Prelude: Heredity, Sex, and Species: The Greek View

1

Τηλέμαχ', οὐδ' ὄπιθεν κακὸς ἔσσεαι οὐδ' ἀνοήμων·
εἰ δή τοι σοῦ πατρὸς ἐνέστακται μένος ἠῦ,
οἷος κεῖνος ἔην τελέσαι ἔργον τε ἔπος τε,
οὔ τοι ἔπειθ' ἁλίη ὁδὸς ἔσσεται οὐδ' ἀτέλεστος.

Homer: *Odyssey*[1]

October has a special significance to the modern scientist, because in this month the Karolinska Institutet in Stockholm announces the year's winners of the Nobel Prizes in three scientific disciplines (as well as in other fields)—medicine and biology, chemistry, and physics. Those scientists who believe that they have made breakthrough discoveries in one of these disciplines await the announcements with hope and trepidation, all others with curiosity. For although there are other awards that recognize the significance of scientific discoveries, none of them carry the prestige that a Nobel Prize does. The accolade is accompanied by great media interest, which then usually lasts until the actual awards ceremony in December. The laureates, however, continue to enjoy a special status among their peers afterward, which often leads to a small avalanche of other awards. They also become adornments to the institutions with which they are affiliated, as well as to their native towns and nations. Outspoken laureates become media gurus, to whom journalists like to turn to for their comments on a variety of political, social, and scientific issues. They remain in the limelight for as long as they are willing to cooperate with the news hunters. For the rest of the laureates, the limelight fades gradually. Nevertheless, they are assured of immortality, even if it may only be restricted to a mentioning of a name followed by a few explanatory lines in a larger encyclopedia. For fame is fickle and the memory of humankind proverbially short—and it is not too difficult to understand why. Nobel Prizes in the three disciplines mentioned have been awarded yearly, with a few exceptions, since their inception at the beginning of the twentieth century. As there are one to three laureates in each discipline each year, in the more than 100 years of award giving, the awardees have grown into a small crowd. Who could remember all their names and accomplishments? Even the practitioners of the three disciplines can at best name fewer laureates than they have fingers on one

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hand. And so all we can expect the active memory of humankind to retain are but a few names that stick out far above the Nobel Prize standard. These are the names of scientists, whose discoveries have changed or have led to a change in the way that humanity views the world. They are scientists like Albert Einstein, Max Planck, and Niels Bohr in the twentieth century; Charles Darwin, Alfred Russel Wallace, and Gregor Johann Mendel in the nineteenth century; Isaac Newton in the eighteenth century; Galileo Galilei in the seventeenth century; and Nicolaus Copernicus in the sixteenth century, when modern science began to emerge.

The inclusion of Mendel in this absolutely top class of scientific giants might surprise some readers, who may be used to thinking of him as a good-natured, pious monk, toiling for years in his small garden, crossing pea plants, until he stumbled upon the observation that their characters segregated at specific ratios. We shall argue in this book that this portrayal of him is nothing more than a myth. We shall argue also against the slander that he cheated, as some biographers have declared, and against the variety of postmodernist claims of Mendel not being a Mendelian (carrying his experiments to disprove Darwin, not carrying any experiments at all, and so on and so forth). We shall show all of these claims to be nonsensical, due to those authors' insufficient knowledge of Mendel's work and of the circumstances under which he labored. We shall show Mendel as being aware of the implications of his discovery, which did nothing less than overturn the more than 2000 year long dominance of the Aristotelian view of heredity and replace it with a modern corpuscular view. But before we turn to Mendel, his life, and his work, we must explain what exactly this old view was and why it prevailed until Mendel's time. What follows will not be easy to read, for it will take us to the heart of Aristotle's philosophy. Hopefully, a reader who perseveres through these difficult parts will come out rewarded with an understanding of the background against which Mendel's achievement must be pitted in order to grasp its real significance. But first a cartoonist's view of the central issue.

Heredity Counter Generation

On a sunny Sunday afternoon a young couple strolls through a park with their newborn son in a baby carriage. As they meet a family friend, he leans over the carriage and exclaims: "How cute! He looks just like his father!" (Fig. 1.1). This scene, which must have played itself out time and again in various versions through the ages, epitomizes one of the most profound mysteries of life: the mystery of *generation* or *reproduction*. These two words derive from the Latin verbs *generare* and *producere*, respectively, both of which mean, "to bring forth," "to give rise," "to bring into being," "to beget," "to procreate," or "to give birth." The addition of the prefix *re-* to *producere* emphasizes a second meaning of both words, namely, that besides the act of bringing forth, they also imply a *resemblance* between that which is brought forth and its originator. In the processes of life, the originator is the *parent* and that which originates the *progeny* or *offspring*. The second meaning of generation (reproduction) is most succinctly expressed by the phrase "like begets

Fig. 1.1 Cuckoo's egg or the incorruptibility of heredity

like." The begetting can be either *sexual* (i.e., involving the union of male and female germ cells) or *asexual* (i.e., not involving such a union). The resemblance between the offspring and its parent has two aspects. The one aspect is that the new individual is normally of the same *kind* (*genus* in Latin) or *species* as the parent (the human species in Fig. 1.1). The second aspect is that within a given species, the offspring resembles the biological parent in a particular feature (the bulbar nose in Fig. 1.1) which is absent in many other individuals of that species. Let us call this transmissible feature *character*, and the phenomenon of transmission *heredity* or *inheritance*. We see immediately how the terms sex, species, and heredity tie neatly together in the concept of generation (reproduction). This concept was developed in ancient Greece in the fifth century Before the Current Era (BCE) by Aristotle and then incorporated into the foundation of Western thought. There it persisted, virtually unchallenged, until the nineteenth century. In that century, however, it underwent a radical reinterpretation, when the speculations on which it rested were subjected to experimental verification. The term "generation" was then largely abandoned in its original meaning (though it eventually acquired other meanings). The three components of generation (sex, species, and heredity) developed into separate sciences: reproduction together with developmental biology, evolutionary biology, and genetics, respectively. The man, who single-handedly accomplished

this transition from generation to genetics, was Gregor Johann Mendel. If we are to appreciate fully the significance and greatness of his accomplishment, we must try to grasp the circumstances under which the generation concept arose and also go into some detail of the concept itself. The aim of this chapter is to do just that. Here we give a brief introduction to the intellectual climate in which the ancient Greek philosophy emerged, followed by an equally brief description of two of its themes which are relevant to the present discussion, and then devote the rest of the chapter to Aristotle's generation concept.

The Mutiny of Reason

In the seventh century BCE, what later came to be called Greece was a loose conglomerate of independent, competing, and sometimes warring city-states strewn on the coast along the Mediterranean Sea. Only a common language, shared gods, and similar culture united the city-states. Like other peoples of that time, the Greeks used gods to explain phenomena and events they could not explain otherwise. Thus, they attributed thunderstorms to Zeus sailing the thunderclouds and hurling thunderbolts; earthquakes to Poseidon stomping his feet and thrusting his trident into the ground; winds to Boreas, Zephyr, Notus, and Eurus, each blowing his breath in a different direction; and so on. These explanations were so simple that even the dimmest person could grasp them and so make sense of the world. But for some people, they seemed a bit too simple. Toward the end of the seventh century BCE, a group of savants initiated a movement that expressed dissatisfaction with the traditional view of the world and developed a new view, from which gods were largely expelled. Two words then came to differentiate the traditional and the new views: *mythos* and *logos*. Initially the words had a similar meaning, but as they evolved, they acquired diametrically opposite connotations.[2] The Greek word *mythos* originally meant "speech" or "thought" but gradually came to stand for "a traditional story of ostensibly historical events that serves to unfold part of the world view of a people or explain a practice, belief, or natural phenomenon".[3] The term *logos* might have originally meant "word" or anything connected with the use of words, for example, a "narration." In this sense it was used interchangeably with *mythos*.[2] Later, however, it assumed a new meaning. As the Romans began translating Greek texts into Latin, they rendered *logos* as *ratio*, in certain contexts. This Latin noun was derived from the verb *reri*, which originally meant "to calculate," and later also processes mentally resembling calculation, such as "to reckon," "to think," and especially to think in a particular way—"to reason." *Logos* thus came to be translated as *ratio*, in the sense of "reason" and *reasoning*. In this special sense, "reason" became nearly synonymous with "cause," and "reasoning" came to mean the kind of thinking in which thoughts followed each other in a cause and effect combination. Other names that came into use for this form of thinking were *rational* and *logical*. These two terms, however, had originally slightly different meanings. As Greek savants established certain rules of thinking and termed the study of these rules *logike* (logic), *logical* became the kind of thinking that adhered to the principles of logic.[3] The Greeks began thinking logically

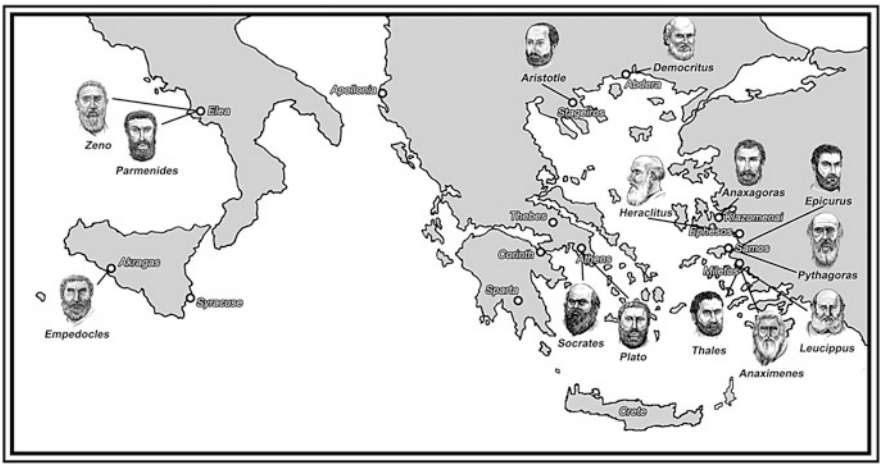

Fig. 1.2 *Frogs about a pond*: the geography of ancient Greek philosophy. The quote is from Plato's *Phaedo*; the "frogs" are the ancient Greeks and the "pond" the Mediterranean Sea, which they colonized

already when they were still in the mythological period of their development.[4] They then conceived stories that were myths by their function (explanation combined with an entertainment) and because they moved back and forth between natural and supernatural but had a tendency toward rationality. Poetic and rational thinking mixed freely in these myths, and it was only a question of time for the rational mode of thinking to prevail over the poetic.

The prosperity of the upper classes, the propensity of the Greeks to use rational thinking, and the absence of organized clergy had led to the rise of a breed of self-supporting freethinkers engaged in an intellectual intercourse that resembled an soccer game. The object of the game was to score points not with a ball but with thoughts challenging the opponents to a response. The game was conducted by verbal exchanges at gatherings or symposia,[5] at schools founded by leading savants, and by means of papyrus scrolls on which the authors recorded their thoughts in writing. One of the first such schools arose in the Greek colony of Miletus, an ancient port on the western coast of Asia Minor (Fig. 1.2). The founder of this *Milesian school*, Thales of Miletus (c. 624–c. 543 BCE), and his followers Anaximander of Miletus (c. 610–c. 546 BCE), Anaximenes of Miletus (c. 585–c. 525 BCE), and others focused their inquiries on nature, which the ancient Greeks called *physis*. Their means of inquiry were observation and rational thinking aimed at explaining the world by the operation of natural (material, physical) agents. Because of their focus on *physis*, they came to be known as *physiologoi* (singular *physiologos*), "those who spoke about nature." They were contrasted with *theologoi* (singular *theologos*), "those who spoke of gods," the thinkers who evoked gods (*theoi*) to explain the operation of the world. Together, the *physiologoi* and *theologoi* began to be spoken of as *philosophoi* (singular *philosophos*),[6] "those who loved wisdom." Since the word

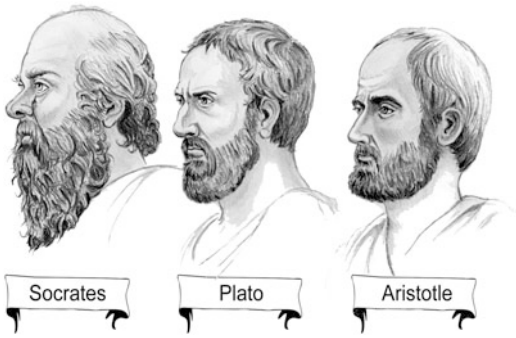

Fig. 1.3 The Athenian Troika

"physiologists" ultimately acquired a more specific meaning, to avoid confusion, we will refer to the ancient physiologists as *philosophers*. The philosophers focused on two fundamental questions regarding the nature of *reality* (i.e., that what is): first, What is? and second, Does it change and if so how? Since the interest in this chapter is the origin of new individuals (genesis, generation), we begin with the second question and come to the first later. Moreover, we restrict our attention to those philosophers, who made the most significant contributions to this subject. They are Heraclitus, Parmenides, and the Athnian Troika – Socrates, Plato, and Aristotle (Fig. 1.3).

