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CHAPTER V

Natural History and Physiology

This chapter is about the world of living things. It could be called a chapter on biology, except for the fact that *biology,* as a word and as a discipline, did not appear until the very end of the eighteenth century. To see the world the way the men and women of the Enlightment saw it, we have to see it through the eyes of natural history. "Natural history" means an inquiry or investigation into nature; and "nature," in the Aristotelian sense, means that part of the physical world that is formed and that functions without the artifice of man. A growing tree and a falling rock are both part of "nature" because they move and grow without human direction. Natural history, then, covers the entire range of observable forms from minerals to man, excluding only those objects crafted by human hands and intelligence. Its method is descriptive, and its scope is encyclopedic. Francis Bacon called it the "great root and mother" of all the sciences and made it the indispensable prelude to his experimental philosophy.

In spite of its enormous scope, natural history did not treat all questions about living things. The purpose of natural history was to describe and classify the forms of nature; it did not include a search for causes. Both plant and animal physiology – that is, the investigation of plant and animal functions as opposed to their forms – were still part of physics. When the Paris Academy of Sciences was reorganized in 1699, the sections that dealt specifically with living beings were the descriptive sciences of botany and anatomy. Any experimental physiology that took place was done in the physics section. In the *Encyclopédie,* all history, including natural history, was classified under the faculty of memory; physics, which included zoology, botany, and medicine, was classified under the faculty of reason. Natural history and physiology were separated by the different methods that they followed and by the different goals that they pursued.

Medical doctors dominated the study of living things because they were the only ones to receive formal instruction on such matters. All members of the botany and anatomy sections of the French Academy were doctors. The naturalists Joseph Pitton de Tournefort (1656–1708), Antoine de Jussieu (1686–1758), and Carl Linnaeus (1707–78) were also medical men. So were Bernard de Jussieu, Hermann Boerhaave, and Georg Stahl, whose names we have already encountered in the chapters on experimental physics and chemistry. In the eighteenth century, however, medical training did not lead inevitably to medical practice. Botany, in particular, was a subject that was beginning to be pursued for its own sake, independent of the needs of pharmacy. Just as medicine was losing its dominance over chemistry in the eighteenth century, so did it lose its dominance over physiology and natural history.

As the century progressed, more of the major contributors to natural history and physiology were persons without medical training. The most striking example is in chemistry. Stephen Hales, Joseph Priestley, and Antoine Lavoisier, while they were bringing about a revolution in chemistry, also clarified the functions of respiration, animal heat, and the relationship between plants and the atmosphere. None of these men were doctors, nor were Charles Bonnet, Abraham Trembley, René de Réaumur, Comte de Buffon, Lazzaro Spallanzani, and Jean Lamarck, whose names will figure prominently in this chapter. (The situation in Scotland was different: William Cullen and Joseph Black were professors of both medicine and chemistry.) Through the academies of science it was possible to obtain positions of status without medical training, and as a result natural history and physiology were no longer the exclusive province of doctors or limited to the subject matter of medicine.

The Mechanical Philosophy and the Study of Life

Descartes had concluded in 1638 that with the exception of the human rational soul all natural objects were caused by inert particles of matter in motion. There was, for him, no basic difference between one's watch and one's pet dog. Of course not all mechanical philosophers were so extreme in their views; most were unwilling to carry their principles this far. Robert Boyle, for instance, distinguished between the watch as a work of man and the dog as a work of God, but nevertheless he retained the same mechanical view of nature as Decartes. From this point of view there was no essential difference between living and nonliving objects. Animals were automata; some philosophers even attempted to build robots that would simulate vital functions. The mechanical philosophy swept physiology in the wake of Descartes, so that by 1670 all major physiologists were mechanists. The *De motu animalium* [*On the motion of animals*] (1676), by Giovanni Alfonso Borelli (1608–78), is the most famous example. Borelli analyzed the mechanics of the muscles and skeleton of the human body and tried to explain muscular contraction as a hydraulic or mechanical inflation of the tissue (see Figure 5.1). He also measured the force of muscle, with special attention to digestion in the stomach, which he believed to be primarily a crushing and grinding process.

The mechanical philosophy was seductive, but it could explain vital phenomena such as growth, nutrition, and reproduction only by resorting to the most outlandish hypotheses, none of which was confirmable by experiment. During the first half of the eighteenth century this easy optimism waned, and physiologists realized that a mechanical analysis of living things might be impossible. In 1733 Bernard Fontenelle stated that mathematics certainly did apply to living things but had been unsuccessful in explaining how they functioned because of their great complexity. Life may be merely the result of mechanical organization, but if so it is beyond the reach of investigation. A better alternative would be to study the vital phenomena themselves and attempt to reduce them to rule, without any suppositions about original causes or imagined mechanisms. As a result, experimental physiology in the eighteenth century became phenomenalistic. Experimenters described and linked vital phenomena to the best of their ability without attempting mechanical models.

Natural history experienced a rebirth in the late seventeenth century at the time when the mechanical philosophy was most strongly held. There were several reasons for the new enthusiasm for natural history. One was religious. The mechanical philosophy recognized a creator God but denied him any role in everyday operations of the universe. Therefore God could be known in nature not from any acts but only from the extraordinary complexity and harmony of his creation. Natural history described this complexity in great detail.

From the beginning of the eighteenth century, English natural philosophers published a continuous stream of books designed to reveal the wonders of God's creation through the new sciences. The *Cosmologia sacra* [*Sacred cosmology*] (1701) of the microscopist and plant physiologist Nehemiah Grew (1641–1712) was followed

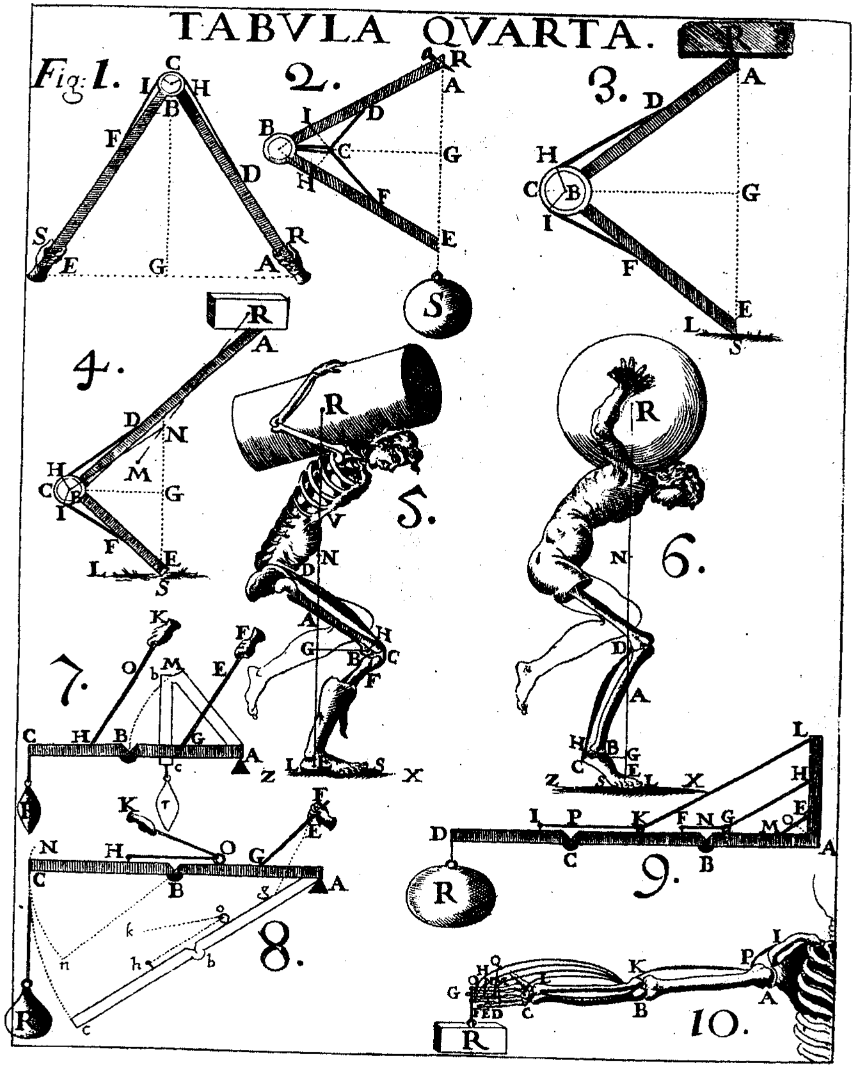


Fig. 5.1. Physiology as mechanical philosophy. G. A. Borelli, in his *De motu animalium* [*On the motion of animals*] (1680) studied the human body as a machine. The mechanical philosophy could explain the action of the bones and muscles in the limbs, and it could explain the action of the heart, but beyond these most obvious mechanical functions it failed to explain the vital functions of the human body. *Sources:* G. A. Borelli, *De motu animalium* (1680). By permission of the Syndics of Cambridge University Library.

in 1704 by John Ray's *The wisdom of God manifested in the works of the creation.* Ray (1627–1705) was the leader of the natural history revival in England and the best naturalist of his age. There was nothing frivolous or shallow about the science that he brought to the revelation of God. The following year, George Cheyne (1671–1743) published his *Philosophical principles of religion natural and revealed,* and in 1713 William Derham (1657–1735) published *Physico-theology, or a demonstration of the being and attributes of God from his works of creation* (see Figure 5.2). *Physico-theology* gave the name to this genre of natural history, and Derham soon followed it with an *Astro-theology.* Ray's *Wisdom of God* went through six editions in ten years, and Derham's *Physico-theology* had three London editiôns in one year and five French editions. The enthusiasm for physico-theology reached the Continent in the 1720s, where the most prominent contribution was the enormously popular *Le spectacle de la nature* [*Spectacle of nature*] of Noël-Antoine Pluche (1688–1761), which began to be published in 1732 and reached its eighth volume in 1750. In France, natural theology declined after 1750 as a result of the antireligious sentiment of the Enlightenment, but in England it continued well into the nineteenth century, where it finally encountered its nemesis in Charles Darwin (1809–82).

A second reason for the success of natural history was a desire to get rid of the animistic "principles" and "souls" that had characterized Renaissance science. Natural history described and classified all three kingdoms of nature – animal, vegetable, and mineral. As a science of forms and categories, it did not have to concern itself with the causes of life and therefore could easily include living and nonliving things within the same schema. Natural history was a complement to the mechanical philosophy, because both approaches to the natural world merged the living and the nonliving together. There was no room in either approach for spirits other than the human rational soul. This characteristic of natural history in the early Enlightenment has led several modern philosophers and historians, especially Michel Foucault, to state that there could be no science of biology before 1750 because there was no understanding of life separate from the nonliving world. Because modern biology attempts to explain life in physical-chemical terms, we may be tempted to think of the mechanists of the seventeenth and eighteenth centuries as precursors of the modern view. In fact the creation of biology as a separate discipline came only after a strong reaction against the mechanical philosophy had separated the study of living things from inanimate nature and had explained "life" by principles that did not apply to the inanimate world.

A third reason for the rise of natural history in the 1670s was the increased emphasis, especially in England, on the empirical sciences. Without repudiating the mechanical philosophy, British philosophers and scientists did repudiate Descartes's rationalist, a priori approach to the study of nature. The world is known from careful observation and study of natural phenomena, not from deductive reasoning on abstract principles. It is no coincidence that natural history revived first in England, where the experimental tradition was the strongest, and only then passed on to the Continent.

