, dissipative structures, and synergetics provided essential steps along the way to the branch that we call brain dynamics. By application of the concepts and methods of the mentioned schools, scientists have collected vast empirical data to approach brain-body-mind integration. Furthermore, the application of these various concepts and the rich amount of data collected should serve to find new types of evaluations closer to the language of the brain and the understanding of the brain-mind by developing new approaches. These possibilities are outlined in Chapters 14, 15, 16, 23, 24, 25 and 26.