Change or No Change?

For the ancient Greeks, "change" was nearly synonymous with "motion." The common view of change was that it represented a transformation of one thing (*A*) into a different thing (*B*). During the transformation, thing *A* ceased to exist and a new thing, *B*, came into being. The process thus involved three states: *Being* (the existence of thing *A*), *Becoming* (the coming into being of thing *B*), and *non-Being* (the cessation of *A's* existence). Early in Greek philosophy emerged two diametrically opposite views of change—that of Heraclitus and that of Parmenides. Heraclitus denied the existence of Being and proclaimed all existence for Becoming. Parmenides, in contrast, denied Becoming and held all existence for Being. Expressed simplistically, Heraclitus claimed that all is change all the time, whereas Parmenides maintained that there is no change in the world at any time. To a commonsense person, these extreme views are both preposterous, for it is apparent that some things change, while others persist. But some ancient Greek philosophers were not commonsense people. Heraclitus of Ephesus (c. 535–c. 475 BCE)[7] argued that things appearing to persist in reality change so slowly that we do not notice it. Rocks crumble, mountains erode, metals corrode, and living things age and die. There is nothing in the terrestrial realm that lasts forever. There is never anything of which we can say that it *is*, because while we think of it as a particular thing A, it has already become something else. There is no Being, there is only

Becoming. If, however, everything flows, as Heraclitus says, then you cannot ever say that something is or is not. What remains constant in the ever-changing world is not the substance or substrate but a process—the process of change. As things change, substances perish, so that there is no single substance or element that is common to all things, not even water or air, which the Milesians held for just such substances. When water changes to air, it "dies" in the process and there is nothing left of it in the air, and the same applies to a change in the reverse direction. Change is so ubiquitous that it itself must be regarded as the real nature of reality.

Like Heraclitus, Parmenides of Elea (flourished in the early fifth century BCE)[8] challenged the commonsense view of change but from a very different position, in which he arrived at the conclusion that change is a logical impossibility. Here is his argument: We start with the statements that *A (Being) is*, whereas *B (non-Being) is not*. The latter statement, however, is nonsense, says Parmenides. Stating that something is not is talking about nothingness, but about nothing there is nothing to be said. As for the former statement, it asserts that *A* is *A* and nothing else. If we then say that *A* is changing into *B*, we must ask: Where does the *B* come from? There are two possibilities. Either it comes from nothing, but this cannot be because we just said that about nothing there is nothing to be said. Or *B* comes from *A*, but this is also impossible because we also said that *A* is *A* and nothing else, otherwise it would not be *A*. If *A* had a trace of *B* in it, then saying that *A* is *A* would not be true, and saying that *A* is *A* and *B* would violate the logical law of contradiction, which asserts that something cannot be two things at the same time. Hence *A* cannot logically change into anything ever. In fact, there is nothing in the world that can change into something else. Not only that, but also there can only be one thing in the world, only One Being, for where would the other Beings come from? Not from nothingness and not from traces of other Beings in the One Being. Furthermore, if the One Being is without a trace of other Beings, it can be said to be homogeneous, exactly alike throughout. Also, since a Being can never change, it remains forever the same, undifferentiated and featureless. Since it cannot come into Being from non-Being and since it cannot turn into non-Being, the One Being is eternal. For the One, time does not exist; the One has no past and no future—it only is. Since it is full everywhere and since it cannot move (remember: motion is a change!), it cannot go anywhere. Parmenides' is a very unappealing vision of the world. Unmoving, unvarying, featureless, uneventful, his is a world without a past and with no future, without evil but also without goodness, without sadness but also without joy. Parmenides' logic seems impeccable, except for the mysteries of where the philosopher himself fits into this picture and how the illusion of many different things arises. Obviously, the senses are deluding us, but in the world of One, there should not be any senses in the first place nor should there be individuals endowed with senses. Is the One dreaming up the world of many? Is it hallucinating? Obviously not, for the same ironclad logic that leads to the One also forbids it to display any activity.

Rather than siding with Heraclitus or Parmenides, most contemporaneous Greek philosophers tried to find a compromise solution between these two extreme views. Generally, the solution had the form of postulating two components of reality, one

fixed and the other changing. The function of the fixed component was to provide continuity and so dodge the accusation of an *ex nihilo* generation. The second component served to introduce the actual change on the background of the fixed component. The various proposals varied in the degree of sophistication, some of them being no more than a charade obscuring but not solving the real problem. Others, on the other hand, had to be taken seriously by Parmenides himself. Among the latter were two proposals, which had a long-lasting influence on Western thought—those of Plato and Aristotle.

Plato's Myth

Plato (c. 428/427–347)[9] admitted that the physical world is changing constantly but at the same time postulated the existence of another world characterized by constancy and permanence. Since the other world overstepped or transcended the physical world, it came to be called *transcendental*. Plato's postulate of a nonphysical realm might have been inspired by his teacher Socrates (c. 469/470–399 BCE).[10] The latter was interested in defining ethical concepts, but when he stopped people on the street and asked, for example, "What is courage?" he commonly got answers such as "Courage is when a person saves a child from a burning house" or "Courage is when a soldier risks his life to bring his wounded comrade into safety." These, of course, were not definitions but merely instances of courageous behavior. Socrates realized, nevertheless, that they pointed at something shared by all of them and that this shared feature was the definition of courage. Plato extended these thoughts to physical objects such as tables or chairs and realized that all objects of the same kind shared a common denominator which he called Idea—"tablehood" in the case of tables, "chairhood" in the case of chairs, and so on. There was, however, no tablehood anywhere in the physical world; there only were particular tables, and the same was true for the chairhood and the particular chairs, as well as for all the other kinds of physical objects and their Ideas. Where then were the Ideas? Since they were not physical, they had to be immaterial and had to occupy a world of their own, a world without space and time—the transcendental realm. The absence of time made the Ideas timeless and changeless, in contrast to the material objects of the physical world, which were all subject to corruption and death. Being eternal and incorruptible made the Ideas perfect, again in contrast to the physical objects, which had various imperfections in comparison to their corresponding Ideas. Since the physical objects of a given kind resembled, if only imperfectly, their corresponding Idea, there had to be some sort of "communication" between the physical and transcendental realm. Plato suggested that the Ideas "participated" in the generation of each physical object, when it came into being. He did not specify what the participation amounted to, but some of his interpreters compared the process to imprinting a seal onto a blob of warm wax. The seal corresponded to the Idea with an ideally executed original pattern; the imperfectly imprinted pattern corresponded to a particular physical object, and the wax to what Plato called a "receptacle," presumably matter. Indeed, since Plato some philosophers hold matter

for something coarse in comparison to purported ideal immaterial substances and the physical world for a degraded version of a transcendental ideal world. And since Descartes (1596–1650 of the Current Era or CE), they try in vain to explain how immaterial substances might communicate with material objects. This conundrum is, however, not the only insurmountable problem with what is sometimes referred to as Plato's doctrine of Ideas; we will mention some of the other problems below when we come to Aristotle. In fact, the doctrine is so full of holes that it is best assigned to mythology. Plato might have been aware of its weaknesses, and this might have been the reason why he had not described it as a whole anywhere in his 26 dialogues. What is now referred to as his doctrine of Ideas has in reality been pieced together by his interpreters from fragments and hints scattered throughout his different works. Plato's first and most prominent critic was his student Aristotle. He was skeptical of his teacher's doctrine not only because it was a relapse into mythology and because of the contradictions and inconsistencies it contained, but also for its implications concerning what did and what did not constitute knowledge. To Plato physical objects—because of their materialness, inconstancy, and perishability—were unworthy of study, for such an inquiry could produce at best only unreliable opinions based on conjectures. The only source of genuine knowledge was the realm of perfect, unchanging, and eternal Ideas, accessible through intuitions and recollections of encounters of the immortal human soul on its sojourn to the transcendental world. The sojourn took place after the death of one individual and before the soul's incarnation into the body of a philosopher coming into being. In contrast to Plato, Aristotle, perhaps because of his family background (he was a scion in a lineage of physicians), had high respect for an empirical approach to a knowledge-gathering process. It is therefore Aristotle, and not Plato, who is the true founder of Western philosophy and science, over which he has held sway over a period of nearly 2000 years. Hence, if we want to learn what the West knew or thought of heredity at the time of Mendel, we must turn to Aristotle. It is for this reason that we devote the rest of this chapter largely to him.

Aristotle[11] and His Inventory of Reality

Aristotle (384–322 BCE) was born into a well-off family in Stageiros, an ancient Greek city on the Chalkidike peninsula. His father was the personal physician of Alexander the Great's grandfather, and his mother brought into the marriage substantial dowry. At the age of 17, Aristotle joined Plato's Academy in Athens, where he then remained for 20 years, until his tutor's death in 347. Whatever else one might think of Aristotle, this much is undeniable: He is matchless in developing the most comprehensive, cohesive, coherent, and systematic philosophical system. Although only some 30 of the more than 150 works he may have authored have survived, this corpus is awe-inspiring in its breadth and depth. It develops and formalizes all branches of philosophy now recognized, as well as many areas, which are now classified as sciences. The coverage is systematic in the true sense of the Greek word *systema* in that its individual parts form a unified whole. And since the system has

been developed by a procedure of inquiry based on defined rules and principles, its parts are logically tied together.

In his early works, with characteristically Aristotelian comprehensiveness, he starts his inquiry with an inventory of reality. He founds his dissection of reality on two assumptions: first, humans think in words, and second, the structure of a language reflects the organization of reality. On that basis, he seeks a correspondence between principal elements of the Greek language and the components of reality. The principal structural component of language is a sentence that asserts or denies something about something else. The basic units of such a sentence or *proposition* are the *subject* and the *predicate*. The English word "subject" is derived from the Latin *subjectus*, which is the equivalent of the Greek *hypokeimenon*. In all three languages, the equivalent nouns mean the same thing—"that which is lying under." Similarly, the English word "predicate" is derived from the Latin *predicatus*, a past participle of *predicare*, whose Greek equivalent is *kategorein*. In all three languages, the essential meaning of the equivalent verbs is "to affirm." The noun predicate (*kategoria*) means therefore "that which is affirmed (said) of something." According to Aristotle, corresponding to the subject and predicate are two principal components of reality, which he calls *ousia* and *kategoria*. The proper translation of *ousia* is "being," but the term is more commonly rendered into English as "substance," which also fits better in the context in which it will be used here. *Kategoria* is commonly transliterated as "category," but in the present context, it will be rendered into English as "attribute" or "property." Thus, in linguistic terms, *ousia* (substance) is the subject of whom something is affirmed, and *kategoria* (attribute) is that which is affirmed of the *ousia* (the attribute affirmed of a substance). This division is the first clear-cut separation of things' attributes from the things themselves. Earlier philosophers failed to make that distinction. For example, Thales of Miletus held not only water but also wetness for a substance. Even Plato, according to Aristotle, confused the two concepts, and it was this error that led him ultimately to the postulate of the transcendental realm. But if *kategories* are attributes of substances, there is no need for an outwardly realm; it is much simpler to assume that properties are *in* the substances or, as philosophers like to say, they are *immanent* in things. Wetness, as an attribute of water, must be in water itself; redness of a poppy flower must be in the flower; courage must be in the courageous person; and so on. We point out this now obvious fact because, as we shall learn later, it will become one of Mendel's important postulates on which he would base his experiments (see Vol. 2 Chap. 3). This circumstance is one of the reasons why we think it proper to start this book with a brief expose of ancient Greek philosophy, Aristotle in particular.