Experimental Physiology

The rise of experimental physiology in the 1740s coincided with the appearance of the theory of subtle fluids in experimental physics and chemistry. Just as chemistry turned from theories based on attractions and repulsions between the atoms to a study of the chemical properties of acidity, alkalinity, and metallicity, so physiology turned from the description of the body's organs as levers, pulleys, pumps, and sieves to an investigation of those characteristics such as growth, nutrition, and regeneration that make living

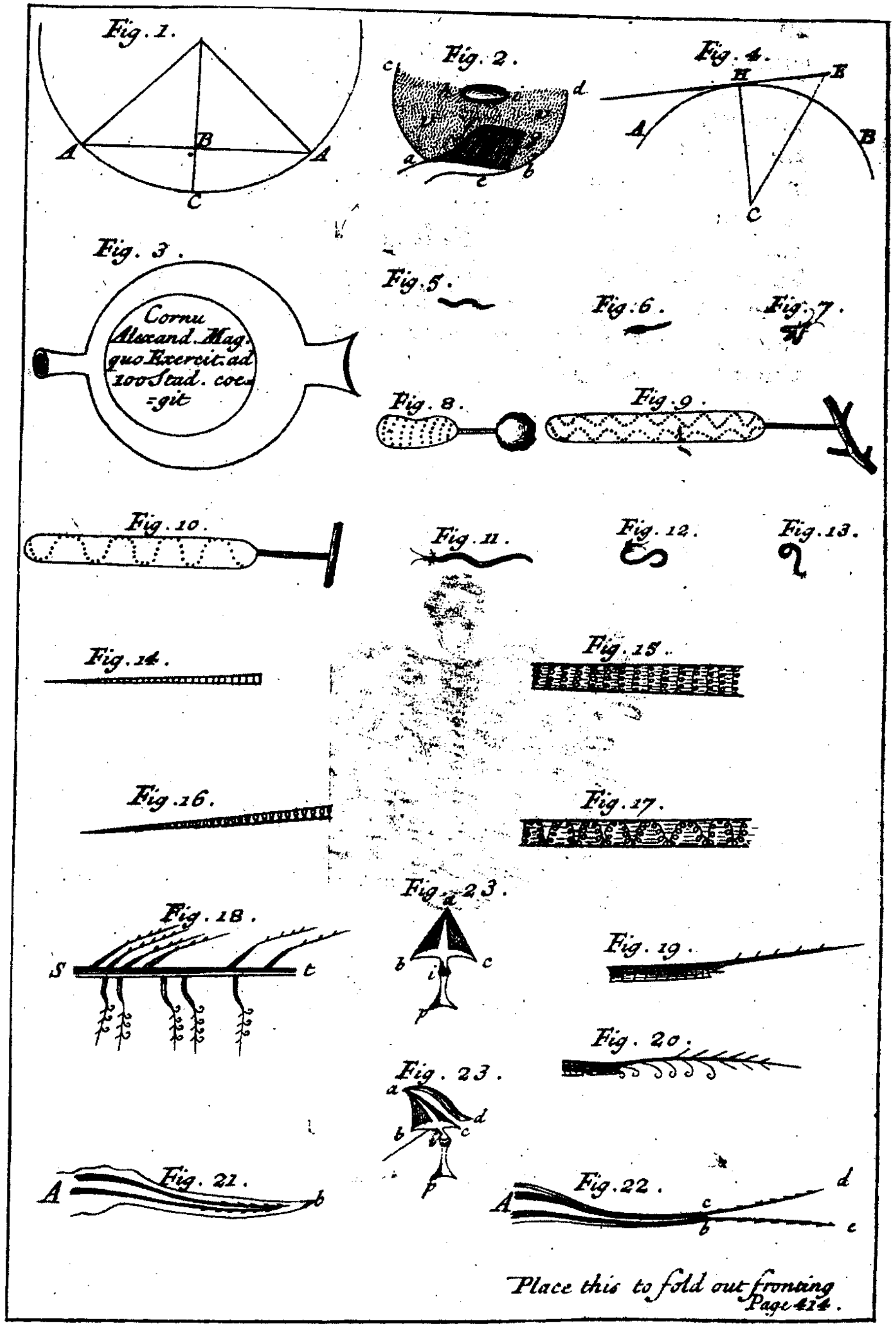


Fig. 5.2. Examples of God's design. William Derham, in his *Physico-theology, or a demonstration of the being and attributes of God from his works of creation* (1713) selected these "contrivances" to illustrate God's wisdom. Derham was especially impressed by the clothing of animals. God created man naked because man was endowed with the faculty of reason, which meant that he would be able to help himself, "but for the poor shiftless Irrationals, it is a prodigious Act of the Great Creator's Indulgence, that they are already furnished with such clothing as is proper to their Place and Business." Figures 14 through 17 depict the appearance of mouse hair, as seen under a microscope. Derham thought that the spiral lines on the hairs might aid the "insensible perspiration" of the mouse. Figures 18 through 20 are microscopic views of bird feathers. God has designed them so that they will interlock and grasp each other, thereby giving the birds "an easy Passage through the Air" and assist "in wafting their Body through that thin Medium." Figures 21 and 22 show the stinger of a wasp, "so pretty a piece of Work, that it is worth taking Notice of," and Figure 23 shows the inner ear of a bird. All of these contrivances reveal God's concern for the welfare of his creatures and prove his wisdom and beneficence. *Sources:* William Derham, *Physico-theology: or, A demonstration of the being and attributes of God, from his works of creation,* 2d ed. (London, 1714), p. 414. Courtesy of the Rare Book Collection, Special Collections Division, University of Washington Libraries.

things different from machines. Before 1740, the standard authorities in physiology were Giovanni Borelli, Lorenzo Bellini (1643–1704), Archibald Pitcairne (1652–1713), and James Keill (1673–1719) – all mechanists – and the mechanist Boerhaave was the major authority in chemistry. After the middle of the century, the Germans Stahl, Friedrich Hoffmann (1660–1742), and Albrecht von Haller became the major authorities in physiology, and Stahl, Etienne Geoffroy (1672–1731), and Joseph Macquer were the major authorities in chemistry. It is tempting to describe this shift as a change from mechanism to vitalism, but creating such absolute dichotomies in the history of science always gets us into trouble, because it ignores the middle ground and the fact that most scientists are more interested in their experimental results than in global theories such as mechanism and vitalism. The comparison to chemistry is again helpful. The new principles in chemistry and physiology were meant to stand for observable qualities, not for the old imagined "souls" or "influences" of Renaissance animism. When vitalism revived around 1760, it was in a strictly experimental context. The failure of mechanical theories made physiology more phenomenalistic.

James Parsons (1705–70) noted in 1752 that mechanical philosophers had sought in vain for "Particles and Pores of different configurations, in vain had Recourse to the *Momentum* of the Blood and in vain endeavoured to reconcile the Doctrine of Secretions to Mathematical Calculation,"[1] and at the same time Diderot argued that the taste of the times had turned to chemistry and physiology because those sciences dealt with nature as it existed, rather than with nature as a mechanical and mathematical abstraction.

Of course the new science of experimental physics and chemistry had a direct influence on physiology and medicine. Electricity promised to hold answers for physiology. The electric eel and the sensitive plant were candidates for study because they both appeared to protect themselves electrically. Electricians in England, France, and Germany concluded from their experiments that electrified seeds germinated faster, that electrified plants sent out shoots earlier, and that electrified animals were slightly lighter than nonelectrified ones. The electric torpedo fish, the electric eel of the Guianas, and the electric catfish of Africa were all studied to discover the source of their electricity. It was difficult to explain how these animals could produce shocks while immersed in a conducting medium, but Henry Cavendish showed that given large enough capacitance a shock could be delivered under water. He even built a model torpedo fish out of leather attached to a large Leyden jar to prove his point.

Electricity produced muscle contractions, which indicated that electricity in the body probably took the form of a fluid that moved through the nerves carrying sense stimuli and motor commands. But the failure of the earlier mechanical theories urged caution, and Haller, the leading physiologist at mid-century, argued that it would be premature to identify the electrical material with animal spirits. Haller's caution was wise, because experimental technique in the eighteenth century was totally incapable of revealing the electrochemical nature of nerve impulses. Medical doctors, however, were soon using electrical therapy with apparent success. It is not surprising, then, that Luigi Galvani (as we saw in Chapter IV) believed that his frogs' legs contained within them organic Leyden jars that caused the legs to kick when they discharged. The complexity of electrical phenomena in physiology put them beyond the reach of eighteenth-century experimenters, but it is significant that they attempted to apply the results of physical experiments in the world of living things.

The chemists had greater success than the electricians in bringing their skills to the aid of physiology. They could not answer the most important chemical questions such as those concerning the nature of digestion, but their achievements in pneumatic chemistry clarified the relationship between plants and the atmosphere and the production of animal heat. Nehemiah Grew and Marcello Malpighi (1628–94) had both observed pores (stomata) in the underside of leaves and had concluded that leaves used them either to take in air or to exude sap. Earlier in the century Johannes van Helmont had performed a famous experiment in which he grew a willow tree in a carefully weighed amount of soil. Since very little if any soil was consumed, he concluded that the increased matter of the tree came from the water that he had regularly added to the soil. Stephen Hales, that intrepid searcher for air, placed a peppermint plant over water under a glass cylinder and discovered that some air seemed to be consumed by the plant, while Priestley, who knew that air came in different varieties, found in 1772 that a mint plant would revivify air in which it was grown. The experiments were difficult to duplicate because Preistley did not fully recognize the importance of light for the action of the leaves and because he did not believe that the scummy "green matter" (algae) that covered the inside of his glass vessels was also a plant. He did, however, collect some bubbles from the leaves in 1778 and found the air to be "dephlogisticated air" (oxygen). Most important, from his point of view, was the discovery that plants are responsible for revivifying the air that combustion and the respiration of animals are constantly polluting with phlogiston. This aerial balance between plants and animals was to him another example of the harmony of God's creation.

Priestley's successes inspired the Dutch physiologist Jan Ingen-Housz (1730–99) to take up the problem. Ingen-Housz was able to show in his *Experiments on vegetables* (1779) that it was sunlight, not heat, that was essential for the production of oxygen by the leaves. He found that in the dark the leaves reversed this process and emitted small quantities of "fixed air" (carbon dioxide), whereas in sunlight they produced large quantities of oxygen. He observed that only the green parts of plants produced oxygen and that it was emitted from the underside of the leaves. These experiments were done by placing the plant entirely under water but still in sunlight and observing the bubbles of oxygen appearing on the underside of the leaves. Ingen-Housz did find, however, that the leaves had to be placed in fresh pump water, not boiled water, in order to have any oxygen released. He interpreted this experiment to mean that the boiled water absorbed the oxygen from the leaves whereas the pump water, which was already saturated with oxygen, allowed it to escape to the surface.

Jean Senébier (1742–1809) found that Ingen-Housz's explanation could not be correct because atmospheric air was not readily soluble in water. "Fixed air," however was highly soluble in water. Even though fixed air made up only a small fraction of the atmosphere, there was enough of it dissolved in pump water to supply the leaves, whereas boiled water contained little fixed air. Senébier showed that in sunlight the leaves absorbed fixed air and emitted oxygen.

Senébier also showed that it was not necessary to have the entire plant in order to produce oxygen. Just the green leaves, or even chopped leaves, would convert fixed air into oxygen. He even dissected the leaf further and found that it was the green interior of the leaf, the parenchyma, that was responsible for the production of oxygen. This description of Senébier's efforts is anachronistic, in that Senébier interpreted the conversion in terms of phlogiston. But Claude Berthollet soon explained Senébier's results according to the oxygen theory (1788).

Nicolas Théodore de Saussure (1767–1845) amplified the theory in much greater detail. He showed that water was a nutrient of plants and not just a carrier of other nutrients. He also showed that plants can survive in a vacuum and in an atmosphere of nitrogen by secreting small amounts of fixed air and oxygen. If these essential gases are removed, however, the plants die. He found that plants grow better in an atmosphere rich in fixed air, up to a concentration of approximately 8 percent, but that in higher concentrations the plant cannot function. And, most surprising of all, he found that even though plants can grow in an atmosphere that is mostly nitrogen, the nitrogen that they absorb comes from the soil. The realization that "airs" are chemical substances, that they can become "fixed" in plants, and that the atmosphere is a mixture of such "airs" were all essential for an understanding of plant nutrition.

Digestion was another physiological process that appeared to be chemical. Borelli and the iatromechanists (those who tried to explain living things mechanically) postulated that digestion was a grinding and crushing process and found some confirmation from crushed objects found in the gizzards of fowl, but most physiologists believed that digestion was chemical. Van Helmont had proposed an *archaeus* in the stomach that he believed to be the innermost essence of life and that acted by fermentation. In fact he hypothesized six digestions or "concoctions," all stages in the conversion of food into living flesh.