In his early works, Aristotle also uses another criterion for grouping items of reality. To the linguistic yardstick described above, he adds an ontological[12] criterion to cluster the items into those that exist independently of other items and those that exist *in* other items. By combining these two criteria, Aristotle differentiates items of reality into four groups, of which only three will interest us here. He calls these three groups *protai ousiai* or primary substances, *deuterai ousiai* or secondary substances, and the *kategoriai* or attributes. The primary

substances function as subjects but never as predicates, and they exist independently of all other items. The secondary substances can serve as both subjects and predicates, and Aristotle describes their mode of existence as "being said of." We will explain below what he means by this expression. The attributes function as predicates only and exist only in the primary substances. Let us now have a closer look at these three groups.

The *primary substances* are the individual material objects, which are the subjects of predication; that is to say, they are the things of which statements are made. Each of the objects is a separate, distinct entity that can be pointed out as *tode ti*, that is, *this* (particular object), and taken one at a time (*kath' hekaston*). We identify some of these *particulars* by giving them proper names, for example, this man Socrates, this horse Bucephalus, this dog Rin Tin Tin, or this wolf Lobo. Both Plato and Aristotle consider the particulars real, but to a different degree: Plato as least real, mere shadows in comparison to the Ideas, whereas Aristotle holds them for the most real things that exist, and that is why he calls them *protai ousiai*, the first beings.

According to Aristotle, none of the *secondary substances* can be pointed out as *tode ti*, as this particular thing or person. Instead, they can be "said of" objects. To explain, we need to diverge slightly. It is a truism that, on the one hand, no two primary substances are identical and that on the other, some objects are clearly similar, their resemblance varying in degree. One can arrange objects into a series of inclusive groups or *classes* according to the declining similarity between the groups. In this arrangement or *classification*, at the lowest level of the hierarchy, individual objects are clustered into groups such that the objects within a given group resemble one another more than they do individuals in any of the other groups. At the next higher level, the groups are placed into fewer groups, each of which encompasses those of the lower level that share many characteristics. This process is then repeated level after level until the group with broadest shared characteristics is reached at the apex of a hierarchical pyramid. Aristotle calls the groups at any level of the sequence *eide* (singular *eidos*) and those in the nearest higher-level *gene* (singular *genos*). Hence, at any level the same group is *eidos* relative to the nearest higher-level items and *genos* relative to the nearest lower-level items. In modern classifications of living organisms, each of the different levels bears a distinct designation and the names *eidos* and *genos* are reserved for the two lowest levels. The English translations of these two terms are *species* and *genus*, respectively. So, by the expression "said of," Aristotle means that an object *x1* has been assigned to the species *X*. For example, in the proposition "Socrates is a human being," the predicate "human being" (a species) is said of the subject Socrates (the individual object). In this classification, therefore, the primary substances are the physical objects, whereas the secondary substances are the "kinds" or species.

One part of their Greek name seems to suggest that the secondary substances are *ousiai*, but the second part, the adjective *deuterai*, mitigates their substantiality, suggesting that it is not genuine. The secondary substances cannot exist without the existence of the primary substances since if there were no objects that could be classified into kinds, there would not be any kinds. Secondary substances come into

being only secondarily, on the basis of what is given primarily—the physical objects.[13] In a stark contrast to Plato, Aristotle does not hypostatize the "kinds," that is, he does not attribute to them a separate existence. He admits that they are real, but not real in the same sense as physical objects are because their realness depends on the existence of these objects. He draws the conclusion that the "kinds" are embodied or immanent in the objects, rather than existing separately from them. This deduction may seem to clash with one of the two criteria he uses in his classification of reality. Namely, the positing of the "present in" against the "said of" could be interpreted as implying that the secondary substances are *not* present in objects, whereas the above deductions imply the opposite. Aristotle resolves this seeming contradiction by suggesting that attributes and "kinds" are present in the primary substances in different ways: The attributes are incidental to the objects (some scholars compare them to parasites in the body of a host), whereas the "kinds" are essential components of the body, without which the object would not be what it is. The difference between these two modes will become more apparent later when we learn about Aristotle's inquiries into the nature of the "kinds."

"Kinds" and attributes have, however, more in common than their residence in the primary substances: Both are in the same class which Plato might have been the first to describe and which Aristotle calls *to kathalon*, "that which pertains to all." The medieval Latin-speaking followers of Aristotle translate this expression as *universalis*, meaning "belonging to the whole collection of items." Thus, the *universal*, as the term is rendered in English, is that which a group of objects has in common. The term is used both as a noun and an adjective and in either case it is contrasted with a unit—an individual or a thing—called the *particular*. It can be said that the particular is an instance of a universal or that the universal has been *instantiated* in a particular. It follows from the foregoing that universals are of two types: species type and attribute type. An example of the species-universal is the human species—the collection of individuals encompassing Socrates, Plato, Aristotle, and billions of others. An example of an attribute-type universal is "redness," instantiated in a red poppy flower, red balloon, red flag, and a countless number of other particulars. These examples illustrate the fundamental difference between the two types of universal. Red poppy flower, red balloon, and red flag have little else than the red color in common. They are unrelated items of reality, which accidentally share an attribute—the red color. We now know that the redness of these items is the result of the reflection of light of specific wavelengths by substances, which are not the same in the three items. By contrast, the similarity among Socrates, Plato, Aristotle, and all the other persons subsumed under the universal "the human species" is not accidental but the result of their *genesis*. This word, translated into English as *generation*, signifies the development of an individual. In Aristotle's view, which we will expound upon later in the chapter, the male semen transmits the essence of the father to the maternal material homolog and from the combination arises a descendant bearing the same essence as the parents. It is this transmission of the same essence that is responsible for a given "kind" begetting the same "kind" and so for the existence of particular groups—the universals. We will

return to the essence momentarily but first we must complete the account of Aristotle's inventory of reality by mentioning the third group of items—the attributes.

Actually, the features that define the essence and so also the species are in reality attributes, which one might call *essential*. But these are different from the accidental attributes that constitute the *accidental* attributes, which may vary in form among the individuals of a given species. Aristotle organizes the accidental attributes into a logical system, which falls back on linguistic analysis of the way people speak when they describe the world. Aristotle asks: What are the most general questions one must ask in order to characterize a thing? And he then proceeds to identify ten such questions and suggests that the answers to nine of them specify groups into which all predicates can be divided. The first of the ten questions identifies the substance. Because the Greek term for "predicate" is *kategoria*, the ten groups came to be known as the *categories*. (Traditionally, substance is included in the list of categories, even though it is not a predicate and hence not a category.) Aristotle's ten questions (categories) are these: What is it? (Substance.) How much of it is there? (Quantity.) What is its nature (Quality.) What is its relation to other things? (Relation.) Where is it? (Place.) When is it? (Time.) In what position? (Position.) In what condition is it? (State.) What is it doing? (Action.) And finally: How is it affected? (Passivity.) They can all be illustrated by a single sentence: "There is a man (Substance), alone (Quantity), looking like a doctor (Quality), and wiser than Hippocrates (Relation); he is in the street (Place), now (Time), walking (Position), barefooted (State), toward a surgery, either to treat a patient (Action) or perhaps to be treated" (Passivity).[14] Overall, the nine non-substantial categories can be divided to three groups covering qualities, quantities, and relations.

Now, to come back to the essence, which, according to Aristotle, distinguishes the different "kinds" from one another, we note first of all that the Latin *essentia*, from which the English "essence" derives, is a botched-up attempt to translate the Greek phrase *to ti en einai*. The literary translation of the phrase is "the what it was to be" but the medieval philosophers, not all of whom were exactly eloquent in both Greek and Latin, puzzling over it took the word *einai*, translated it as *esse*, "to be," and made the term *essentia* from it. In a simplified version, the essence of a thing is that which makes the thing what it is. The "thing," in this case, is not a concrete thing but a "kind," which we from now on will refer to as *species*. Taking as an example the species we are best familiar with, our own, let us now ask: What is the essence of the human species? There seem to be two ways of determining what makes the human species that what it is. One could be to compare it to all other species and enumerate all the differences that distinguish the human species from them. Considering that there is a very large but unknown number of species, this approach does not seem quite realizable. Aristotle therefore chooses the second approach that exploits as a shortcut his classification of nature into a hierarchy of species and genera. He determines the position of the chosen species, in this case the human species, in this hierarchy, identifies the genus to which humans belong, and then ascertains what distinguishes the human species from all the other species subsumed by that genus. In his primitive classification, the genus to which the

human species belongs is identified as "animals." In the next step, he therefore determines what distinguishes the humans from all other animals and thus automatically from all nonanimal species in nature. He decides that the distinctive feature of the human species is the capability of rational thinking. He thus *defines* the humans as animals capable of rational thinking and proclaims this capability to be the essence of the human species.

The Hylomorphic Doctrine

The division of substances into primary and secondary, followed by the placement of the secondary into the primary substances, led Aristotle to the realization that the *ousia* might not have a single but dual nature. At the same time, as we will explain later, he also realized that the assumption of a substance's dual nature was necessary to explain movement without falling into the trap set up by Parmenides. The doctrine of a substance's dual nature, as expounded in Aristotle's mature works, came later to be called *hylomorphism*. Its principal thesis is that substance (*ousia*), the basic stuff of nature, is never simple but always compounded of two components, *hyle* and *morphe*. In old Greek, the word *hyle* stood for construction material, especially wooden material, but Aristotle elevates it to a technical term, which is commonly translated into English as *matter*. The Greek *morphe*, familiar from terms such as morphology, can be translated as "shape" or more generally as "form." However, Aristotle also uses a second term for the substance's second ingredient, namely, *eidos*, which he earlier used as a specific designation of the secondary substance. Since he uses the terms *morphe* and *eidos* as nearly synonymous, the implication is that the second ingredient of the hylomorphic substance is the former secondary substance, which he previously identified as species (*eidos*), essence (*to ti en einai*), and as one class of the universals. Consequently, all four terms have now become virtually synonymous, and Aristotle uses them interchangeably, choosing one or another of them depending on the particular aspect of the second ingredient he wants to emphasize. Let us now have a closer look at the two ingredients; for clarity we write "Form" with a capital letter.

Matter and Form are so tightly associated that it is impossible to describe or imagine one without the other. In the world of sensible objects, Form never occurs without matter and vice versa. One can think of pure matter (Aristotle calls it *prote hyle*, first or prime matter) by mentally stripping away all attributes from an object. What remains cannot be perceived because it does not have any attributes human senses could register. How, then, do we know that anything is left at all? We know it indirectly from the analysis of change. Since change does take place, we must assume that there is something that endures through the process and receives a new Form in place of the old one, and we call this "something" matter. Other than that, we cannot say anything about the prime matter; it lies outside the grasp of human knowledge. It does not fit into any of the categories of being. Aristotle assumes that in some respects, matter is the opposite of Form. While Form is an actuality, matter is a potentiality for having a Form impressed on itself. Form is

activity, whereas matter is passivity. Form is differentiated and determinable, whereas matter is undifferentiated and indeterminable. Yet, Form is not a thing; it is the *way* in which matter is organized into a functional whole—the hylomorphic object. A modern-day person, brought up in the tradition of Christian matter-spirit dualism might be tempted to seek parallels with the Aristotelian matter-Form dualism. Such temptation must, however, be resisted. In the *prote hyle*, there is no sign of materialness, however one defines it, for in this formless and propertyless "pure matter," there is no sign of anything. Similarly, although the pure Form is Aristotle's Unmoved Mover, which with its helpers runs the universe, it has little in common with the Holy Ghost of the Christian triune God. Also, as we explain later in the chapter, the Aristotelian concept of the "soul" is very different from the "soul" of Christian mythology. In a material object of Aristotle's reality, it is through the action of the Form that the object's materialness reveals itself in the manner of weight or extension in space. Thus Aristotle's matter and Form do not fit into mold of the traditional matter-spirit dualism. The distinctiveness between the matter and the Form is primarily in the opposite's potential and actual or passive and active, and not in materialness versus spirituality. For Aristotle the borderline between the matter and Form domains is fuzzy anyway. Thus, strictly speaking, a block of marble is a formed matter (i.e., a hylomorphic compound), but Aristotle has no qualms about calling it "matter" waiting to receive its Form under the hands of a sculptor. In this sense the terms "matter" and "Form" are relative, and the relativity arises because the imposition of a Form on matter is a complex process passing through many stages in which matter can be informed to different degrees.

Aristotle uses the term "Form" in different senses, some of which are apparent from the equation *deuter ousia* = *eidos* = *to ti en einai* = *to katholon*, since the four terms of this equation can be held for aliases of not only each other but of Form as well. In addition, since Form relates to the appearance of an object, it has obviously much to do with attributes or properties, which can be classified in three groups—essential, accidental, and individual. Above, we described the first two of these groups. The essential attributes are those that determine the essence of a species—they are species specific and hence they define the *substantial Form*. In the second group are properties for which Aristotle uses the term *symbebekota* (singular *symbebekos*), which is translated as *accidents* (from Latin *accidere*, to happen, as by chance) and which we called earlier "accidental." But, perhaps, better would be denoting them as *variable attributes*, for they are responsible for variability within a species. Aristotle is rather noncommittal regarding the origin of this variability but seems to be inclined to attribute it to a potential of the species Form for variation in certain properties under the influence of environmental factors on matter. In the third group are properties, which make the individual object unique—the *individual-specific attributes*. Aristotle argues that *individual Forms* do not exist, but if they do exist, they are of little significance. The latter claim is rooted in Aristotle's contention that scientific knowledge is the knowledge of the universals and that studying particular individuals makes little sense for reasons of their transiency. Some scholars insist, however, that the postulate of the individual Forms is necessary in order to save Aristotle's late works from internal logical inconsistencies.

There is yet another term that Aristotle uses for the Form and that must be mentioned here: *psyche*. Before Aristotle, the term was used with a variety of meanings. In Homer's time, it stood for "breath" and breath was associated with life, just as it is to this day. When Homeric heroes died, the *psyche* residing in their head escaped through the mouth to live a ghostly life in the underworld.[13] What was left behind was a motionless body, and this observation was taken as an indication that *psyche* was somehow responsible for motion. The early Greek philosophers took over this notion and attributed *psyche* to all natural objects, including stones. After all, didn't some stones, specifically magnetite, cause motion of other objects? Subsequently, however, some philosophers, for example, Heraclitus and Pythagoras, made psyche responsible for all non-corporal ("psychic") activities, separated it from the body, and attributed to it a divine origin together with immortality. This trend culminated in Plato, whose concept of *psyche* later became the inspiration for the notion of the *anima* (Latin) and *soul* (English) of the Church Fathers of Christianity. Aristotle, in opposition to Plato, returned to the early concept of *psyche* as the power behind the activities associated with change in matter. His *psyche* is intimately associated with matter, non-divine, and incapable of separate existence from matter; in other words, it is one additional alias of the Form.

Aristotle's dualistic conception of physical objects reopens the question concerning the nature of the *ousia*—the substance or being, whichever translation of the term you prefer. One consequence of the hylomorphic doctrine is that Aristotle is now forced to abandon the distinction between the primary and secondary substances and renew his search for the true substance. In this search he goes through the whole gamut of concepts he has accumulated in the meantime and confronts them one by one with the criteria a substance, in his view, must meet. We don't need to follow him in these deliberations since, if we accept the synonymy equation above, we can limit the number of candidates to three: compound of matter and Form, matter alone, or Form alone. Furthermore, since the first criterion of a substance is simplicity, we can eliminate the compound precisely because of its compoundness. We are then left with two candidates only—matter and Form. The former, the *hyle*, is the substrate (*hypokeimenon*) of being, the determined element of the compound, whereas the latter, the *eidos*, the determining element, is that by which matter is made into an object we perceive through our senses. One might perhaps expect Aristotle to choose matter as the substance, if for no other reason than its materialness underlying the existence of the natural world, but in fact, he gives the title to the Form. The next two sections should help us to understand why.

Aristotle's Theory of Change

Like most post-Parmenidean thinkers, Aristotle seeks to resolve the puzzle of change by the postulate of two components, one lasting through the alteration and the other coming into and going out of existence. He finds these components in matter and Form of the hylomorphic compound. Before going into details of his explanation of

change, let us first clarify what he understands under this term since his conception of change is different from modern. He distinguishes between change (*metabole*) and motion (*kinesis*) but often uses these two terms interchangeably, since for him they are manifestations of the same principle. In correspondence with his division of reality into substantial and non-substantial, Aristotle differentiates between substantial and non-substantial (accidental) changes. In the latter he distinguishes three kinds, corresponding to three of the nine non-substantial categories: quality, quantity, and place. The substantial change differs fundamentally from the three non-substantial changes in that it entails extinction of one substance and emergence of another. It is thus a replacement of one substance by another or *generation* (birth, coming into being, Greek *genesis*) and *decay* (death, passing, Greek *phthora*) of substances. In nature, an acorn vanishes when an oak tree grows from it, and an egg ceases to exist upon hatching of a chick. In the *non-substantial* or *accidental changes,* the substances persist through the change and only nonessential attributes (accidents) come and go. There is no need here to go any further into Aristotle's classifications and characterizations of different kinds of change, so we now return to the gauntlet thrown down by Parmenides.

The gist of Parmenides' arguments for the impossibility of change, let us remind ourselves, is in three assertions or principles. First, nothing can come from nothing. Second, everything either is or is not; there is nothing between existence and nonexistence. And third, nothing happens without an explanation or a sufficient reason. Aristotle accepts the three principles but with qualifications, which then enable him to refute the conclusions that Parmenides draws from them. Aristotle argues ingeniously that although indeed nothing comes from nothing, something can come from what is not. What leads him to this claim is his distinction between actuality and potentiality. An object, he says, actually possesses certain attributes and lacks certain others, which it potentially *can* possess. He calls the state of potential possession *steresis* (literally "lack of something"), which is commonly translated as *privation*. *Steresis* is not nothingness; it is a state in which something is not actually but can be potentially. When the potential is realized and the actual attribute arises, it does not arise from nothing but from something that, though lacking, had the potential to be. To give an example, Socrates is pale and the paleness of his skin is thus his actual attribute. But he has in him the potential for another attribute, which, if actualized, would substitute the paleness of his skin for tanness. All he has to do to actualize the potentiality is to expose his skin to the sun for a few hours. What the change that he thus undergoes amounts to is not a dissolution of the paleness into nothingness and the emergence of tanness from nothingness, for that would indeed violate the first principle of Parmenides. Rather, it is the actualization of a potential tanness (which existed in the state of privation), accompanied by the transition of the actual paleness into a potential paleness (into a state of privation). This process is clearly a *change*, which is possible without the violation of the first principle of Parmenides because in it a thing comes to be not from nothingness but from privation and another disappears not into nothingness but into privation.

As for the second principle, Aristotle points out an error in Parmenides' logic, which, when corrected, refutes the implication that change is impossible. The error is

in that Parmenides confounds existence with predication. Parmenides interprets the second principle as implying that existence is all or nothing and that therefore everything existing is complete. By completeness he means that what exists has all the possible attributes that can be predicated of it. Aristotle disagrees. In his interpretation of change, an existing thing is incomplete in that it lacks many attributes it can potentially have and that change is precisely this: the actualization (coming into being) of the potential attributes. Parmenides' mistake is that he takes the "is" in a statement of existence ("something is," meaning it exists) for being the same as the "is" in a statement of predication ("something is an attribute of a subject).

Parmenides uses the third principle to buttress the interpretation of the second. He argues that if something is, there is no sufficient reason for something to become what it already is. Aristotle's reinterpretation of the third principle follows from the qualification he attaches to the second principle. Since, when something is, it can be incomplete in its existence, there is sufficient reason for it to actualize attributes that it possesses potentially—and so to change.

Aristotle does not by any means assert that all the attributes that there are exist as potentialities in an individual object such as Socrates. On the contrary, a single object disposes with only a limited number of "dormant" attributes, which it could potentially "awake" to replace some of the attributes it actually expresses. Thus, Socrates, for example, cannot grow horns like a bull or a beak like a bird because he simply does not have these attributes in his dormant repertoire. Furthermore, during a change, the disappearing attribute cannot be replaced by just any attribute randomly chosen from the repertoire. There seem to be a certain link between the disappearing and emerging attributes in that the two attributes commonly form a pair of *opposites*. Thus, in the above example of non-substantial change, the two attributes, paleness and tanness, are generally thought of as opposites. The concept of opposites existed in Greek philosophy long before Aristotle and several of the Pre-Socratics operated with it in their interpretations of the world. Notably, Pythagoras (sixth century BCE) held opposites for reflections of the fundamental duality in the makeup of the universe. And Heraclitus espoused the view that the tension between the opposites was responsible for the constant flow of things. It was not, however, until Plato and Aristotle that the notion of the opposites had received a systematic makeover. Plato tried, largely unsuccessfully, to integrate the concept into his doctrine of transcendental Forms. The two concepts seemed incompatible and all his effort ended in a hopeless entanglement of speculations. It was then left to Aristotle to develop the first comprehensive theory of opposites, but it would take us too far astray to go into the details of his doctrine. Suffices to say that, in his view, a change always comes from an opposite. He calls this conclusion the *first principle of change,* and since, in his view, change is the foundation of natural science, it is, at the same time, also one of the first principles of this scientific discipline. It fulfills the criterion that Aristotle sets for the first principles of science: It is not derived from any other principle, while everything else is derived from it.

Thus, Aristotle dissects the change into three parts:[15] the initial object, that is, the thing that undergoes the change; the resultant object, that is, the thing that results from the change; and the persisting object, the thing that underlies the change—the

hypokeimenon, the subject of the change. There are, therefore, three ingredients of change—the two opposites and the subject of the change, the *hypokeimenon*. The two opposites are important, but neither one nor the other persists through the change; this part is reserved for the subject. It is the persistence of the subject that protects Aristotle's doctrine from the corrosive effects of Parmenides' principles. The opposites are attributes, which cannot exist on their own. They inhere in the subject of whom they are predicates, and the subject is a substance. But how does the change take place? It seems that Aristotle favors the possibility that in some cases, one opposite transforms directly into the other but that generally the change is indirect in the sense that it takes places via privations. Either way, the comings and goings of the attributes cannot transpire without the substrate, on which the very existence of the attributes depends. The substrate (the subject) remains through the change. The comings and goings of the attributes of course change somewhat the subject, but since what changes are accidental properties, essentially the subject remains one and the same.

What we have described thus far, however, has been only one of the two major types of change—the non-substantial change. What, then, of the other type, the *substantial change*? Aristotle's answer is that, in principle, it takes place in the same way, provided that we make one all-important modification in the concept of the subject. In early works Aristotle supposes that the primary substance is ontologically simple, which means that it is not further divisible into even simpler, more fundamental components. But this supposition now becomes untenable because it clashes with the requirement that something in it must persist through the change in order to neutralize the challenges of Parmenides' principles. In the non-substantial change, the traffic of attributes alters the subject, but inessentially, so that no substantial change takes place. In the substantial change, however, one substance goes and another comes in its place, so the subject cannot be the persisting ingredient of the change, unless the supposition of the substance's simplicity is incorrect. If the substance were complex, composed of two components, as the hylomorphic doctrine postulates, then one of the components could persist, while the other is changing. Since the change affects the substance in this case and since the component responsible for the difference between two substances is the *morphe*, *Form*, or *eidos*, it must be the Form that changes. Hence the component that stays the same through the change must be the *matter* (*hyle*), which is responsible for the materialness of the substance. And so, in his later works, Aristotle takes the radical step to revise the original concept of substance. He abandons the distinction between the primary and secondary substances and from here on speaks only of *substance* (*ousia*) and means by it that what had previously been the primary substance, but with the big difference that the primary substance was ontologically simple, whereas the new substance becomes complex. It is now a compound consisting of two components, Form (*morphe*, *eidos*) and matter (*hyle*). This assumption solves the problem of the substantial change, in that the Form is now free to come and go, while the matter stays put.