Eighteenth-century physiologists put aside the *archei* and attempted to do experiments directly on the digestive fluids. Regnier de Graaf (1641–73) had investigated pancreatic juices with limited success. Réaumur had persuaded a chicken to swallow a sponge on the end of a string, which he could then retrieve to obtain a sample of the gastric juices. He also had a pet kite (a kind of hawk) that would swallow and later regurgitate perforated spheres in which he placed a variety of substances to analyze the gastric juices. Lazzaro Spallanzani (1729–99) confirmed Réaumur's experiments and did others on the digestive action of saliva. In order to discover whether the juices in the human stomach were like those in animals, he performed the experiments on himself, swallowing various tubes and bags of samples, in spite of the danger to his alimentary canal. In Edinburgh, Edward Stevens (ca. 1755–1834) did much the same experiments with the help of a human carnival performer who swallowed stones for a living. Stevens placed his specimens in hollow perforated silver spheres that the volunteer would swallow and later regurgitate. The state of chemistry in the eighteenth century was not advanced enough to allow a very thorough analysis of digestion, but it is significant that these scientists put aside the vital principles and *archei* and sought a direct experimental analysis of the process of digestion.

Although the attempts to create a chemical physiology of animals were not very successful, there was a noticeable change in the way in which chemistry and physiology were studied after 1740. Instead of trying to arrive at the structure of living things, physiologists placed greater emphasis on vital function. As we have seen, the same thing was true in chemistry. Attempts to discover the structure of matter gave way to a desire to rationalize chemical processes.

Undoubtedly the most important figure in this transition was Georg Stahl, who was both a chemist and a physician. Not only was he the first to criticize mechanistic explanations, but his books on chemistry and physiology had great influence throughout Europe. In spite of his vast knowledge of chemistry, he denied that it had any connection to medicine. Living matter was entirely separate from nonliving matter because living matter contained an *anima sensitiva* that kept it from corruption. Blood, for instance, immediately putrefies when it is lacking this principle of life. No purely chemical analysis can detect the anima, but it is apparent in all living things. Certain parts of the body such as the heart and the limbs undoubtedly serve a mechanical function, but their mechanical purpose is superficial, and a more penetrating investigation shows that they are quite unlike inanimate matter. All organic forms work towards a final goal, but brute machines work blindly, responding only to the motions communicated between their parts. In his *Theoria medica vera* [*True theory of medicine*] (1708) Stahl argued his medical theories aggressively and soon found himself in conflict with his colleague Friedrich Hoffmann, whose theory of medicine was more mechanical (although Hoffmann believed that animals contained an organizing force acting through the ether that was not present in nonliving objects). Stahl's equally famous *Fundamenta chymiae dogmaticae et experimentalis* [*Foundations of dogmatic and experimental chemistry*] (1723) was translated into English by Peter Shaw (1694–1764) in 1730 and was greatly admired by William Cullen for its thoroughness, although Cullen opposed Stahl's medical theories. Robert Whytt, Cullen's colleague at Edinburgh, was the first in Britain to pick up Stahl's physiology in his *Essay on the vital and other involuntary motions of animals* (1751). Whytt argued that the irritability of living tissue came from a living principle contained in it – not necessarily the anima described by Stahl, which was an extension of the soul, but still a quality or characteristic that was unique to living things.

In France, Stahl's medical theories were popular at the medical school at Montpellier. The appearance of truly vitalistic theories around 1760 was the work of graduates from this school, most notably Henri Fouquet (1727–1806) and Gabriel-François Venel (1723–75) (both of whom wrote articles on physiology and chemistry for the *Encyclopédie*) and Théophile de Bordeu (1722–76), who was chosen by Diderot to be the expert interlocutor in his dialogue entitled *Rêve de d'Alembert* [*D'Alembert's dream*] (1769).

At the center of these new debates in physiology was Albrecht von Haller. Haller was born at Berne and studied at Tübingen and Leiden under Boerhaave. In 1736 he became professor of medicine at the University of Göttingen, and it was there that he carried out his famous investigations into the sensibility and irritability of animal tissue. The property of "irritability" had first been recognized by Francis Glisson (1597–1677), who used it to explain why the gall bladder does not discharge bile into the intestines constantly but only when bile is needed. Haller did experiments to show that the gall bladder discharged more bile when irritated and therefore that irritability performed a controlling function in the body.

Haller generalized this concept of irritability and distinguished it from sensibility, which he believed to be an entirely different property. Irritable tissue contracts when it is touched. Sensible tissue sends a message to the brain. Thus nerve tissue is eminently sensible but not irritable, because it does not contract upon touch. Tendons, bones, the cerebral membrane, liver, spleen, and kidney all lack sensibility. Muscle tissue is sensible, but it is also highly irritable. Although the nerves themselves did not appear to be irritable, Haller showed that the diaphragm could be made to contract by irritating severed nerves, which indicated that nerves had some connection with irritability. But this irritability seemed to be a property of the material of the muscle itself and did not depend on the action of the soul. Stretched muscle fibers contract spontaneously to their former length. Irritability could not be a vital force because it continued for some time after death. Haller's careful experimental technique was matched by the cautiousness of his theorizing. He refused to explain irritability by any abstract and unspecified vital force, nor would he accept a completely mechanical model. He saw his physiology as an *animata anatome,* an experimental science that investigated and explained the special properties and functions of living matter without going beyond the information obtained from the senses.

Bordeu and the other doctors from the medical school at Montpellier criticized the distinction that Haller made between irritability and sensibility. Bordeu claimed that all living matter was sensible and that irritability was only a special case of sensibility. It was this belief in a universal property of sensibility, not any religious commitment to belief in an immortal soul, that made Bordeu a vitalist. Haller was the one whose religious convictions caused him to insist on the unity and spirituality of the soul.

It is here that we confront the central paradox of physiology during the Enlightenment. The antireligious sentiments of the philosophes inclined them to materialism and away from any dependence on the Christian concept of the soul. Mechanism, however, had failed in physiology because it could not account for the properties of life. Therefore animals could not be machines composed of inert particles. The answer of the materialists was to revive the ancient Stoic *pneuma* and endow all of matter, or at least all of organic matter, with life. The Stoics had chosen activity and change, rather than structure and permanence, as the foundation of nature. They explained natural phenomena by forces rather than by the organization of matter. The *pneuma* was the breath of the cosmos, the activating principle responsible for all change and all life. The materialist philosophers of the eighteenth century made matter active by giving it the properties of life. In essence, they distributed the soul throughout matter in order to get rid of it.

Diderot, who carried his materialism as far as the evidence and his common sense would allow, preferred the physiology of Bordeu over that of Haller. In *D'Alembert's dream* the world becomes a living being, infinitely elastic and full of force. Stones become thinking beings, and thinking beings incessantly change their forms. "All beings circulate from one to another; as a result all species . . . are in perpetual flux. . . . All animals are more or less men; all minerals are more or less plants; all plants are more or less animals. Nothing is precise in nature."[2] For Diderot there was no difference between the organic and the inorganic except in the degree of organization. His whole world was dynamic. The universe was a great animal, and it was also one enormous elastic body conserving *vis viva*. There was no real difference in his philosophy between the dynamic and the vital, no difference between physics and physiology.

The philosopher who had argued most compellingly for the existence of force and vitality in matter was Leibniz. But Leibniz would

Fig. 5.3 Anatomic illustration in the eighteenth century. Albrecht von Haller was the acknowledged leader in the study of physiology and anatomy during the eighteenth century. This drawing by Joel Paul Kaltenhofer illustrates the major artery in the human pelvis for Haller's anatomic study *Icones anatomicae* (1749). *Sources:* Albrecht von Haller, *Icones anatomicae quibus praecipuae aliquae partes corporis humani delineatae proponunter et arteriarum potissimum historia continetur* . . . (Göttingen, 1749), pt. 4, illustration entitled "Arter Pelvis T.IV." By permission of the Syndics of Cambridge University Library.

have had no sympathy for the imprecise and everchanging world described by Diderot. As a mathematician and rigorous metaphysician, Leibniz believed that the universe in all past, present, and future states followed a "preestablished harmony" laid down by God at the time of creation. This harmony was maintained by the smallest metaphysical units, or "monads," which were endowed with activity, perception, and will. Thus the properties of consciousness existed at the most fundamental level. Mechanical action was merely a phenomenon detected by our senses. It was "real" in the sense that it could be observed, but it was not fundamental. According to Leibniz, there was no way that mechanism alone could create an animal.

Leibniz's influence undoubtedly crept into all vitalistic thought during the eighteenth century, but it appeared most explicitly in the works of his disciple Louis Bourguet (1678–1742). Bourguet's *Lettres philosophiques sur la formation des sels et des crystaux et sur la génération et le mécanisme organique {Philosophical letters on the formation of salts and crystals and on generation and organic mechanism}* (1729) was mechanistic, but it was mechanism with a difference. Bourguet noted that inorganic matter could grow, as in the formation of crystals, but it always grew by accretion of more matter on the outside, repeating the form of the initial crystal. Living things, on the other hand, grew by molecules added throughout their interiors. He called this process *intussusception* and used the term to distinguish organic from inorganic matter.

Bourguet also pointed out another way in which an "organic mechanism" differs from an inorganic or "general mechanism." A crystal is its own mold and merely repeats its form, but in an organic mechanism the molecules are organized according to an internal arrangement that is not a simple mold. The molecules are "accomodated" to the system of the living being and united to its principle monad. Not all molecules are assimilated into an organic mechanism. Only the organic produces the organic, according to Bourguet. Only organic molecules are assimilated by living things, because the distinct qualities of life exist throughout the organism, even at the molecular level. There is a difference between "organic" and "organized." Organization is only an arrangement of molecules. Life cannot be simply a matter of organization, because organization only determines structure. As we saw in the case of Stahl, the characteristics of life depend not on structure but on vital function.

Bourguet's ideas found popular exposition in the writings of Buffon. Buffon wished to avoid the vitalism of Stahl, but he was also

aware of the inadequacies of strict mechanism. He retained a belief in atoms but held that living matter was composed of "organic molecules" that the organism took in through nutrition and sifted out from the atoms of inorganic matter. The organic molecules were directed by an "interior mold," and the property of intussusception required a special "penetrating force" that carried the organic molecules to their proper places in the interior mold. Buffon had begun his career as a mathematician and a strong disciple of Newton. (He translated Newton's *Treatise of fluxions* and Hales's *Vegetable staticks* into French.) But he realized, as Leibniz had realized before him, that attraction and repulsion between inert atoms could never make a living animal. Some special force and guiding principle beyond those of mechanics would have to be added.

The most scandalous physiology of all was *L'homme-machine* [*Man the machine*] (1748) of Julien Offroy de La Mettrie. La Mettrie studied with Boerhaave and spent his early years translating the works of his mentor. When he came to create his own theory, it was blatantly materialistic and atheistic. In his human machine there was no essential difference between conscious and unconscious behavior, no freedom of will, no rational soul, and no moral good beyond the perfectibility of the mechanism. La Mettrie drew from Leibniz and cited Haller and the other physiologists of the age, but his polemic sounds much more like the ancient atomists Epicurus and Lucretius than any contemporary author. His radical books were in the vanguard of the antireligious sentiment of the Enlightenment, but he was not in the vanguard of physiology. As speculative philosophy his theory was stimulating and even learned in places, but it lacked the experimental basis that characterized physiology in the 1740s.

Diderot, like Buffon, had studied mathematics and also like Buffon had repudiated it in favor of natural history and chemistry. In fact, Diderot was strongly impressed by Buffon's *Histoire naturelle,* which provided inspiration for his own *De l'interprétation de la nature* [*On the interpretation of nature*] (1753). Diderot's first philosophical work, *Pensées philosophiques* [*Philosophical thoughts*] (1746) had been deistic – that is, it had demonstrated the existence of God through the order of nature and had drawn from the English deists, especially Lord Shaftesbury. But Diderot's *Lettre sur les aveugles* [*Letter on the blind*] (1749) began his gradual conversion to materialism. The *Letter on the blind* discussed the psychology of sensation, and particularly its moral implications. The book was dangerous enough to rouse the authorities, and Diderot was jailed at Vincennes outside of Paris at the crucial time when the *Encyclopédie,* of which he was chief editor, was just getting under way. His *Interpretation of nature* (1753) turned from psychology to scientific method and marked a further step in Diderot's march from a mathematical, rationalist deism to a dynamic, vitalistic materialism.