In a substantial change, either a new substance comes into being (in a process termed *generation*) or an existing substance passes out of existence (a process termed variously as *degeneration*, degradation, decay, or perishing). In the living world, the

two processes are tightly interconnected, resulting in birth and death cycles, repeated over and over. The death in each cycle is the death of the individual, while the rolling of the cycles assures the continuation of the species. In each cycle, generation and degeneration operate based on the three-ingredient doctrine. In generation/degeneration, the two opposites are the Form and the privation of the Form; the persisting underlying ingredient is matter. The generation is an actualization of the potential Form existing in the state of privation. The degeneration is the reverse of the generation: the passage of the Form from actuality to potentiality, that is, into the state of privation. Both processes involve matter as the component in which the changes take place but which itself remains one and the same. One of Aristotle's examples of a substantial change is the growth of an acorn into an oak tree. The acorn comes with the Form of an oak tree in a potential (privation) state. The growth of the oak tree from the acorn is the actualization of this potentiality. The mature tree produces new acorns, in which the Form of the tree is in the state of privation. The old tree dies ultimately and with it vanishes one source capable of recycling the oak tree Form. Only its matter will survive but it too will be recycled ultimately. In the meantime, however, the acorns the tree has produced will undergo new cycles of generation securing the persistence of the oak tree species Form.

Aristotle argues that to understand a thing fully, we must know what the thing is made of, the means by which it has been made, what it is, and what it is for. Each of these different aspects of a thing has a different *aition*, a different explanatory reason or *cause*. He thus recognizes four different causes: *material cause*, that from which a thing comes; *efficient cause*, the agent imposing the shape and structure upon a thing; *formal cause*, the thing's shape and structure; and *final cause*, the purpose for which a thing exists. In the example of an acorn growing into an oak tree, the material cause is the stuff of the acorn; the efficient cause is the tree that produced the acorn and that gives it the potential of developing into a tree of the same kind; the formal cause is the Form actualizing the tree; and the final cause is the fully developed oak tree capable of producing new acorns and thus propagating the kind. Some of the causes, however, seem to fuse. So, in the case of the acorn, the Form is both the formal and the final cause. Furthermore, both these causes seem to coalesce with the efficient cause, which concerns the Form as well. Here, then the four causes reduce into two, one involving matter and the other the Form. The three Form-involving causes, however, must not be thought of as being identical, for each concerns a different aspect of the Form. The efficient cause can be viewed as representing the Form as the initiator of the development, the formal cause the process of the Form's actualization, and the final cause the goal of the process, which is the perpetuation of the Form and so the perpetuation of the species.

Aristotle's Concept of Animal Reproduction[16,17]

Up to this point, we have dealt with Aristotle's concept of *genesis* (generation) in general, philosophical terms, describing how something arises from something else. Aristotle, however, also offers a more restricted view of *genesis*, limiting the

"something" to living things and even more specifically to animals. Why this partiality? One likely reason is nepotism, for he considers himself a member of the animal clan. But the more important reason is that in animals the cycles of *genesis* and decay are much more obvious and regular than in other things. So obvious, in fact, that later-day biologists would call the cycling reproduction—the bringing into existence again of other things of the same kind. Reproduction, however, is not synonymous with *genesis*, for the latter term is broader than the former. Viewed from a modern-day perspective, Aristotle's *genesis* encompasses two different processes, which are now subject matters of distinct scientific disciplines: the generative process covered by reproduction biology and embryology and the transmission of resemblance from parents to offspring covered by genetics. In Aristotle's time the transmission of resemblance was held to be incidental to the generative process concerned with all aspects of the construction of a new individual. We will return to this important difference between ancient and modern views in the next section. Here we restrict the coverage to the generative process and divide it to subsections according to the important issues that arise from it. As a preamble we provide a brief introduction to Aristotle's classification of animals.

The Kinds of Animal. In his classification of living things, Aristotle distinguishes two major groups, animals and plants, and uses generation to set them apart. Animals propagate sexually and plants propagate by other means. Although both animals and plants are divisible into species, only in animals do individuals of the same species fall into two types—males and females—often distinguished by their appearances. That the two types belong to the same species becomes apparent when they procreate: Only a male and a female of the same species can mate and when they do, their offspring are of the same species as the parents, though again differentiated into males and females. In many species the procreation act begins with copulation (coition), during which the male introduces semiviscous fluid, the semen (*sperma*, the seed), in the genitals of the female. There are many modes of animal propagation among the species, the chief ones being viviparity and oviparity. In viviparous animals, the female delivers living young, whereas in oviparous animals she lays eggs, from which hatch the young after an incubation period.

Generation in Aristotle's vocabulary is the coming into being. It is yoked with its antithesis, the passing into nonbeing—the decay, degeneration, or corruption. Aristotle, expounding on Plato, interprets generation as an individual's striving to leave behind, after its own demise, a being of the same species and as close to its own identity as nature's laws allow it. It is an individual's way of participating in eternity. Because it cannot escape mortality, an individual makes every effort to ensure that at least some part of it endures. The meaning of procreation, according to Aristotle, is a continuous renewal of existence and life, for to be is better than not to be, living is better than not living, and being ensouled is better than not being ensouled.[18] Generation covers the entire process of nonbeing to becoming a being, from the conception to the birth or the hatching of an animal. Before Aristotle, other philosophers had also speculated on the biological nature of generation,[18,19,20]

but of these theories only fragments survive, and most of them Aristotle has taken into account in his description of the process. In what follows, we limit our account of generation largely to that provided by Aristotle.

The Origin of the Semen.[21,22] Ancient Greeks knew that there was a causal connection between mating and procreation and that underlying it was the male semen or *sperma*. However, the origin of the *sperma* remained controversial, the three main contenders for the site of the *sperma* formation being the brain/spinal cord, the whole body, and blood. Aristotle was a strong supporter of the hemic hypothesis and provided a detailed description of how semen originated from blood. According to him, the foodstuff that animals consume comprises plant and animal substances made up of the four elements (water, air, fire, and earth) at different ratios and of different degrees of complexity. From these an animal extracts nutrients for use in its various physiological functions. The extraction consists in physical and chemical degradation, first in the stomach and then in the liver and spleen. Heat (*thermon*) is the agent effecting the degradation called *pepsis*, which in common Greek is used for material changes caused during the cooking of food in a pot over fire. Correspondingly, *pepsis* is often translated as "cooking," but also as "concoction" in the sense of "boiling together various ingredients" or simply "boiling." According to Aristotle, *pepsis* has two effects: It softens the food and separates it (breaks it down) into its components. The body's internal (vital, innate, connate) heat subjects the foodstuff to three or four rounds of *pepsis*.[23] In each of the rounds except the last, the heat separates the material into fluid nourishment (*trophe*) and a residue (*peritoma*). Also, in each of the rounds except the last, the nourishment is forwarded to the next station for the next round of *pepsis*, while the residue is separated into useful and useless fractions. The useful residue is collected for the final round of *pepsis*, whereas the useless fraction is channeled for excretion, the solid material through the intestine and the liquid stuff through the kidney. The first round of *pepsis* takes place in the stomach, the second in the liver or spleen, and the third in the heart. The forwarding from one cooking station to the next takes place via the blood vessels, of which, however, Aristotle has inadequate knowledge and so postulates some interorgan connections that in reality do not exist.

Aristotle makes the heart the center of nutrition, but also of sensations, emotions, and even intellect. He claims the heart to be the body's hottest place and makes it therefore the central organ for the generation and distribution of the inner heat. He says that the heart is the body's citadel (*akropolis*) or a hearth holding the kindling fire of an animal. It is the seat of the fire of life, the *vital heat*. Life begins with the kindling of the fire and ends with its quenching. The pulsation of the heart resembles boiling caused by the vital heat expanding the blood. The temperature of the vital heat must be regulated lest it burst into flames consuming the body. Refrigeration is accomplished by cold air brought into the heart from the lungs via the pulmonary vessels. This false view of the heart and of blood's nature and movements stood fast until the seventeenth century CE.

Upon their delivery to the tissues, the blood nutrients convert into the body's constituents in a process now called *assimilation*. Aristotle explains the process as an

actualization of a potential that blood acquires in the series of concoctions. The key factor in this explanation is the vital heat. What exactly is the vital heat? Before we answer this question, we must introduce two other concepts with which he operates in this context: *psyche* and *pneuma*. The first of the two is what we already know as one of the aliases of the Form. To what we have learned already about the psyche or soul, we need to add here that Aristotle distinguishes three kinds of soul, which he calls nutritive, sensitive, and rational. All living creatures have the *nutritive soul* concerned with nutrition, growth, and generation—the lowest and most basic grades in the expression of life. All animals have, in addition to the nutritive soul, also the *sensitive soul* concerned with sensitivity/perception, desires, and locomotion. Only humans have in addition to the nutritive and sensitive souls also a *rational soul* concerned with rational thinking and all that comes with it. According to the types of soul they possess, living beings fall into three hierarchical categories in the order plants, animals with the exception of humans, and humans. The three kinds of soul reflect, according to Aristotle, three major groups of activities through which life manifests itself. These activities are giveaway signs of actuality (as opposed to potentiality), and since, in Aristotle's metaphysics, actuality is the Form shaping (informing) the matter, *psyche* is, as we already know, another aspect of the Form. It is an aspect that emphasizes the active side rather than the structural (*morphe*) features of the Form. Although all objects, both animate and inanimate, are composed of matter and Form, only the animate objects have a Form characterized by the special activities that go under the appellation of *psyche*. Present-day biology too distinguishes two aspects of living things: the organization of their bodies, which corresponds to Aristotle's *morphe*, and the activities, which Aristotle calls *psyche* but which modern science refers to as the *functions* of the body. Corresponding to these two aspects is the distinction between two branches of biological sciences: morphology/anatomy and physiology. In Aristotle's biology, the two aspects of the Form pertain not to individuals but to groups of individuals that go under the name of *eidos* or species. The three terms (*psyche*, *morphe*, *eidos*) thus come together as three different aspects of the Form. In Aristotle's metaphysics, Form is actuality and matter potentiality. He therefore defines *psyche* as the Form (of a natural body) that has the potentiality of life. To drive this point home, he distinguishes two senses of actuality, often referred to as the first and the second. When a body is capable of exercising an activity but is not manifesting it, for example, in the case of a man asleep, it is said to be in the state of *first actuality*. Whereas, when a body not only has the capability of certain activity but also exercises it, as in the example of a man awake and going about his business, it is in the state of *second actuality*. Taking into account this distinction, Aristotle defines *psyche* as the first actuality of the body that potentially possesses life and he calls such a body *organic*. Hence to say that something is *ensouled* (i.e., that it possesses soul) is to say that it is alive. Obviously Form and soul are not synonyms since soul is only one kind of Form. At the same time, however, Aristotle assigns to living substances a special position in the universe of things in that he makes them paradigmatic of all substances, as if in the strictest and most proper sense, living things were substances exclusively.

Since *psyche* is idiosyncratic with life and life is in every part of a living body, then so must also be the soul. Nevertheless, Aristotle allocates the central seat of all three kinds of soul to the heart. In the light of what we said about *pepsis*, the allocation of the nutritive soul to the heart makes sense. But why does he assign the other two kinds of soul to the heart as well? In the case of the sensitive soul, the simple reason might seem to be his belief that it is blood that transmits stimuli from sense organs to the heart, which then acts as a coordinator of responses to them. This explanation, however, has two hitches. First, the function of blood is the delivery of nutrients to the different parts of the body, and according to his theory, each tissue can only have one function. And second, Aristotle specifically denies the possibility that blood is the carrier of sensory stimuli. He does not exclude, however, the possibility that something else present in blood is the carrier. It has therefore been suggested that the carrier is the *pneuma*.[24,25] Because of its involvement with perception, *pneuma* is also thought to be behind Aristotle's placement of the rational soul in the heart. But what is *pneuma*?

According to Aristotle *pneuma* is air, but not just any air. Not only is it hot, but also the heat is of a special kind, which he variously refers to as "soul heat" (*thermoteta psychiken*) or "vital heat" (*thermoteta zotiken*) and describes it at one point as analogous to the element of the stars. This sentence calls for a brief excursion into Aristotle's cosmology. He views the universe as a set of concentric celestial spheres enveloping the earth in the center. The closest sphere to the earth is that of the moon. This lunar sphere divides the universe into the terrestrial or sublunary realm and the heavenly or the celestial realm. In the terrestrial realm, things are made of the four elements, are subject to change, and move naturally in straight lines, up and down. All celestial bodies are made up of a fifth element (*quinta essentia* in Latin) or *ether*. In Greek *aither* meant originally the pure, fresh air breathed by the gods, and so the word had from the beginning the connotation of divinity. Aristotle's ether is unaging and unchanging, even though it is a material element. In contrast to the terrestrial elements, ether has circular natural motion, which is perpetual. It pervades the entire heavenly realm, but is absent in the sublunary realm. It lacks qualities analogous to hot, cold, dry, and wet, characteristic of the terrestrial elements. *Pneuma* is not ether but it contains something that behaves ether-like in certain biological and psychological situations. Opinions differ on what exactly Aristotle's reference to ether in the context of the vital heat means. The two opposites in the range of views are a straightforward nonmystical interpretation on the one hand and mystical on the other. The latter extends the divinity of the ether in the heavens to the vital heat down on earth. The nonmystical interpretation[24-26] attributes to Aristotle the view that *pneuma* is like ether insofar as they both have a similar effect on certain physiological processes, especially generation. In this interpretation the vital heat in the *pneuma*, though not etheric in its constitution, is credited of being able to endow the male *sperma* with similar power in sexual generation. But if we reject the divinity of the vital heat, what alternatives remain for Aristotle to explain its presumed effects? Here we must remind ourselves that the ancient Greeks commonly identified life with heat and equated digestion with a kind of cooking. These two beliefs go a long way toward

explaining some of the connections Aristotle makes in his physiology: fire—heat—life—birth—production of new substances—digestion—generation.[23] The question is: Is the heat produced by fire the same as the vital heat produced by the body? Seemingly not, because the ordinary fire burns things to ashes rather than bringing anything to life. On the other hand, one could argue that fire and vital heat have different effects, but sun and vital heat have similar effects and that it is this latter similarity which Aristotle has in mind when he draws the analogy between ether and vital heat. Indeed, he says that heat can power different processes, much like a baker who uses heat to bake different products such as bread, cookies, or cakes. Taking a present-day stance, we might say that the vital heat is nothing more than energy that powers metabolic processes in the body.[26] It was in fact Aristotle who coined the word "energy" (*energeia*), along with another term—entelechy (*entelecheia*). He uses these two words nearly interchangeably, but they do have subtly different meanings. He applies both to the actualization of potentialities but uses *energeia* for powering of the process and *entelecheia* for its completion.

To sum up, *psyche* as a Form associated with matter is a substance, as is *pneuma* (warm air), whereas vital heat is a power or energy. Aristotle uses all these terms in explications of what we would today call *metabolism* (from Greek *metabole*, change), the set of chemical changes, which provides energy for the construction and degradation of living matter and for the execution of its functions. Aristotle's description of metabolism may seem naïve and primitive, but in reality it comes amazingly close to capturing the essence of the process. It is now known that blood, heat, and sun energy do indeed play critical parts in metabolism; that blood carries oxygen, which constitutes 21 % of the air; that air is critically involved in reactions charging certain molecules with energy; that heat is intimately associated with energy, as indicated by the fact that food energy is expressed in calories, which are units of heat; and that the sun is directly or indirectly the source of energy for most of life on earth. Moreover, the production of energy by a process involving oxygen is often called "burning;" metabolism does indeed start with the processing of food and the production of nutrients; and metabolism does underlie processes such as growth, repair, locomotion, and generation. Understandably, however, when it comes to details of metabolism, Aristotle's explanations are often well off the mark.

The Quest for the Female Semen. Beside the origin of the male semen, the second much debated question among the Greek philosophers in connection with animal generation was whether females produced an equivalent semen and if they did, what was its nature? Virtually all of them agreed that females produced something related to generation, but they differed in their views on the nature of this "something." The most common attitude was to identify the so-called female semen with the monthly blood flow or *menses* (from Latin *mensis*, month), *katamenia* in Greek. This was also Aristotle's position. Simplifying somewhat his complex explanation, one might say that *sperma* and *katamenia* result from the same process that produces nutrients and that generation is akin to the assimilation of nutrients by tissues. The difference between the two processes is in that the *sperma* undergoes an additional round of *pepsis*, which ordinary nutrients do not.

Where the additional round of concoction takes place is unclear. Some scholars read Aristotle as suggesting that it occurs in the male reproductive organs, presumably the testes, while others place the event in the heart. Wherever it happens, the final bout of concoction changes not only the appearance of the product from red to white and its consistency from fluid to viscous but also its potential. A similar process produces, according to Aristotle, also milk in females and fat in both sexes, neither of which possesses the potentialities of the *sperma*. The additional round of *pepsis* is not accorded to the *katamenia*, however. The latter therefore retains the red color of the blood, although it too acquires, at some stage of the process, new potentialities, different from those of the *sperma*. Aristotle claims that the essence of assimilation, the conversion of blood (nutrients) into homoiomerous substances (the same in structure) of the individual tissues, is the transfer of the Form from the tissue to the nutrients. As blood reaches particular tissue, the latter communicates to the former the Form it possesses. In other words, the tissue imposes upon the nutrients its own Form by making them to assume the same organization as the tissue itself has. The vital heat presumably effects this whole transaction.

According to some interpreters,[24] Aristotle's view is that generation operates on a similar principle. His fundamental assumption is that both sexes contribute to the generation of a new individual, but unequally. The male, through his *sperma*, contributes the Form (*eidos*), whereas the female, through her *katamenia*, contributes the matter (*hyle*). The Form of the *sperma* imposes itself on the matter of the *katamenia*, when the two substances meet at coition. The imposition is effected by the vital heat, which the *sperma* acquired at the extra round of concoction. This concept of generation raises numerous questions, to which various Aristotelian scholars give diverse answers, since Aristotle's own answers are mostly ambiguous. In what follows, we introduce some of these problems and a selection of solutions offered. Since, according to the hylomorphic doctrine, all objects consist of matter and Form, the first question one might ask is: What happens to its own Form when the *katamenia* receives the Form of the *sperma* and, reciprocally, what happens to the matter of the *sperma* when it loses its Form? Aristotle's answer to the first part of the question is presumably: The same thing that happens to any object when it acquires a new Form; the old Form goes in the privation mode. Aristotle's answer to the second part of the question is unclear: Does it disintegrate as in decay or does it integrate into newly forming individual? We return to this question later. A second question is at once more difficult and more important: Where and when does the *sperma* acquire the Form, which it then communicates to the *katamenia*? If man begets man, as Aristotle says, then the Form of the *sperma* must be that of the human species (*eidos*) rather than a Form of a tissue as in nutritive assimilation. Hence, the only place in which the *sperma* can take on the species Form is the heart, which Aristotle holds for the center of an individual's life and for the seat of the soul, which is also the *eidos*. The problem is that in Aristotle's system, the Form is actuality, which in the case of living beings is the *psyche*, the *psyche* of a living being is life, and life is organization and activity. But the *sperma* does not show an organization in which one could recognize the species. Aristotle explicitly rejects any kinds of *preformation*, which postulates just such kind of a structure and

activity in the semen. One possible resolution of this dilemma is to assume that the Form is, in modern vocabulary, like a computer program, which must be opened to start running. The opening of the species program in the *sperma* is the encounter with a matter receptive to just this kind of program—the *katamenia*. This suggestion comes close to saying that the actuality in the *sperma* is really a *potentiality of actuality* or *first actuality*. We come back to this problem in the penultimate section of the chapter.

The Origin of a New Individual. All this brings us to the third and the most important question: How does the development of a new individual begin? According to Aristotle, the primary requirement for the initiation of the development is the encounter between the *sperma* and the *katamenia* in the uterus of the female parent. The *sperma*, which during the coitus has entered the womb, is informed, ensouled, or impressed with the Form (the nutritive and sensitive soul) of the male parent from which it comes. More specifically, it has been endowed with the capability to enfold the structure and movement (activities, functions) of all the different tissues comprising an adult male of the species. Likewise, in the female parent's heart, the *katamenia* has been prepared for the encounter by the imposition on its matter of receptivity (potentiality) to receive the Form (soul) of the male. Later, the encounter—the mixing of the *sperma* and the *katamenia* in the uterus—came to be called *fecundation* (from Latin *fecundus*, fruitful) and later still, after the true nature of the process had been elucidated, *fertilization* (from the Latin *ferre*, to bear fruit). In the act the *sperma* imposes its Form upon the receptive matter of the *katamenia,* and the Form begins to convert the matter's potentiality into actuality. The intermediary between the Form and the matter is the vital heat associated with the *pneuma*. Both of these are provided chiefly by the *sperma* and come originally from the last concoction in the heart. The association with the *pneuma*, combined with the presence of the ensouled (informed) matter, furnishes the vital heat with a creative power, which ordinary fire-produced heat lacks. Other than that there is no principal difference between the vital and the ordinary heat. One way of interpreting the communication between the Form and the matter in the actualization of the latter's potentiality is to imagine that the vital heat, with the help of the *pneuma*, warms up or cools down the *katamenia* to precisely the temperature required for the particular movement (action) prescribed for the specific time and stage of development. To understand this interpretation, it is important to remember that Aristotle operates with only four elements and four qualities; that among the latter the pair of warm-cold opposites is dominant and determines the dryness and wetness of a substance; and that the ratio of the four elements determines the activity of the substance. It is only against this background that the creative power of the vital heat makes good sense and averts the need to invoke the divine power of the fifth element.

Embryonic Development. Aristotle calls the effect that the *sperma* triggers in the *katamenia sunistanai* or *setting*, which he defines as imparting the proper movement to the *katamenia*, that is to say, a movement with which the *sperma* itself is

endowed. In the English translation of the Greek term, the word "setting" is used in the sense of causing a fluid substance to become firm or solid, as in the case of setting milk for cheese. Indeed, Aristotle compares the action of the *sperma* on the *katamenia* to that of rennet on milk:[27] It causes the fluid *katamenia* to coagulate into solid curds. As in the case of milk, where the rennet does not become part of the curds, the matter of the *sperma* does not enter the coagulum, but instead dissolves into *pneuma* and evaporates. The male Form is thus an impulse that sets in motion a process, which then sends an impulse to initiate another process, and so on, in a manner of a chain reaction. Aristotle, who does not know about chain reactions, prefers to think about the *fetation* (the formation of *fetus*, from Latin "newly delivered"), in terms of a mechanical toy, in which the movement of one part triggers the movement of another part, and this a movement of a third part, and so forth. All these transfers of movements follow sequentially the first movement. This, according to him, is how fetation (or embryonic development, as we say today) works. In the case of the mechanical toy, it is the player who provides the first impulse. In the case of fetation, it is the *sperma* in the form of the vital heat from the last round of *pepsis*, which initiates the setting. The embryonic development is as orderly as the transfer of movements in the mechanical toy. The reason for the orderliness is different in these two cases, however. In the case of the mechanical toy, it is in the structure, in the way the toy is constructed. In the case of fetation, the reason for orderliness is the Form. The development follows a purpose, which is the actualization of the same *eidos* as that of the parent. By having the beginning in its end, the species achieves immortality by the concatenation of endless cycles of generation and decay.

Aristotle provides a rather detailed description of the way he interprets the development of the vertebrate embryo. It is based in part on his own observations of chicken egg development. Here we give only a few selected highlights of it.[26] In viviparous animals, the *sperma* and the *katamenia* meet in the vagina and the mixture is then drawn into the uterus, where it coagulates. The surface of the liquid surrounding the central coagulum cools into a scum that develops into fetal membranes around the embryo. A root-like structure sprouts out of the coagulum and connects with the uterine wall from which henceforth the embryo draws nutriments. The embryo's potentiality to develop all body parts actualizes stepwise in a fixed order, in accordance with Aristotle's concept of *epigenesis*, that is, the gradual, successive differentiation of individual body parts. The first organ to develop is the heart. From it then originate all the other body parts. Blood vessels sprout from the heart in all directions and branch out from the main trunks. Blood, which is essentially nutriment, seeps through pores in the blood vessels and develops into flesh, skin, and bones. Shortly after the heart and near it emerges the brain, the chief cooling organ. Other organs then follow in a rapid succession.[28]

Generation in Plants. It may seem incomprehensible that sexuality of plants had remained unrecognized through much of human history. After all, flowers display impudently their sexual parts for every human eye to see and some plants, as if in mockery, even mimic human genitals.[29] Every meadow, every coppice, and every

orchard bustles and buzzes with their sexual activities and people have suffered for ages from pollen allergies. Yet, it had not been until some 300 years ago that the first convincing evidence for sexuality in plants had emerged (see Vol. 2 Chap. 2). The usual explanation for the delay is human prudery about anything sexual, but the fact is that societies relatively open about sexual matters had not been more enlightened about plant sexuality than the puritanical ones. In ancient Greece, sex had been free of the odium that Christianity and related religions had later imposed on it, yet, Aristotle, as well as his student and successor Theophrastus of Eresos (c. 371–c. 287 BCE), "the father of botany," knew much less about the sex life of plants than an elementary school pupil knows today. The real reason for the delay must have been therefore something else, perhaps the fact that the true similarity between plant and animal sexuality lays at the microscopic level, which had not become accessible until 300 years ago.