In his dialogue *D'Alembert's dream* he brought together the ideas of Spinoza, Leibniz, John Toland, Buffon, Maupertuis, Haller, and Bonnet into one wildly speculative account of life. The dialogue begins with a late-evening conversation between Diderot and his friend d'Alembert. Afterward, tired of Diderot's wild speculations about the nature of life, d'Alembert goes off to bed. During the night he begins talking in his sleep about the subjects that he and Diderot had debated earlier. Alarmed by his raving, his mistress, Mademoiselle de Lespinasse, calls Doctor Bordeu to his bedside. Bordeu understands the profound importance of d'Alembert's words and explains them to Mademoiselle de Lespinasse. The dialogue mixes philosophy, science, art, and speculation in a style that is uniquely Diderot's. Diderot claimed that it was at once the craziest and the most profound writing possible. In a later letter of 1765 he described the basic idea of *D'Alembert's dream* and revealed his debt to Bordeu. "Sensibility is a universal property of matter, a property that lies inert in inanimate objects [but one] that becomes active in the same objects by their assimilation into a living animal substance . . . The animal is the laboratory in which sensibility, beginning from its inert state, becomes active."[3] In the works of La Mettrie and Diderot, the scientific debate over vital function moved into the wider domain of Enlightenment philosophy, with all its social, political, moral, and religious implications.

Generation

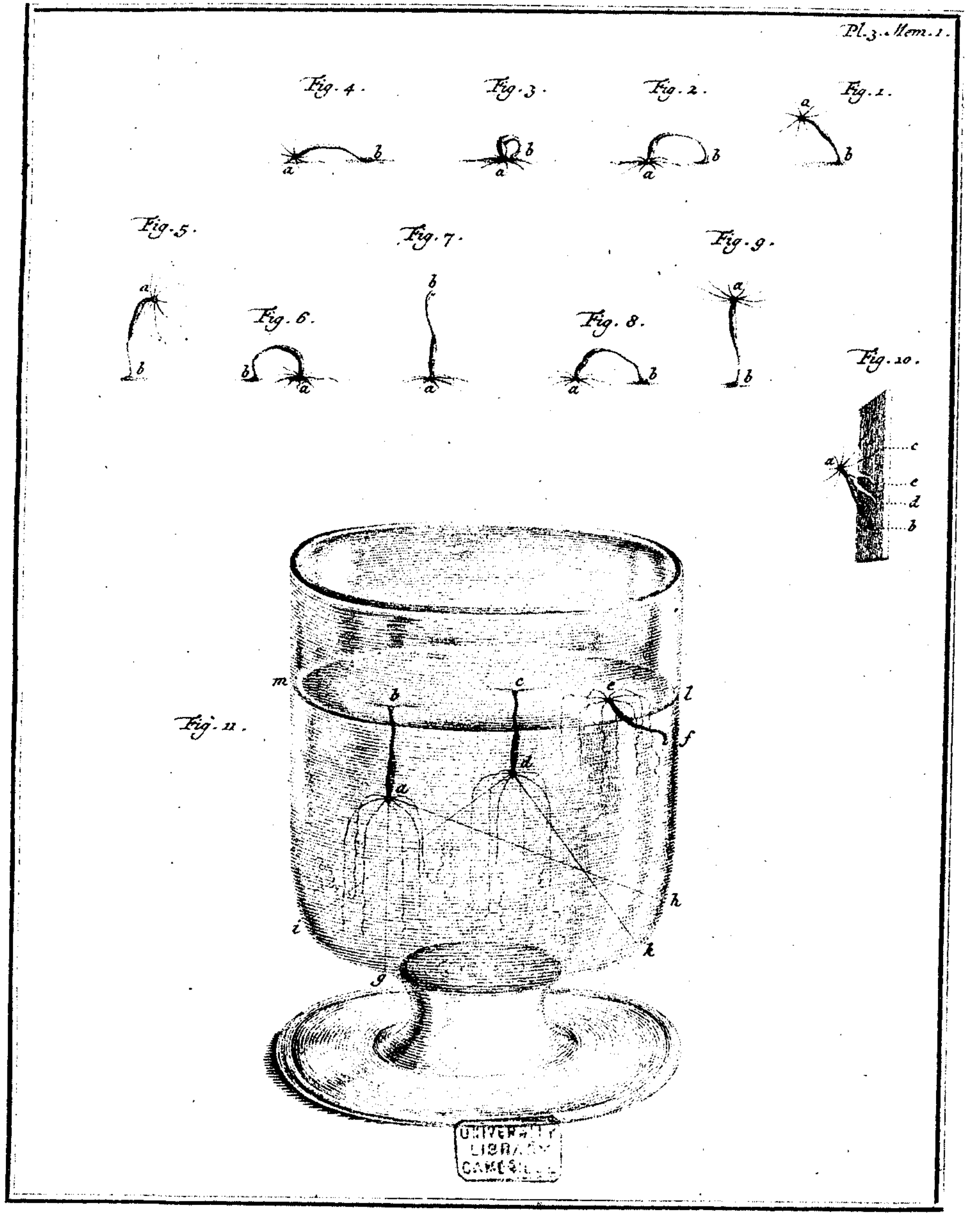
The change that we have noted in physiological theories around 1740 was caused by the failure of the mechanical philosophy to adequately account for the functioning of living organisms. Nowhere was this more striking than in the problem of "generation," which included both the reproduction of organisms and the regrowth of body parts. One might suppose an equivalence between the structures of living and nonliving things, but there seemed to be no way that mechanism could account for growth and reproduction. The more physiologists learned, the more inadequate mechanical explanations became. Two sensational new discoveries in generation coincided with the change in physiological theories, and as a result the nature of generation became the most exciting problem in the life sciences.

The first was the discovery of parthenogenesis of aphids by Charles Bonnet (1720–93). Antoni van Leeuwenhoek (1632–1723) had observed that the young of the aphid, or plant louse, were present as miniature adults within the parent. This indicated that aphids, unlike most insects, were viviparous and brought forth their young alive rather than from eggs. Still more surprising was the fact that no one could observe any males. Réaumur, who also made a detailed study of insects, suggested that aphids were all female; Leeuwenhoek suggested that they were hermaphrodites carrying the organs of both sexes, but Réaumur denied this, arguing that there was no sign of male organs in any of the individuals he dissected. Other microscopists claim to have observed two distinct sexes and that the female laid eggs like other insects.

In a careful series of experiments beginning in 1740, Bonnet, on Réaumur's suggestion, took up the problem. He raised a newly born female in seclusion and eventually obtained ninety-five young from this single aphid. In another experiment he raised aphids through ten generations with no males present, demonstrating conclusively that aphids reproduced parthenogenetically. Bonnet's results reinforced the ovist view that the embryo of every species was preformed in the mother as a tiny seed and merely grew. In animals that reproduced sexually the role of the male, according to the ovist theory, was merely to initiate growth of the preformed embryo. This theory did not adequately explain the existence of male characteristics in the offspring, but the ovists argued that the semen, by initiating the growth of the preformed embryo and by nourishing it in its early stages, impressed on the embryo the characteristics of the male.

A second startling discovery was made by Abraham Trembley (1710–84). Trembley's subject was the fresh water hydra, or "polyp," as it was called. These small creatures, about a quarter of an inch long, grew on the bottom of lily pads and other aquatic plants. Leeuwenhoek had observed that they reproduced by budding and had assumed them to be plants, but Trembley found on closer observation that they caught food in their tentacles and delivered it to an interior stomach. They also reacted to touch and could move, using a primitive foot (see Figure 5.4). These characteristics made them animals, but of the lowest form, at that point on the scale of living beings where animal forms pass over into plant forms.

In order to discover whether the polyp could regenerate itself, Trembley cut a specimen in two. To his great surprise he saw each piece regenerate a complete polyp. He then cut polyps crosswise, lengthwise, and in different numbers of pieces. Each piece always



produced an entire polyp. As an experimental pièce de résistance, he turned a polyp inside out by inserting a bristle into its gut and peeling the body back as one would pull a glove inside out. The polyp accepted its new condition and merely grew an outside on what had formerly been an inside. In 1744 Trembley published a detailed account of his experiments. Réaumur and Bonnet extended them to other animals. They found freshwater worms that regenerated in the same fashion, and since worms were definitely animals, previous doubts about the animality of the polyp lost their force.

These experiments produced a major philosophical dilemma. If each part of an animal could regenerate the entire animal, then where was its "soul," or organizing principle? Naturalists had long known of the ability of crabs and salamanders to regenerate missing parts, but in these cases the severed parts died. It had been assumed that the organizing principle was not in the lost claw or tail but in the animal from which it was taken. In the case of the polyp, however, each piece regenerated and therefore had to contain within itself the power and form needed to reproduce the whole. The modern solution – that animals are composed of tiny cells, each one of which contains within its nucleus sufficient information to create the entire animal – would have appeared ridiculously fanciful at a time when cells were unknown. The microscope had revealed that animals appeared to decrease in size without limit, which suggested that a complex animal might be reduced in scale to a germ or seed, but the seed, in order to become an embryo, would have to be in one part of the animal, not distributed throughout it. To La Mettrie and Diderot, the experiments with the polyp proved that there was no soul and that the properties of life were distributed throughout matter. It was a useful argument for a philosopher advocating materialism and atheism, but it did not help the phys-

Fig. 5.4. Trembley's polyp. Is it an animal? And if so, where is its soul? Abraham Trembley found that the polyp could move and feed itself, as shown in this illustration from his *Mémoires pour servir à l'histoire d'un genre de polypes d'eau douce . . . [Memoir on the natural history of a species of fresh water polyps]* (1744). This would make it an animal. But it could also regenerate an entirely new polyp from any severed part, which would make it more like a plant. The regeneration of the polyp contradicted the notion that the embryo could be preformed in any part of either parent. *Sources:* Abraham Trembley, *Mémoires pour servir à l'histoire d'un genre de polypes d'eau douce, à bras en forme de cornes* (Leiden; 1744), pl. 3, memoir 1. By permission of the Syndics of Cambridge University Library.

iologist, because it did not explain how this distribution of life took place.

The debate over the polyp complicated a debate that had been going on since the middle of the seventeenth century. William Harvey (1578–1657) had claimed in his *Exercitationes de generatione animalium* [*On the generation of animals*] (1651) that all animals came from an egg. He had experimented with developing chick eggs and with deer from the Royal Park. The "eggs" that he obtained from pregnant deer were actually undeveloped embryos. Harvey did not, however, claim that the embryo was preformed in the egg. Instead he followed the Aristotelian notion that the embryo began as a homogeneous mass and that the organs formed one after another from this homogeneous substance, a process called *epigenesis*.

Epigenesis made sense for an Artistotelian, because according to Aristotle all change takes place by a process in which unformed substance takes on a form that is potentially, but not actually, in it. The mechanical philosophy had repudiated Aristotle, however, along with his concepts of form, potentiality, and final cause. The mechanical philosophy required that the embryo have an immediate mechanical cause. It could not just appear.

In 1688, Jan Swammerdam (1637–80) had shown that the insect larva, pupa, and imago can exist simultaneously, all nested one within the other. He also showed that the legs of a frog were already present under the skin of the tadpole before they began to emerge. Swammerdam concluded from this evidence that there was no epigenesis but that the embryo always existed preformed in the adult. The philosopher Nicolas Malebranche carried preformation to its logical conclusion. Locating the preformed embryo within the parent did not solve the problem of its formation but merely moved it back to the previous generation. Malebranche's solution was to have all generations preformed, one within the next. The seeds of all living things had been formed by God at the Creation and merely unfolded in successive generations. This highly unlikely theory of preexistence solved two difficult problems. It explained the existence of Original Sin, since the entire human race was present in Adam and Eve at the time of the Fall, and it explained where the embryo came from. It also removed the need for the concept of continued spontaneous generation, which was strongly opposed by the mechanical philosophers.

The microscope might have put an end to the theories of preformation and preexistence if it had been powerful enough, but good compound microscopes that made it possible to observe the cell and its structure were not available until the 1830s. Carl Ernst von Baer (1792–1876) first observed the mammalian egg in 1826, and Wilhelm August Oscar Hertwig (1849–1922) first observed the fecundation of the ovum by sperm in 1875. Embryologists in the eighteenth century could only posit mechanisms of generation to explain what they observed on a grosser level.

The sperm, however, had been observed through the microscope by Leeuwenhoek in 1677. Whereas the ovum had to be imagined, the "animalcules" or "spermatick worms" were plainly visible in the semen. Their mere presence in the semen, however, did not prove that they were the agents of generation. Microscopists regularly found parasites in the blood, intestines, and ovaries of animals, and the spermatozoon could easily be just another parasite that had found its ecological niche in the male testicles. The word *spermatozoon* was coined by von Baer in 1827. The name means "animal in the seed," and it shows that there were able embryologists in the nineteenth century who still believed that the animalcules were only parasites. It was not logical to expect a mammal, for instance, to be fertilized by a worm, especially since the animalcules were never observed in the uterus. It made more sense to assign the power of fecundation to the liquid part of the semen or to some principle given off by the semen. Girolamo Fabrici d'Aquapendente (ca. 1533–1619) had spoken of a seminal spirit in 1621, and Swammerdam first used the term *aura seminalis* in 1685. Until the semen could actually be observed in the uterus, it made more sense to assume that the fertilization was accomplished by a spirit or influence.