Actually, Aristotle did believe in plant sexuality, but in one that did not express itself morphologically in differences between males and females. Rather, he thought that plants were unisexual and that the reason for this was that they were, in contrast to mobile animals, affixed more or less permanently each to one spot. This feature would have made contact between males and females for sexual union, if such had existed, impossible. Aristotle posits that instead of semen and *katamenia*, therefore, plants produce seeds, which are equivalent to animal eggs. An animal egg consists of two parts: germ, from which a new individual develops, and nourishment. Similarly, a seed contains a germ of a plant and nourishment for the shoot and the first root. A seed arises by concoction of nutrients in the pericarp, the part of the fruit enclosing the seeds. The concoction is effected by vital heat, which originates in part in the plant but comes additionally also from the outside. It is unclear, however, how Aristotle attuned this concept of unisexuality (two in one) with his general theory of generation, in which the male provides the Form and the female the matter.

Spontaneous Generation.[30] Most ancient Greeks, common people and philosophers alike, believed that certain animals arose without parents of their own kind, and Aristotle shared this view with them. The notion that life could spring from a source other than already existing life came to be called *generatio spontanea* in Latin and *spontaneous generation* in English, whereby the word "spontaneous" was used in the sense of growing naturally, without being planted, as in the Latin root *sponte*, "of its own" (the Greek equivalent being *automaton*). Aristotle's problem was to explain how the same species could repeatedly arise spontaneously. In sexual generation, the same species arises again and again because of the Form that the parents provide and that guides the development of the new individual toward this very same species. In spontaneous generation, however, an individual arises from matter such as mud, dirt, or putrefying stuff, which has no resemblance to the organism (fish, frog, mouse) that arises from it. In spontaneous generation, there is no Form that could inform the matter how it should change into the shape of, say, a mouse. Aristotle could not have possibly believed that pieces of dirt could by chance assemble, all by themselves, into a living being such as a mouse. Amazingly, however, he did find a way of sidestepping this improbability problem and came up

with an explanation, which—though false because it is based on untenable assumptions—would have had some merit if the assumptions were valid. Let us reiterate: In ordinary generation, the Form is passed from parents to offspring like a baton in a relay race. In animals, the act of passing the "baton" involves two individuals, the male and the female. In plants, the male and the female principles exist in the same individual, and the passing of the "baton" takes place within that individual. In both animals and plants, out of the mix (*kymena*) of the male and female principles develops a new individual. In both cases the male principle contributes the Form and the female principle the special matter of the *kymena*. Also, in both cases, the two principles are generated by concoction, the male principle becoming a special vital heat present in the *pneuma*, and the female principle a special matter. The principles are special in that the male vital heat is programmed to actualize the potentiality present in the matter of the female principle. To explain how spontaneous generation can give rise to the same species repeatedly, Aristotle invokes the same two principles: vital heat programmed to actualize a certain Form and matter with the potentiality to assume that Form. The creator of the programmed vital heat (Form) is, according to him, the sun, and the sources of the special matter are primarily two of the four elements—water and earth. This claim calls for a second brief digression into Aristotle's cosmology.

According to Aristotle, the sun itself is not hot, for it is made of ether, which does not have any of the qualities characterizing the terrestrial elements. Rather, the sun-heat is a mere by-product of the sun's motion and the resulting friction. The friction causes the air below to ignite, and it is the heat of this fire above the earth that we perceive as sun-heat. Here on earth, there are certain environmental pockets where, by chance, specific earth-to-water ratios occur and where, also by chance, sun-heat creates specific temperature conditions that allow certain organisms to develop without parents. Aristotle thus manages to integrate the notion of spontaneous generation into his overall concept of generation, but only by stretching the doctrine of the vital heat to its limits. Within the framework of his speculations, he makes it appear possible that in small environmental pockets, conditions might conspire to mix earth and water in such proportion that at the right temperature of the air, a process might "ignite," which then the changing heat conditions stir toward the development of a living being. After all, this seems to be happening when seeds are planted into the soil or tortoise eggs are deposited in the sand and warmed up by the sun—with one important difference: The seeds and the eggs come from parents of the same species as the germinating plants or the animals hatching from the eggs. As biologists now know, only life in the form of seeds, eggs, and other form of germs can beget life. The way Aristotle imagined it as an interplay of chance (the creation of the right conditions) and necessity (the development steered by these conditions), spontaneous generation can no longer occur on earth. Biologists believe, however, that life on earth once started by *abiogenesis* from inanimate matter under the special primal conditions on the planet, and then evolved gradually from very simple organic structures to more complex forms.

Aristotle's Theory of Inheritance[16,31]

We reemphasize that dividing Aristotle's concept of generation into generative and transmission of resemblance parts is against the spirit of his treatment of the subject. Hence, calling the latter part "heredity" or "inheritance" is an anachronism comparable to a soldier lighting a cigarette in a movie about Ancient Rome. The English terms "heredity" and "inheritance" and their equivalents in other languages, including Greek, had not been introduced into biology until the second half of the nineteenth century (see Vol. 2 Chap. 2). Indeed, the Greek equivalents of these two terms do not appear anywhere in the whole text of Aristotle's *Peri zoon geneseos*, his major work on this subject, now better known under the Latin title *De generatione animalium*.[16] You may find these terms in some translations of the work, but such cases must be taken as anachronistic inaccuracies. To give an example, an accurate, word-by-word, translation of the Greek sentence *pithana de kai ta toiayta martyria taytais tais dokses; oy gar monon ta symfyta proseoikotes ginontai tois goneysin oi paides, alla kai ta epikthta* is this: "plausible are these evidence for these opinions; not only by birth (innate) resembling become to the parents the children, but also by acquired," which in the context of a scholarly translation reads *"Children are born which resemble their parents in respect not only of congenital characteristics but also of acquired ones."*[32] However, in an attempt to make the meaning of the sentence better understandable to a modern reader, an English translator may be tempted to choose the word "inherited" instead of "congenital" as in this translation: "*Children are born resembling their parents both in their whole body and in its individual parts. . .Moreover this resemblance is true not only of inherited but also of acquired characters."*[33] The current Greek word for "inheritance" and "heredity" is *klhronomikothta* or *klironomikotita*, in which the *klhros* or *kliros* stands for a piece of wood used in lottery or voting, and the *nemw* (or *nemo*) means "to distribute." Together, the meaning is "transferring a set of characteristics through birth."[34] Apparently an equivalent to "heredity" and "inheritance" did not exist in ancient Greek. This absence is also suggested by the quote heading this chapter. Here, too, we might be tempted to replace Athena's roundabout talk[1] by saying simply: "If you, Telemachos, have inherited your father's great strength . . ." These arguments may seem like linguistic haggling over nuances. In reality, however, the absence of a technical term for the transmission of resemblance in ancient Greek is a telling point. It indicates that at that time, the phenomenon was held for, at best, a side issue to the phenomenon of generation or, at worst, for a deviation from the normal process of *genesis*, whose vital goal was the perpetuation of the *eidos*, the species. The seeming unpredictability in the transmission of individual characteristics surely must have meant to the ancient Greeks that chance, rather than rule played the decisive part in the process. And chance, for them, meant deviation from norm, fickleness, and abnormality. With this view in mind, let us now have a look at some of the mental acrobatics Aristotle had to resort to in order to explain how Socrates, in the process of becoming a human being, got his maleness and his snub nose, short stature, together with the rest of his individual characteristics.

Aristotle distinguishes four levels of resemblance between parent and offspring when he says that humans beget humans. At the broadest level, the product of the procreation act, the offspring, has, like the parents, the features common to all animals, which to Aristotle represent the genus, into which the human species belongs. In his rendering, these features include the possession of both the nutritive and sensitive soul, as well as a body composed of flesh and bones. At the next, the species level, the offspring possesses, like the parents, features common to all human beings and different from all other animals: featherlessness, bipedality, and possession of a rational soul. At the third, the gender level, the offspring resembles either the father or the mother in what would today be called primary and secondary sexual characteristics. It is either a male or a female. Finally, at the fourth level, the level of the individual, the offspring resembles the father, the mother or some more distant ancestor in characters other than those shared by all human beings, by all human males or by all human females.

The fourth level of resemblance differs from the other three levels in that it is based on comparisons of individuals within a group rather than on comparisons of groups of individuals. The comparisons reveal that all individuals, with the exception of identical twins, are unique. The uniqueness is patently apparent to us when we compare individuals of our own species; to become aware of it in other species may require meticulous observation. To recognize uniqueness of individuals, it helps to compare not their overall appearances but rather individual features and thus to view an individual as a mosaic of *characters* and search for differences in *character states*. For example, eye color is a character, whereas blueness, grayness, and greenness of eyes are different character states. The uniqueness of an individual is in the specific combination of the character states. Modern science calls the particular combination of character states the *phenotype* (from Greek *phainein*, to show, and *typos*, type). Thus the uniqueness of Socrates is in the combination of character states such as shortness of stature; swaggering gate; wide-set, piercing, and bulging eyes; upturned, broad, snub nose with flaring nostrils; and wide mouth with large fleshy lips. The appearance of some of the character states seems accidental in that they do not reappear in the offspring; these, therefore, do not interest us here. Others "run in families" and these are the ones that Aristotle uses in the description of the four levels of resemblance. In principle, the resemblance at any of the four levels can be dissected into individual characters; the difference is only how widely the characters are shared. This lack of *principal* distinction among the four levels must also be the reason why Aristotle does not see any need for giving the intraspecies characters a special status under a distinct name. From his point of view, characters at all four levels are inherited. If he were to use this term, though, those at the fourth level are inherited least predictably. Indeed, he might have viewed the fourth-level characters as the proverbial monkey wrench thrown into his philosophical system. Here is why:

The concept of resemblance presupposes *variability*. If things are the same, we speak of *identity*. It is only when they differ that we speak of resemblance. Variability, however, presents a problem for Aristotle in that he has no place for it in his hylomorphic doctrine. If Form determines the appearance of things and if it is immutable, where does variability come from? He follows Plato and blames

variability, which is a departure from the norm, on matter. When Form thrusts itself upon matter, the latter resists the imposition. Unless it manages to master the imposition fully, differences from the norm represented by the Form arise. In this view, variation is de facto a deviation from the standard, and if one holds the standard for perfect, the deviation becomes a defect. The seriousness of the defect depends on the level of resemblance at which it occurs. If it occurs at the level of the genus or species, it results in what Aristotle calls a *monster*. If it occurs at the gender level, it leads to the opposite of maleness, which is femaleness. It is in this sense that he calls femaleness a "deviation" because the norm is the male Form. It is at the level of characters differentiating the individuals of the same species that he runs into the problem. Actually, the problem lurks already at the gender level, because Aristotle leaves unexplained the source of the femaleness: Where does the femaleness, the opposition to the maleness, come from? If from the female, does it mean that it is part of the female's Form, and if so, that the female contributes part of her Form to the embryo? The same questions arise at the level of characters differentiating the individuals of the same species. Does it mean that the characters are in some manner part of the male and female Forms? If so, it would mean that Aristotle would have to extend the concept of Form from the species to the individual level. Some scholars think that this is indeed what he is doing. But Aristotle nowhere clearly states that this is what he means, and for obvious reason. Admitting the possibility of individual-specific Forms would undermine the whole metaphysical infrastructure of his philosophy and threaten to collapse it. The problem thus remains unresolved from the interpreters' point of view and perhaps even for Aristotle himself.