One group of microscopists, the "animalculists," beginning with Leeuwenhoek and Nicolaas Hartsoeker (1656–1725), believed that the sperm did indeed reach the uterus and that they contained the preformed embryos. Hartsoeker even described the "homunculus," or preformed embryo, that he believed had to exist in the head of the human sperm. Since the animalcules were present in great numbers in the semen, very few of the preformed embryos they contained would ever grow to birth. There had to be a great destruction of potential animals. It did not seem that God would be so wasteful of his creatures. It was also hard to explain how the mother could pass on her characteristics to an embryo coming entirely from the male, and therefore the animalculist view declined in the early eighteenth century. Some even denied the existence of the animalcules. Linnaeus (a great naturalist, but a poor microscopist) said that they were inert masses of fatty material; others denied that they swam on their own or else claimed that their only purpose was to stir the semen. Bonnet's discovery of parthenogenesis contradicted the animalculist theory completely. Even Hartsoeker, the most outspoken of the animalculists, renounced the theory of preformation in 1722 after he had performed experiments on regeneration. If a crayfish could easily replace an amputated leg or claw, then the same intelligence responsible for regenerating the claw could also form an entire animal. Regeneration made any simple preformation theory untenable.

By 1744, when Trembley did his experiments on the polyp, theories of generation were becoming more sophisticated. The preformed human embryo, if it existed, was no longer thought to be a miniature human curled up in part of the ovaries or in the body of the animalcule. It merely had to carry in some fashion the form or plan from which the embryo could be built. It did not have to resemble the adult any more than a blueprint resembled a house. Considered from this point of view, the theory of preformation was not far from the truth.

The theory of epigenesis was equally sophisticated. It no longer required Aristotle's concepts of substance and form. It could be understood as a statement about proper scientific method. The chick gradually appeared in the undifferentiated yolk of the fertilized egg. No form could be observed in the yolk of a freshly laid egg. To claim that it contained a preformed embryo was to claim what could not be seen. What could be seen were the organs of the chick gradually appearing as the yolk incubated. From this point of view epigenesis was a statement about the need for caution in drawing conclusions from experiments in embryology. It refused to imagine structures that could not be seen or otherwise demonstrated.

Neither position can be taken as absurd; each has its own compelling logic. From our modern perspective we cannot say that one theory was right and the other wrong. In the eighteenth century embryologists had to work their way through this maze to create a theory that would not offend either their logic or their senses.

Philosophers of the eighteenth century attempted to understand the origins of living things by studying the phenomena of reproduction and regeneration. An alternative would have been to study heredity, the laws by which characteristics appear in subsequent generations. It was a subject that could have been investigated experimentally with the knowledge and equipment available in the eighteenth century, but because the mechanism of generation was such an important philosophical problem, the possibility of reducing the transmission of characteristics to rule was largely overlooked. Stock breeders built a fund of information about heredity, but they were more concerned about practical results than scientific

principles. Also, the large animals that they raised were not the most suitable subjects for studying heredity; they bred slowly and were expensive to maintain. Plants, once their sexuality had been recognized, made good subjects because they could be bred much more rapidly and cheaply.

The first studies of heredity in plants were investigations of hybrids. Linnaeus searched for hybrids and thought that he had found many, but he never tested them for purity of type. He classified any plant intermediate between known species as a new species without checking to see if it bred true. Much more thorough experiments (on tobacco plants) were performed by Joseph Gottlieb Kölreuter (1733–1806) beginning in 1760; his results were published as *Vorläufige Nachricht von einigen das Geschlecht der Pflanzen betreffenden Versuchen und Beobachtungen* [*Preliminary report on experiments and observations of certain species of plants*] in 1761, with later supplements. Kölreuter carried out more than five hundred different hybridizations and described the pollen of more than a thousand plant species. Because he believed that the order of nature required the fixity of species, he performed his experiments in order to discover why the existing order of nature was not swamped by innumerable new hybrid species.

He found the answer when his tobacco hybrids proved to be sterile; all of the flowers fell off, and the plants produced no seed. It was, for him, "one of the most wonderful of all events that have ever occurred upon the wide field of nature." Kölreuter's hybrid was, as he said "the first botanical mule which has been produced by art."[4] By backcrossing his hybrids with the original nonhybrid species, he was able to create second-generation hybrids. He later discovered that first-generation hybrids of some plants such as pinks, carnations, and sweet williams were partially fertile and therefore was able to obtain true second-generation hybrids by self-fertilization of his first-generation hybrids. The results were puzzling. The first-generation hybrids were always the same, whereas the second-generation and backcrossed hybrids showed a bewildering variety.

Kölreuter concluded that the lack of orderly characteristics in second-generation hybrids was the result of man's interference with nature. By bringing together plants from different parts of the world and by pollenating them artificially, the naturalist was creating conditions that would never occur in nature. Because the hybrids did not breed true, he concluded that they could not create new species. To explain his results, Kölreuter imagined a chemical analogy. Male and female "seed materials" united in the plant in a way similar to the union of an acid and an alkali to form a crystalline salt.

The variety of second-generation hybrids was a result of the great variety of proportions in which the seed materials could combine.

A similar conclusion was reached by Pierre Maupertuis, the same Maupertuis who invented the principle of least action and led the expedition to Lapland to study the curvature of the earth (see Chapter II). Whereas Kölreuter studied heredity in plants, Maupertuis worked with animals. His interest in heredity was stimulated in 1743 when an albino Negro was exhibited in Paris. There was a great interest at the time in physical abnormalities, both as carnival attractions and as clues to the mechanism of generation. Although Maupertuis's previous work had been almost entirely mathematical, he had always kept a large number of pets and bred them to obtain special characteristics. He concluded, as did Kölreuter, that both parents contributed to the formation of the offspring and that the embryo could not be preformed in either parent. Instead he suggested that both the male and the female produced a semen containing special particles that mingled to create the embryo. Like Kölreuter, he believed that fertilization was a dynamic chemical process similar to the formation of an elaborate crystal.

Because the offspring could resemble either parent or even a grandparent in any part, the particles in the semen must be collected from all parts of the parents' bodies and even be carried over from previous generations. Maupertuis suggested that if the genetic particles had to migrate from all parts of the body, a mutilation of one part consistently, through several generations, would probably cause the defect to become heritable. Some abnormalities were extreme enough to make survival of the individual impossible, but if the abnormalities were small and if these individuals were to mate with one another rather than with normal individuals, then their abnormal characteristics might become permanent in their posterity. In this way an entire race of albino Negroes could appear.

In order to learn more about the transmission of abnormal characteristics, Maupertuis investigated polydactylism in humans, which is the appearance of extra digits on either or both hands or feet. Réaumur had suggested breeding fowl with different numbers of digits to discover how this characteristic was transmitted, but Maupertuis said that the information could be obtained more easily from human families that were polydactylous. In his *Lettres de M. Maupertuis* [*Letters from Monsieur de Maupertuis*] (1751) and his *Système de la nature* [*System of nature*] (1757), Maupertuis gave the genealogy of the Ruhe family of Berlin. The data that he obtained, covering four generations, showed that the trait could be transmitted by both the male and the female and that its occurrence in four consecutive generations could not have been accidental, since the probability of its occurring accidentally was astronomically small. Réaumur obtained similar information on the Kelleia family, also polydactylous, with similar results.

Maupertuis's contemporaries mention other breeding experiments that he performed, one in particular in which he duplicated an unusual marking on an Icelandic dog by breeding its puppies for several generations. If Maupertuis had chosen a more suitable subject, had studied more cases, and had measured the frequency of the characteristics among his samples rather than the probability of their appearance among the population as a whole, then he might have obtained valuable rules for the transmission of characteristics, but he did not seek that kind of information. His interest was in embryology, not in heredity as such, and once he had demonstrated that abnormal characteristics such as polydactylism must indeed be inherited, he made no effort to reduce the frequency of their appearance to any general rule.

Moreover, Maupertuis's experiments did not investigate the order of nature but deviations from that order. It was not obvious in the eighteenth century that deviations from nature could be or should be reduced to rule. Kölreuter, we noted, was greatly relieved to discover that hybrids did not disrupt the order of species. The "Detailed explanation of the system of human knowledge" in the *Encyclopédie* divided all of natural history into the "order of nature" and "deviations from nature." These were two separate categories, one set of observations evidencing order, the other evidencing disorder. Maupertuis was trying to learn about the mechanism of generation by studying abnormal cases. If he had hoped to discover rules of heredity, he would have studied normal cases.

Buffon adopted a theory of generation similar to that of Maupertuis. In the second volume of his *Histoire naturelle* [*Natural history*] (1749), he brought forward his theory of organic molecules, interior mold, and penetrating force. He also adopted the theory of the double semen. He believed that there was no female ovum but that a semen produced by the Graafian follicles in the ovaries mixed with the male semen in the uterus to form the embryo. The vital part of both semens was composed of organic particles that were in excess of the needs of the interior mold and were stored in the ovaries and testicles for the future production of offspring. Buffon believed that the reason why individuals ceased to grow at puberty was that the body at that time no longer needed the organic molecules and they could begin to accumulate in the reproductive organs.

Because the organic molecules were distributed throughout nature and were never themselves destroyed, they could appear in a variety of microscopic forms. Buffon claimed that the small animals observed in putrefying broth were groups of organic molecules released from dead material by the absence of an interior mold. Buffon persuaded John Turberville Needham (1713–81), an English microscopist, to perform experiments on spontaneous generation in beef broth and hay infusions. Needham believed that the enormous number of little animals he observed could not all have come from seeds in the infusions. To see if they came from the outside or were generated in the liquid, he heated his flasks of broth to kill all the animals and corked the flasks tightly. He found that after a short time there were again numerous objects swimming in the broth. Buffon concluded that the objects were not real animals at all but collections of organic molecules in various degrees of organization. The experiments were difficult, and Needham had been careless. The infusoria either had not been killed by the heat, or the corks that he used to seal the flasks were not tight.

Lazzaro Spallanzani carried out experiments in 1765 and again in 1776 to check Needham's results. He used flasks with slender necks that could be melted shut, guaranteeing a seal against organisms entering from the outside. Spallanzani found that boiled broth in a sealed container would remain sterile indefinitely but that if he broke the neck of the flask animals soon appeared in the liquid in great numbers. He attacked Buffon's assumption that the objects observed in the infusion were not real animals. Buffon had said that these infusoria were only the remains of animals and observed that they had lost their tails and did not move under their own power but were moved about mechanically by the liquid.

Spallanzani showed that the tails were still there but merely rolled up in the cases that Buffon had observed. He saw the little animals move, navigate, ingest food with cilia, and reproduce in a variety of ways. In short, they were true animals, not just collections of organic molecules.

The Revival of Preformation

By the time Spallanzani did these experiments, the preformation theory was staging a comeback. Just before its revival, however, one of the strongest appeals in favor of epigenesis was made by Caspar Wolff (1734–94), a follower of the chemist Stahl and the Leibnizian philosopher Christian Wolff. In his *Theoria generationis* [*Theory of generation*] (1759) and later in his "De formatione intestinarum" ["On the formation of the intestine"] (1768–9), Caspar Wolff argued that the embryo was created by a *vis essentialis* (essential force) inherent in living matter. In the tradition of Leibniz's dynamic philosophy, he held that matter was essentially active, but he made no claim to a detailed knowledge of this force. He wrote: "We may conclude that the organs of the body have not always existed, but have been formed successively – no matter how this formation has been brought about. I do not say that it has been brought about by a fortuitous combination of particles, a kind of fermentation, through mechanical causes, through the activity of the soul, but only that it has been brought about."[5] This positivist attitude was characteristic of the new theories of generation.

Albrecht von Haller had begun as an epigenesist, but after carrying out his own experiments on the chick embryo he was converted to preformation. With his knowledge of physiology, Haller recognized the extent to which the organs were all interdependent, and he could not believe that they appeared successively in the embryo. A heart or liver by itself could not live and function. Therefore the organs had to appear together, even if they were observed successively. By using different reagents to harden the parts of specimen embryos to produce greater contrast, Haller showed that the developing embryo had greater differentiation in the early stages than one would conclude from simple observation. If the organs had appeared all together, one would have had to conclude that they existed in some preformed state.

Beginning in 1760, the three best experimentalists of the century – Bonnet, Haller, and Spallanzani – were all drawn to the ovist version of the preformation theory. Bonnet was the most speculative of the three. His eyesight had failed after his important work on parthenogenesis in the 1740s, and he had turned his efforts to finding a logical mechanism of generation. In his *Contemplation de la nature* [*Contemplation of nature*] (1764), Bonnet defined preformation in a way that shows the flexibility and abstractness of the theory: "I understand by the word 'germ' every pre-ordination, every preformation of parts capable by itself of determining the existence of a plant or animal." Regeneration produced problems for the preformation theory, but Bonnet urged that the word *germ* "be taken in its widest sense." Even the polyp could be said to regenerate from a germ if the germ were defined as any "secret preorganization." Moreover, the germ in the female did not fully

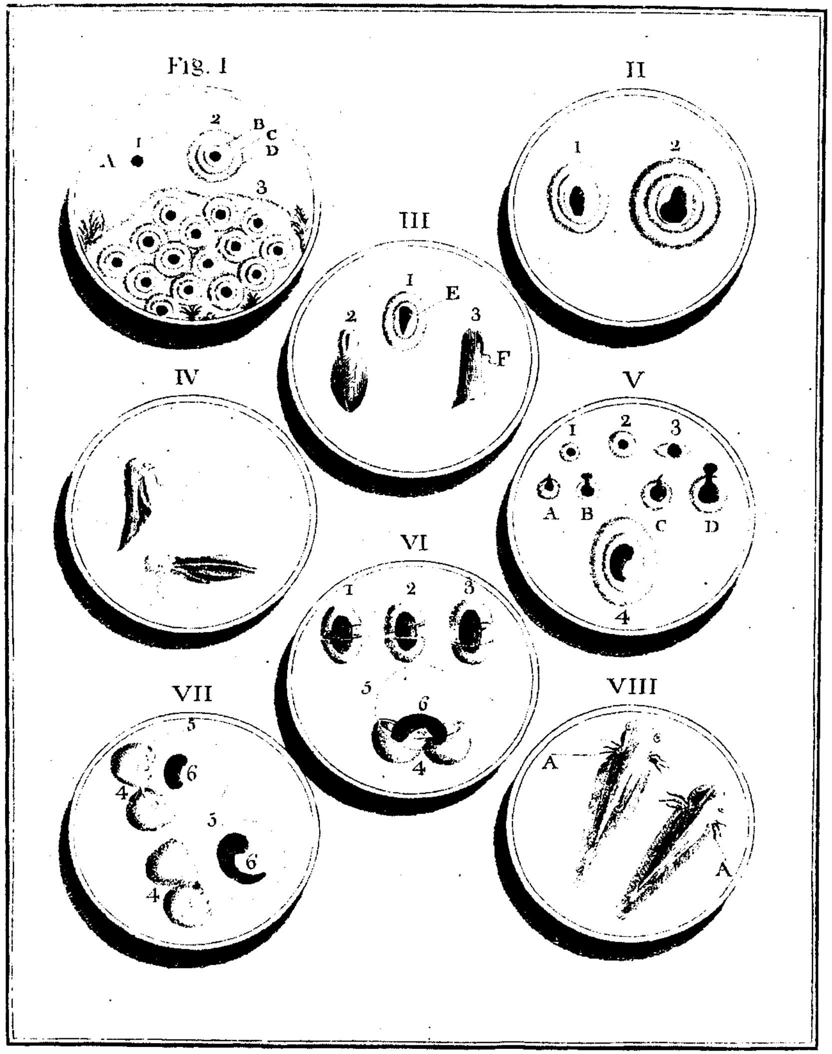


Fig. 5.5. The generation of the tadpole. Spallanzani's description of the development of the tadpole of the green frog. Figure I shows a mass of eggs, one of which is magnified to show its structure. The other illustrations show different stages of development. In these illustrations Spallanzani wishes to show that the tadpoles do not come from true eggs but are preformed in the mother's body. He writes that "as greater deference was due to what nature shewed me so plainly . . . than to the authority of the most celebrated writers, I am obliged to call these globules tadpoles or

determine the embryo; the action of the semen and the process of nutrition created the variations observed in every species. A germ, for Bonnet, was "a miniature man, a horse, a bull etc., but it [was] not a *certain* man, a *certain* horse, a *certain* bull, etc."[6] The individual variations came from outside the germ.

The best experiments on generation during the entire eighteenth century were those done by Spallanzani. After revealing the errors in the observations of Buffon and Needham, Spallanzani extended his experiments to spermatozoa. Buffon had argued that the spermatozoa were like the infusorians that Needham had observed in broth; they were merely clumps of organic particles caused by decay, not real animals. Experimenting with canine semen, Spallanzani showed that the spermatozoa were in the semen from the time it was taken from the dog and that Buffon's observations on semen were extremely misleading. Because Buffon had not used fresh semen, he had not been observing the spermatozoa at all but had described infusorians in the putrefying semen. Spallanzani was even able to observe the sperm in place in the transparent vas deferens of a live fasting salamander.

His most important experiments investigating the nature of sperm were performed on frogs. Frogs were especially good subjects for these experiments because they fertilize their eggs externally. As the female releases the eggs in water, the male sprays semen on them. Eggs touched by the semen produce tadpoles, whereas those taken from inside the body of the female are sterile. Spallanzani made tight-fitting taffeta pants for the male frogs to contain the semen. The frogs were then allowed to mate normally. None of the eggs developed. The story of Spallanzani's taffeta frog pants often elicits laughter, but it was an important and difficult experiment. Réaumur and Nollet, both able experimenters, had tried to carry out this same experiment and had failed. Once he had demonstrated that the fertilization of frogs' eggs was external, Spallanzani was able to use artificial insemination, which gave him much greater experimental control.

He took semen from the seminal vesicles of male frogs and painted it onto unfertilized eggs taken from the female. The unpainted eggs

Caption to Fig. 5.5 *(cont.)*
fetuses instead of eggs; for it is improper to name any body an egg which, however closely it may resemble one, takes the shape of an animal without leaving any shell." *Sources:* Lazzaro Spallanzani, *Dissertation relative to the natural history of animals and vegetables*, 2 vols. (London, 1784), vol. II, pl. I. By permission of the Syndics of Cambridge University Library.

decayed, but the painted eggs produced tadpoles. As he improved his experimental technique he found it more convenient to place the semen on the eggs with a needle, scratching the outer surface – a change that produced unexpected confusion in his results, as we shall see.

Spallanzani next set out to determine what part of the semen was responsible for fertilizing the eggs. His first experiment disposed of the *aura seminalis*. He attached twenty-six eggs to a small watch glass, which he suspended over another watch glass containing fresh semen. The eggs were placed as close as possible to the semen without actually touching it and were obviously being bathed in any aura that might be leaving the semen. The eggs remained sterile. He then determined the external circumstances that might affect the sperm. Vacuum, cold, and oil had no effect. Heat, evaporation, wine, and filtering destroyed its fertilizing ability. In 1784 he published the results of experiments in which he had filtered the semen. The liquid portion of the semen would not fertilize eggs; the thick portion containing the sperm did fertilize eggs. From our perspective, this experiment should have been conclusive; we would conclude that Spallanzani had shown that the "spermatic worms" were the actual agents of fertilization – but this is not what Spallanzani concluded. He believed that the liquid left on the filter paper was responsible for fertilization and that the spermatic worms were just that – parasites in the semen.

This case has often been put forward as an example of an experimenter blinded by a previous commitment to an erroneous theory – in this case preformation. But Spallanzani had reason for caution. In the first place, he performed the experiments not to separate out the sperm but to separate two fluids in the semen, one that he found in the seminal vesicles and called the "seed," the other, a more dense liquid, that he called the "juice of the testicles." In the second place, the sperm did not appear to be responsible for fertilization. On two occasions he had placed sperm-free liquid from the semen on eggs, and they had developed. On another occasion semen treated with wine to kill the sperm had also fertilized eggs. It is possible that Spallanzani's supposedly sperm-free liquid actually contained sperm, but this is unlikely considering his skillful experimental technique. In 1910, Jean-Eugène Bataillon (1864–1953) showed that frogs' eggs could be made to develop parthenogenetically by pricking them with a glass needle or micropipette. Probably Spallanzani's technique of applying semen to the eggs with a needle sometimes caused parthenogenesis of unfertilized eggs.

The decline of the preformation theory during the first half of the eighteenth century and its revival in the 1760s tells much about what was happening in the life sciences. In its earliest form, preformation was the only answer that the mechanical philosophy could give to the problem of generation. The preformed embryo was regarded as a completely formed animal that needed only to grow to become an adult. The theory explained generation without resorting to special vital forces. But the mechanical philosophy proved unable to explain vital phenomena. The emphasis on structure gave way to an emphasis on vital function and to a phenomenalist experimental approach.

The preformation theory that reappeared in the 1760s was quite different from that of the seventeenth century. By this time the idea of the preformed embryo had become an abstract concept applying to any preexisting order, form, or mold that gave form to the embryo. Moreover, the theory implied that living things were different from nonliving things and no longer constituted a strictly physical-chemical explanation of life.

Natural History

For natural historians to make any sense out of the multitude of natural forms, they must first reduce these forms to some kind of order or classification, and that classification will be arbitrary to a certain extent. One could, for instance, choose to list all plants by classifying them in terms of an essential characteristic such as the flowering parts. This might help distinguish among different forms, but it would not describe any form in its entirety. Distinguishing between plant forms on the basis of a single characteristic would therefore be "artificial." The goal of naturalists in the eighteenth century was to find a "natural" system, one that identified plants and animals by their "essences" – that is, those things that made them what they were. The essence of man was his rational soul, not the color of his eyes. According to Aristotle, the first was an essential property, the second a mere accident. In Christian terms, the search for a natural system was a search for God's plan. No one doubted that the forms of living things were related in some harmonious way to fulfilling God's purposes in his creation.

There was great difficulty, however, in deciding what constituted the essence of a plant or animal, and consequently which systems of classification were natural. The immediate problem was whether a natural system required a single characteristic or a whole complex of characteristics to define a species. A single characteristic such as the leaf or stem might serve to distinguish among forms in one part of the plant kingdom and fail completely in another part. An alternative was to subordinate certain characteristics to others. The shape of the flower might be made the principal differentiating characteristic; other characteristics would be made subordinate to this major one and used for further differentiation among plants that had similar flowers. Deciding which characteristics were dominant and which were subordinate, and in what order, inevitably involved a certain amount of arbitrariness, which raised doubts about whether the system was natural.

Aristotle's formal logic was based on a systematic arrangement of things into categories and classes, and one would therefore have expected Aristotle to apply it in his natural history. But Aristotle was also an acute observer, and he soon realized that the principal divisions required by his logic did not apply to living things. He concluded that the entire complex of characteristics defined the species and that therefore the entire complex had to enter into the system of classification.

Aristotle's influence still dominated natural history in the seventeenth century, but that domination was broken in taxonomy by the discovery of the sexuality of plants. Since most plants are hermaphrodites, containing both male and female reproductive organs, the fact that they reproduce sexually was not obvious, and only a few cases, such as that of the date palm, were known to antiquity. Rudolph Jacob Camerarius (1665–1721) was the first to demonstrate experimentally the sexuality of plants. In his *Epistola . . . de sexu plantarum* [*Letter on the sex of plants*] (1694), he showed that in order for plants to bear fruit the pistils of the female flowers had to be provided with pollen.

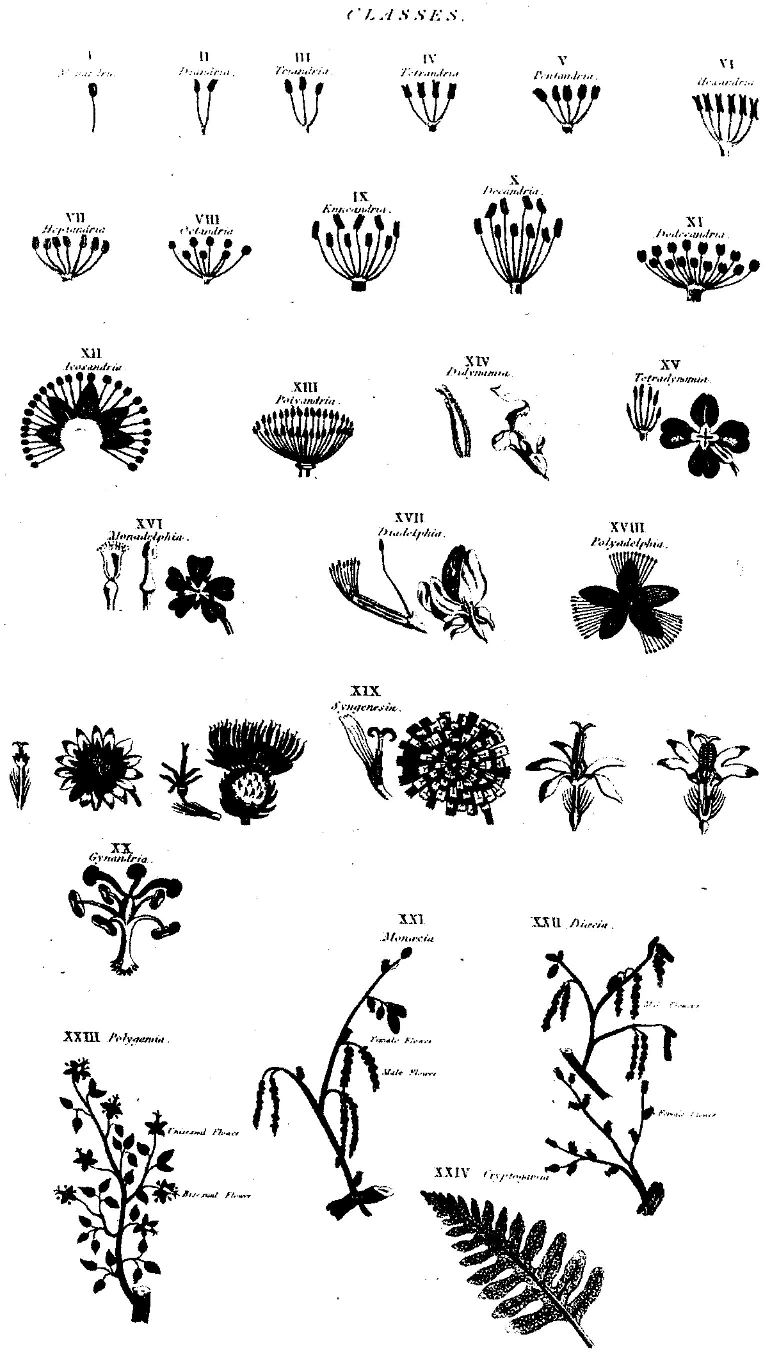
The sexuality of plants provided a possible basis for a natural system of classification because the mechanism of generation must of necessity also determine the plant's form. Camerarius was not himself a taxonomist or even an especially prominent naturalist, but his discovery gave support to the earlier very important system of Andrea Cesalpino (1519–1603), which was based on the plant parts involved in fructification, and to the more recent system of Joseph Tournefort, who chose the reproductive organs of plants – that is their flowers and fruits – as the only reliable characteristics that could form the basis for classification. In the case of animals, it was more obvious that species were determined by their ability to reproduce, and therefore the analogy to plants lent further support to the notion that any natural system should be based on the species's reproductive characteristics.

John Ray struggled with the problem of the natural system in his

Methodus plantarum nova [*New method of plants*] (1682), his *Historia plantarum* [*History of plants*] (1686), and his later *Methodus plantarum emendata* [*The Method of plants emended*] (1703). For simplicity of classification he originally followed Cesalpino and the systematists, but the methods of British natural philosophy at the time persuaded him that no single characteristic could create a natural system. These different points of view became explicit in a controversy between Ray and Tournefort that we will examine shortly, so that during the Enlightenment there existed two sharply divided camps – those who believed in the possibility of a natural system based on a single characteristic and those who insisted that a complex set of characteristics was necessary. A typical statement of support for the latter type of classification is this passage from Michel Adanson's (1727–1806) *Familles des plantes* [*Families of plants*] (1763–4): "The botanical classifications which only consider one part or a small number of the parts of the plant are arbitrary, hypothetical and abstract, and cannot be natural . . . Without doubt, the natural method in Botany can only be attained by consideration of the collection of all the plant structure."[7] Linnaeus, on the other hand, argued that "systematic division of the plants should take as its basis the primary structure. Therefore, as Nature confirms that fructification is the only systematic foundation of Botany, it can thus be demonstrated to be the absolute foundation. This has been accepted by the greatest systematists as the prop and mainstay of Botany."[8]

Linnaeus was undoubtedly the greatest botanist of the eighteenth century, and probably of all time. He obtained his botanical training in Sweden, traveled to Holland to obtain a medical degree, and subsequently went to Leiden, where he worked with Boerhaave. It was in Leiden that his famous *Systema naturae* [*System of nature*] appeared in 1735. In that work and in two subsequent works – *Fundamenta botanica* [*Foundation of botany*] (1736) and *Classes plantorum* [*Classes of plants*] (1738), Linnaeus used the characteristics of fructification to classify plants in a system that was more precise and useful than any previously devised (see Figure 5.6). He recognized that his system was not completely natural and constantly attempted to improve it, but he did not doubt that some system was necessary for botany and that a natural system did indeed exist. His classification began with the species, which he believed to have been fixed from the time of Creation. But even here his own experiments on hybridization raised doubts, and in the last edition of the *Systema naturae* he no longer insisted on fixed species.

Another of Linnaeus's contributions was the binomial nomencla-



ture that he introduced into botany in 1753 and later into his classification of animals. The first Latin word in the name identified the genus and the second Latin word identified the species, a reform of taxonomic language comparable to the new chemical nomenclature of the French chemists at the end of the century, and just as permanent.

The debate between the supporters of a taxonomy based on a single characteristic and the supporters of a taxonomy based on a complete set of characteristics reached its climax in the first volume of Buffon's *Histoire naturelle.* Buffon began his attack on the Linnaean system at the Paris Academy of Sciences in 1744, just as that system was obtaining almost universal acceptance from botanists. Moreover, Buffon criticized not only Linnaeus's system but all systems of classification that depended only on external characteristics. He believed that the universe was made up of individual objects. To force them into a rational set of categories was to impose an artificial abstraction of the human mind on nature. He wrote: "The more one increases the number of divisions in natural things, the closer one will approach the truth, since there actually exist in nature only individuals. . . . The Genera, Orders, and Classes exist only in our imagination."[9]

Buffon turned from systematic taxonomy to the image of the Great Chain of Being, a view of nature that had originated with Aristotle and had been employed by Leibniz in his metaphysical system. The Great Chain of Being, or Scale of Nature, was a linear, hierarchical progression of forms stretching from the simplest to the most complex. Leibnizian metaphysics demanded that it be continuous and full. There could be no gaps in the chain and no marked transitions between forms. Buffon described it as a chain

Fig. 5.6. The classification of plants according to Linnaeus. Linnaeus divided plants into twenty-four classes according to the character of their flowering parts. The number of stamens determines the first eleven classes, and the shape of the stamens determines the next nine classes. Plants in the next three classes have stamens and pistils in separate flowers. The twenty-fourth class consists of plants that lack true flowers. This is an "artificial" system because it employs only a single characteristic (the stamens and pistils of the flowers). Even though that one characteristic may be "essential" – that is, necessary for the plant to be what it is – the system cannot be "natural," because it ignores the multiplicity of characteristics that determine the plant form. *Sources:* Robert John Thornton, *A new illustration of the sexual system of Linnaeus* (1799–1807). By permission of the Syndics of Cambridge University Library.

of degradation descending from man at the top: "One can descend by almost insensible degrees from the most perfect creature [man] to the most disorganized matter. . . . It will be seen that these imperceptible gradations are the great work of Nature; one will find such gradations not only in size and form, but also in the motions, the generation, and the succession of each species . . . It will clearly be perceived that it is impossible to give a general classification, a perfect systematic arrangement, not only for Natural History as a whole, but even for a single one of its branches."[10] At first glance this criticism seems misguided (How can a naturalist work without any classification?) and incomprehensible in light of Buffon's past career as a mathematician and Newtonian physicist. In the *Premier discours* [*First discourse*] to his *Histoire naturelle,* he not only condemned the Linnean system but also condemned mathematics as an abstract creation of the mind not corresponding to nature as it really exists.

Buffon's criticism makes more sense if we see it as a continuation of the debate over taxonomy that began at the beginning of the century between Ray and Tournefort. Ray had directly revealed the source of his doubts – John Locke's *Essay concerning human understanding* (1690). Buffon was less explicit a half century later, but his contemporaries recognized nevertheless that standing behind Buffon's "untenable pyrrhonism" were "the doctrines of Mr. Locke."[11]

In his later *Methodus plantarum emendata* (1703) Ray had argued the Lockean position that the essences of things are wholly unknown to us and that we obtain knowledge of nature only through our senses. Thus we receive only collections of sensations, none of which can be the essence of the object we perceive. Reflecting on this multitude of sensations, we make judgments about essences. Just as the secondary qualities of taste, smell, color, and so forth are in our way of perceiving objects, not in the objects themselves, so the external characteristics of plants are mere indications. They cannot be the essences themselves, and therefore no single characteristic can be the basis of a natural system of classification. By considering the entire complex of characteristics, we can make the best judgment about the relationships among different plant forms, but even if we use all of the characteristics, our knowledge of essences can only be probable knowledge, which can never reach the certainty of mathematics. When Buffon criticized Linnaeus's taxonomy, in 1749, he reechoed the arguments of Locke and Ray. Linnaeus's taxonomy, Buffon claimed, shared the weakness of mathematics. It was abstract, artificial, and precise, because it came from the mind, not from nature. It obtained precision at the expense of realism.

Buffon's answer was to determine species not by any characteristic but by their reproductive history. He adopted the reproductive characteristic used by Ray and Réaumur. Two individual animals or plants are of the same species if they can produce fertile offspring. The members of any single species can, of course, be identified by some physical characteristics, but those characteristics can only be accidental properties. The essential identification of the species is the history of its propagation, not any physical form. Thus, according to Buffon, "species is an abstract and general term . . . to which a corresponding object exists only in considering Nature in the succession of time, and in the constant destruction and renewal of beings."[12] The meaning of *history,* in the term *natural history,* has here taken on a temporal dimension. Buffon argues that we know the essence of natural things only through their succession in time. If we know species only by the history of their propagation, then it is absurd to use the same principles for classifying living and nonliving things. Rocks do not mate and have offspring. The taxonomy of the mineral kingdom cannot be based on the same principles as that of the animal and vegetable kingdoms.

Nevertheless, Buffon did not intend to limit history to plants and animals. His natural history was both temporal and cosmic. It was not limited to a pure description of things as was, for example, Réaumur's marvelously detailed *Mèmoires pour servir à l'histoire des insects* [*Memoirs on the history of insects*] (6 vols., 1734–42) but revealed the whole scheme of nature. Thus the first volume of Buffon's *Histoire naturelle* began with a history of the earth.

Buffon borrowed his inspiration for a temporal history from the physico-theologians of the beginning of the century. For them also natural history was temporal, because they saw God working his Providence through time. But for Buffon, natural history was entirely natural. His history of the earth simply ignored Genesis and biblical chronology. Throughout his life he altered his estimates of the age of the earth, but they were always much greater than the six thousand years calculated from the biblical story. In his *Epoques de la nature* [*Epochs of nature*] (1778), he divided the earth's history into seven epochs. The earth was originally a molten mass torn away from the sun by a colliding comet about eighty thousand years ago. Because of its smaller size, the earth cooled faster than the sun. Its surface solidified as gases were vented into the atmosphere. Then, as it cooled, the solid crust shrank and cracked, creating the oldest valleys and mountains. When the temperature dropped far enough for the vapors to condense, seas formed, eroding the mountains and depositing sediments. The first forms of life appeared, leaving their fossil remains in these sediments. The seas then retreated, since much of the water disappeared through rents in the cooling crust. Plants appeared on land, while volcanoes, fueled by the organic matter that was washed into crevices in the earth, changed the landscape. Land animals appeared as the earth continued to cool. The continents separated, and new islands arose in the Atlantic. Finally, in the seventh epoch, man appeared and began to control and shape the earth. Within another ninety-three thousand years the earth will become too cold to support life. The key to all of these changes was the cooling of the earth. Buffon heated globes of cast iron and measured their rates of cooling. From this information he extrapolated to a globe the size of the earth and estimated the time for each epoch. Today his history appears fanciful in the extreme, but it employed natural causes and gave a temporal dimension to natural history.

The historical dimension in Buffon's writing separated him from his contemporaries. Charles Bonnet, for example, also believed in the Great Chain of Being, but it was a chain without a temporal history. In his *Considérations sur les corps organisés* [*Considerations on organized bodies*] (1761) and his *Contemplation di la nature* [*Contemplation of Nature*] (1764), he reiterated the principle of plenitude. There were no gaps or demarcations between the forms of living things; classifications were entirely nominal. For Bonnet the continuity of the chain was necessary to guarantee its rationality. Leibniz had made the same argument fifty years earlier, and for Leibniz it had a mathematical foundation. Leibniz believed that the forms of things stood in relationships similar to those that exist in mathematics. If the forms were discontinuous, then the functions relating them would be discontinuous, and in mathematics at mid-century a discontinuous function had no meaning at the point of discontinuity. Rationality required continuity.

Bonnet's rational philosophy had no place for time. Like logic and mathematics, it stood outside of time and was not contingent on temporal events. Bonnet included minerals in the Chain of Being because they were merely the simplest forms in the chain. His belief in the preformation of germs was also consistent with his view of nature as static. Buffon, on the other hand, insisted on the temporal dimension, criticized the use of mathematical analogies in natural history, refused to include minerals in the Chain of Being, denied preexistent germs, and included historical geology. Buffon changed the meanings of both the terms *nature* and *history* in natural history.

Buffon's separation of the study of the earth from natural theology was characteristic of geologic method during the second half of the eighteenth century. In Fact the terms *geology* and *geologist* were first used regularly with their modern meanings by Horace Bénédict de Saussure (1740–99), author of *Voyages dans les Alpes* [*Voyages in the alps*] (1779–96), one of the earliest geologic field studies of the Swiss Alps (see Figure 5.7). Jean Guettard, who, as we saw earlier, employed Lavoisier in his geologic survey, was the first to realize the extent of volcanic geology in Europe. He recognized that the black milestones that he encountered near Moulins in central France were probably volcanic in origin, and he traced them back to the quarry from which they came. He identified the quarry as an old lava flow and determined that the abrupt rocky mountains in central France called *puys* were cores of old volcanoes. Nicolas Desmarest (1725–1815) continued to seek evidence of volcanic activity in Europe and showed that it was much more extensive than even Guettard had supposed. More important, Desmarest concluded from studying different kinds of rock associated with volcanoes that basalt was of igneous origin.

The emergence of geology as a science at the end of the eighteenth century is usually associated with a German teacher of mining, Abraham Gottlob Werner (1749–1817), and with the Scottish philosopher James Hutton (1726–97). The views of these men are usually described as representing another dichotomy in the history of science, like that between mechanism and vitalism, or between the theory of preformation and the theory of epigenesis – the assumption being that one side was right, the other wrong, and that right inevitably triumphed over wrong. In fact, their views were not entirely opposed.

Werner believed that rock strata were either sediments originally deposited at the bottom of the sea or crystalized deposits precipitated from seawater. Werner gave only a minor role to volcanic action. This emphasis on water as the chief agent of rock formation caused Werner and his colleagues to be named "Neptunists." Those who emphasized volcanic action were called "Vulcanists" or "Plutonists."

Hutton believed that the warping and tilting of strata was caused by the earth's internal heat, which also was vented occasionally through volcanoes. More important, he believed that basalt had crystalized as it cooled from a molten state and was not, as Werner had thought, formed by precipitation from the seas, although Hutton readily admitted the role of water in eroding the land and in depositing sediments. Hutton was the first to state clearly, in his *Theory of the earth: with proofs and illustrations* (1795), that the earth

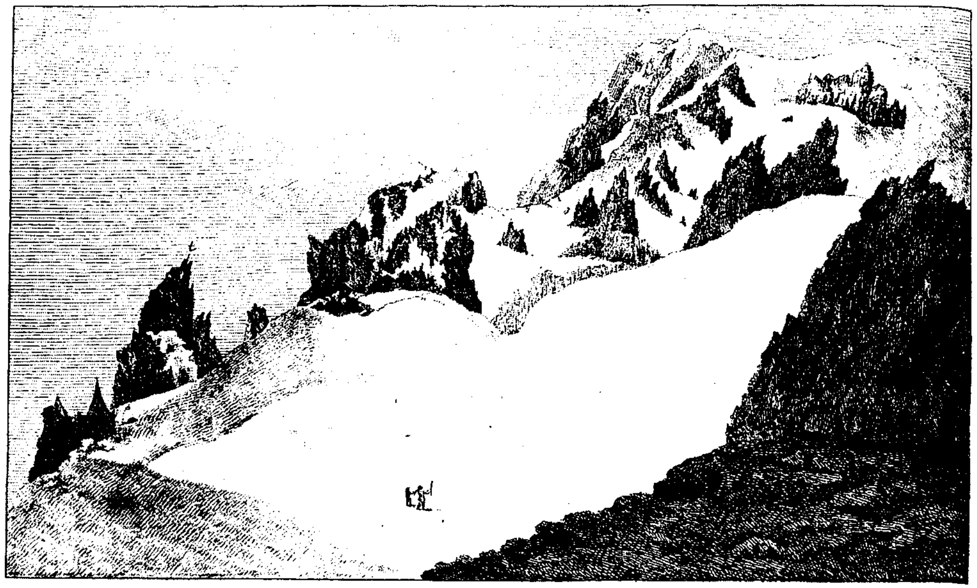


Fig. 5.7. The geology of the Alps. The first description of geologic fieldwork in the Alps was Horace-Bénédict de Saussure's *Voyages dans les Alpes* [*Voyages in the Alps*] (1779–96). In this illustration from the book, the two climbers are dwarfed by the immensity of Mont Blanc. De Saussure concluded that the distorted strata seen in the mountains could only have been created by explosive forces deep within the earth. *Sources:* Horace-Bénédict de Saussure, *Voyages dans les Alpes précédés d'un essai sur l'histoire naturelle des environs de Genève* (Neuchâtel, 1779–96), vol. IV, pl. IV. By permission of the Syndics of Cambridge University Library.

changed only slowly and uniformly by the processes that have been observed during historic time. "We find," he wrote, "no vestige of a beginning – no prospect of an end." This "uniformitarian principle" can be juxtaposed against a doctrine of "catastrophism" – the assumption that land forms were caused by geologic events greater than any observed by man.

The Noachian Flood was one such catastrophic event, and a "Neptunian" one to boot. Catastrophes also helped to fit geologic time into the chronology given in the Bible for human history. But the developments of geology in the nineteenth century demanded a geologic time scale much greater than any that the Bible would allow. It also became clear that basalt had not precipitated from the seas but had an igneous origin. Both of these developments supported the Vulcanist and the uniformitarian positions, and this supposed victory of the Vulcanist-uniformitarians over the Neptunist-catastrophists has been seen by some as a triumph of science over religion and as another instance of the superiority of British science. In fact, Hutton was profoundly religious, although not an orthodox Christian. In keeping with the natural theology tradition, he believed that the erosion cycle was God's means of replenishing the soil and providing mankind with food. Nor was he totally averse to catastrophes. He stated in his *Theory of the earth:* "The theory of the earth that I here illustrate is founded on the greatest catastrophes which can happen to the earth, that is [continents] being raised from the bottom of the sea and sunk again."[13] John Playfair (1748–1819), who popularized Hutton's theory in his *Illustrations of the Huttonian theory of the earth* (1802), removed both the catastrophes and the action of God from the theory. Since the supreme being was no longer allowed to move the continents up and down, this particular part of Hutton's theory remained unexplained.

A less artificial distinction between the works of Werner and Hutton than that which implies that they were totally opposed in their beliefs can be found in their methodology. Werner was a famous teacher at a mining school in Saxony. The primary emphasis of his work was on mineralogy, and he sought to make an encyclopedic description and classification of the mineral kingdom. Hutton emphasized historical geology and the study of land forms. Simply put (too simply for complete accuracy), Werner was more like Linnaeus and Hutton was more like Buffon. The differences in their approaches to natural history were more differences of subject and method than differences of belief.

These differences of method were most clearly spelled out in the German tradition. Leibniz and Christian Wolff had made a careful distinction between the visible world of nature and the ideal, abstract world of the mind. History, in this philosophical tradition, belonged firmly in the visible world of nature, because history could only record a continuous series of actual beings or events. The history of nature involved no arbitrary choice of characteristics and no logical division of forms such as those employed in the taxonomy of Linnaeus. Buffon knew of this distinction in Leibnizian philosophy largely through reading Madame du Châtelet's *Institutions de physique.* Buffon's familiarity with it can be seen in his statement of method in the *Histoire naturelle,* where he condemned Linnaeus's taxonomy for being artificial. Buffon believed that his taxonomy was natural because it was historical.

Kant, the eighteenth-century philosopher who most skillfully unraveled these metaphysical and methodological knots, read Buffon's *Histoire naturelle* and used the same methodological distinctions as early as the 1750s. Kant distinguished between the history of nature (*Naturgeschichte*) and the description of nature (*Naturbeschreibung*). A taxonomy in *Naturgeschichte* need not be artificial, because the reproductive histories of families of individuals define the species without making it necessary for the natural historian to arbitrarily select characteristics. But taxonomy in the realm of *Naturbeschreibung* would of necessity be a logical division imposed by the mind upon nature. In geology, Hutton and Werner ended up on opposite sides of this distinction, Hutton favoring a historical treatment of the earth, and Werner favoring a descriptive treatment. But the fact that the system of characteristics employed in *Naturbeschreibung* was artificial did not make it invalid. Kant did not denigrate *Naturbeschreibung.* He recognized, as Buffon had not, that a taxonomy such as that given by Linnaeus was valuable, in fact essential, even though it was to a large extent arbitrary. The same thing can be said of Werner's mineralogy. A taxonomy of rocks and minerals, combined with careful descriptions of their usual occurrences and formations (Werner called this "geognosy"), may not tell us much about their origins, but it is indispensible for geology.

Werner's attachment to the tradition of *Naturbeschreibung* can be seen from the title of his most famous treatise, *Kurze Klassifikation und Beschreibung der verschiedenen Gebirgsarten* [*A short classification and description of the different mineral assemblages*] (1786). It was possible, of course, to have a plain description of nature that did not attempt a taxonomy, and "plain description" was definitely Werner's primary goal. He chose to describe minerals by their external characteristics, such as color, taste, texture, smell, and hardness, rather than by internal characteristics, such as chemical composition and crystalline structure. His motive was largely pragmatic since for miners it is more important to be able to identify minerals than to be able to classify them. Werner said that "to classify minerals in a system and to identify minerals from their exterior . . . are two different things." He would "rather have a mineral ill classified and well described, than well classified and ill described."[14] From a philosophical point of view, a natural system of classification based on history would be more valuable than an artificial system based on external characteristics, but from the point of view of the practicing mineralogist an artificial system that did not require a prior knowledge of the history of the earth was more valuable.

From our modern perspective, *Naturgeschichte* would seem to have had one important advantage over *Naturbeschreibung:* Its temporal nature would appear to make it more receptive to ideas of evolution. But in fact this was not the case. The historical view of nature was most strongly advocated at the middle of the century by Buffon and at the end of the century by Georges Cuvier (1769–1832), both of them believers in the fixity of the species, and both of them natural historians who did not believe in evolution. The philosophers who advocated or at least seriously considered the idea of the transformation of species were Maupertuis, Diderot, and Lamarck, none of whom had any real interest in history. Their emphasis was on generation and the forces in living matter. Thus one finds history and transformism both appearing in the study of the living world during the eighteenth century, but not together.

The ideas that would be important for the theory of evolution appeared during the Enlightenment, but not the theory itself. What was true of evolutionary theory was true of most fields of biology. They were disciplines almost formed by the end of the century – but not quite. The life sciences had changed greatly. The mechanical philosophy, which had been so successful in the physical sciences during the previous century, had failed in the life sciences, but it had succeeded in destroying Aristotle's methodology. A return to the concepts of substantial forms and final causes was impossible. With the old foundation gone and with the new mechanical philosophy also proving inadequate, a search for new methods of investigation and for new theories was inevitable. What the philosophers of the life sciences found – or rather founded – was the science of biology.