Undeterred by these problems, Aristotle pushes ahead and offers a physiological interpretation of inheritance.[16,18,35] His explanation of resemblance between offspring and their ancestors has some remarkably modern features. The first of these is that he seeks an explanation applicable to all four levels of resemblance, and he does so despite the fact that it brings him in conflict with parts of his metaphysical doctrine. His unifying approach to generation makes sense since the basic stance "like begets like" applies to all levels of likeness, from the genus down to the individual. It is therefore reasonable to think that the physiological mechanism responsible for this likeness is essentially the same at the different levels. We will argue later (see Vol. 2 Chap. 3) that this is also the stance Mendel assumed when he began his experiments with the hawkweed. Mendel's followers, on the other hand, started from the position that the study of inheritance at the individual level should be separated from that at the other three levels. They distanced themselves from the old concept of generation and banded together under the banner of *genetics*. It would only be much later that further developments would reveal that Aristotle's unifying stance was right after all. The second modern feature of Aristotle's physiological explanation is that it is based on an approach that could be called *atomistic*. When we notice a resemblance between two individuals, generally we perceive it as an overall likeness, without consciously paying attention to specific characters that the individuals share. Aristotle is perhaps the first to view an individual as a mosaic of characters, each of which has to be dealt with separately. Here again, this would much later become the standard method on which

genetics would be founded. The third remarkable feature of Aristotle's physiological analysis of inheritance is that he separates the cause from the effect in the mechanism responsible for the likeness between individuals.[20b] He holds the character for an effect caused by an agent responsible for its appearance. In the terminology of modern genetics, the individual characters are part of the *phenotype*, whereas the agents responsible for the development of the characters are the *genes*, which are part of the *genotype*. The implication of this separation is that the appearance of the characters is a process having its beginning in some material substance. Here once more, Aristotle foreshadows Mendel, who in modern times would become the first scientist to make this distinction.

Aristotle calls the agent that initiates the developmental process leading to the appearance of a character *dynamis* and the process itself *kinesis*. In the present context, *dynamis* is the physical substance in the semen capable of initiating a movement leading to the appearance of a particular character in the developing embryo. The *dynamis* is the special vital heat present in the *pneuma*. Depending on the specific qualities of the vital heat, different movements are triggered and different characters emerge. The variation in the quality of the vital heat also gives the female a chance to contribute to the developing embryo more than just matter. The variation and the consequent interplay of the *dynamei* with the potentialities present in the matter on the maternal side enable Aristotle to explain the different modes of character transmission, which we now call inheritance.

The principle of the transmission is the same at all four levels of parent-offspring resemblance. The standard setting of generation reproduces the male parent as accurately as the resistance of the maternal matter allows it. Any departure from the standard, viewed by Aristotle as a deviation, is the result of interference with the actualization of the male program. Some of the interferences are trivial and result in chance deviation; others are more profound and are effected by movements initiated by the maternal side. The latter deviations can be either of a "changeover" or of a "relapse" type. In the *changeover type*, the embryo acquires a character opposite to that which would have been effected by the specific *dynamis* and *kinesis* of the male semen. The most profound example of a changeover is the switch of the program to producing a female instead of a male embryo. In the *relapse type*, the embryo acquires a character state from a more distant ancestor than the parents. Important points to remember are, first, that for each character there is a separate *dynamis* and *kinesis* and that the different *dynameis* act independently of one another. Not only that, but also, and that is the second point, the *dynameis* responsible for the different levels of resemblance assert themselves independently. Using Socrates as a representative human being, we now illustrate the various possible outcomes of generation on the example of his having children with his wife Xanthippe. For simplicity, we consider only the third (gender) and fourth (individual = Socrates/Xanthippe) levels of resemblance and take all the Socrates-specific characters *en bloc*. The standard outcome of Xanthippe's pregnancy would be a boy, who would take after the father—in fact, it would be Socrates' clone. This, according to Aristotle, would happen if the impregnating *sperma* had a very high content of vital heat in all gender- and individual-determining *dynamei* so that it

would have been able to master any resistance put up by Xanthippe's *katamenia*. In the opposite situation, in which Socrates semen's vital heat would be very weak in both kinds of *dynamei*, while Xanthippe's *katamenia* would be strong, the outcome would be a clone of Xanthippe, because the semen would fail to overcome any resistance put up by the *katamenia,* and a complete changeover would be the outcome. Now, if Socrates' gender-determining *dynamei* were strong, but all the individual-determining *dynamei* were too weak to overcome the resistance of the *katamenia*, Xanthippe would have brought to the world a boy, who would take after his mother in all characters. In the opposite situation, an unlucky girl would have been born who would look like Socrates. In all these situations, we have assumed en bloc the inheritance of character at each level. In reality, the probability of this happening is very low. Instead, some of the individual-determining *dynamei* of both the father and the mother could be strong and others weak in random combinations, so that the son or the daughter would take in some characters after the father and in others after the mother. If it so happens that some of the individual-specific *dynameis* of either parent are not strong enough to accomplish mastering, the system goes into the relapse mode. It switches to the corresponding *dynamis* of Socrates' father, and if that does not work, then to Xanthippe's mother. If these two options fail, the switching continues to successively more remote ancestors (Socrates' grandfather, Xanthippe's grandmother, and so on). All these *dynameis* lie "in reserve," so to speak, or, in Aristotle's vocabulary, they are present as potentialities that can be actualized when need be. Aristotle seems to assume that the parents bear in potentiality the whole histories of their respective lineages. In this way, Aristotle explains the reappearance of character states that have been silent over several reproductive cycles (what we now call "generations") and then suddenly reappear in one of the offspring. He goes even further and postulates that the chain of relapses can reach beyond the species into the genus level. In the case of the human species, the genus is, in his reckoning, an animal other than human. When this happens, a "monster" is born, a creature displaying characters of different species. This retracing of characters along a genealogical lineage may seem to be implying an evolutionary scenario, but such interpretation is far from Aristotle's mind.

Viewed from a present-day perspective, Aristotle's theory of inheritance is remarkably modern in its generalizations but wanting in specific details. Its modernity is in its integration of the concept of inheritance into the general notion of reproduction and development, in the recognition of the need to dissect inheritance into units, in the distinction between characters (phenotype) and entities that determine them (genotype), in the formulation of regularities in the pattern of inheritance, in the recognition of the principle of dominance (and recessivity) of characters, and in an attempt to provide a physiological interpretation of the mechanism of inheritance. Although incorrect in detail, his is a very clever interpretation of heredity.

Aristotle's Species Concept[36,37]

The existence of words in the ancient Greek dictionary, equivalent to the English words "man," "dog," "horse," or "blackbird," reveals that the ancient Hellenes had some notion of animal species. They generally distinguished species the way common people have done since time immemorial: by their *appearances*. This is, actually, what the word "species" meant originally in both Latin and Greek languages. The Latin word derived from the verb *specio* means "to look" or "to behold," and the Greek verb *eido* stands for to "see" or "to observe." The words *eidos* in Greek and *species* in Latin even had the connotation of an apparition, of something unreally real, for everybody could say he or she had seen a *particular* dog but not a dog species. Everybody also expected that a pregnant woman would deliver a human being, an impregnated bitch a dog, and a gravid mare a horse. Aristotle was, of course, familiar with this common view of species, but as a philosopher he also reflected on species in more sophisticated ways. In his logical and metaphysical works, he used the word *eidos* in the sense of Form, with all its diverse connotations described earlier in this chapter under a variety of names. An application of the philosophical species concept in biology should not have therefore presented a serious problem to him. Theoretically, Aristotle's concept of species should be applicable to any part of reality and hence also to living things. Yet, since to this day neither biologists nor philosophers can agree on a single species concept, it is perhaps not surprising that scholars cannot even agree on what Aristotle's biological species concept is. According to the traditional interpretation, Aristotle managed to combine metaphysics with biology splendidly. The trouble is, however, that now many scholars are seriously questioning this conclusion.[38] Let us therefore have a quick look at the main points of the traditional interpretation.

To reiterate, in Aristotle's usage, the word *eidos* has two meanings. First, it means the appearance of an individual, its *morphe*, or Form, and second, it stands for a species, a group of individuals sharing the same Form. The connection between these two meanings is the act of generation,[38] that is, the passage of the Form from the parents to the offspring and the resulting close resemblance between the begetters and the begotten. It is on the basis of this resemblance (appearance) that the offspring is assigned to the same species as the parents. It is also on the basis of their appearance that individuals sharing the same Form and so belonging to the same species are capable to interbreed and produce fertile progeny. Furthermore, since the Form is the essence and the essence is what defines a species (a universal), the universal is present in some way in each individual (particular) member of a species. This presence makes the individual general enough to be knowable. Finally, since one interpretation of Aristotle's doctrine makes the Form the ultimate substance (*ousia*), it seems that all the important concepts of his metaphysics are applicable to his biology. Some scholars argue, however, that there are, in reality, several inconsistencies in the traditional interpretation. One of them is the fact that nowhere in his works does Aristotle state exactly what his concept of biological species is. Although he is the first to make a clear distinction between *eidos* and *genos*, and consistently holds the former for a lower classification category than the

latter, he nevertheless keeps using both terms at different classification levels so that his species is always relative to the genus but at different levels. One can therefore only guess from the context at what level of generalization he actually uses the *eidos*. To make things worse, frequently he seems to use *genos* even at the lowest level, where one would expect him to use *eidos* instead. Uncertainties arise also regarding Aristotle's use of expressions such as "like begets like." It seems that Aristotle is a bit too permissive in allowing exceptions to this rule, citing anecdotal evidence for mating between species, of which we now know that they do not interbreed to produce viable offspring. All these and several other ambiguities make some scholars wary of accepting the validity of the traditional interpretation.

The impression one gets from the critique of the traditional interpretation is that of a considerable fluidity of Aristotle's species concept. The title of an essay "Aristotle: A Zoology without Species" used by one critic of the interpretation[38] in one of his essays is a hyperbole but the exaggeration is only slight. Aristotle has apparent difficulty in delineating the species both in downward and upward directions on his hierarchical scale of generality. This difficulty is, however, very modern: Biologists struggle with it to this day. It is therefore somewhat paradoxical that some twentieth-century biologists and some historians of biology accuse Aristotle of dogmatism hindering the acceptance of Darwin's theory of evolution. Specifically, they charge him with two major offenses that go under the names "essentialism" and "teleology."[39–42] Aristotelian scholars[43] and some other historians of science[44–46] reject these accusations. The first accusation is based on two claims attributed to Aristotle: first, that the Form is unchangeable and eternal, and second, that the Form is equivalent to the essence. We have seen, however, that Aristotle had problems with the unchangingness of biological Forms (species) and that certainly in the case of the human species, he was well aware of its variability. Note also that he defines the human species relative to the genus "animal" and that modern genetics recognizes groups of genes (e.g., the so-called *Hox* genes) that have remained remarkably constant during the entire animal evolution. Aristotle's position on the eternity of the Form is equally ambiguous. On the one hand, he accepts that Forms come and go in the process of generation/degeneration, but on the other, he introduces the concept of privation, which amounts to an admission of Forms persistence in a potential mode. He fails to clarify under what condition and how long the Form can last in the privation mode. He is probably aware of the difficulties into which eternally existing Forms would bring him. At any rate, he does not need the Form to be eternal in this mode, for the generation cycles seem to assure the Form's *virtual* eternity.

As for the accusation of essentialism, we must first clarify, what is meant by it.

Essentialism is "a theory ascribing ultimate reality to essence embodied in a thing perceptible by the senses."[3] Since Aristotle's hylomorphic doctrine attributes to physical objects a dual nature, having them composed of matter and Form, the latter of which he also holds for essence, he is by this definition an essentialist. For the same dictionary holds an essence for "the ultimate nature of a thing," and for Aristotle the most fundamental nature of a thing is that which it has in common with all the other objects belonging to the same species and in which it differs from

other species. But what exactly do Aristotle's critics mean by an "essentialist species concept?" Their answer is: It is a concept that is distinguished by four characteristics.[47] First, the species consists of similar individuals sharing in the same essence; second, each species is separated from all others by a sharp discontinuity; third, each species is constant through time; and fourth, there are severe limitations to the possible variation of any one species. How well then does Aristotle's species concept match this essential species concept? Well, we cannot say because, as we have seen, scholars do not agree on what Aristotle's concept of biological species is, or whether he even has one. The four points of the essentialist species concept match roughly Aristotle's *logical* species concept, but in the absence of his clear delineation of a *biological* species concept, it is futile to try to confront the four criteria with the latter. All one can say is that there are indications in Aristotle's biological works that can be interpreted as contradicting these points, with the possible exception of the first, but this is so because the concept of essence is rather fuzzy. One thing is clear, however: Aristotle is no evolutionist. The fundamental axiom of his metaphysics is that the universe has no beginning and no end. It enables him not only to escape the Parmenidean existence-nonexistence paradox but also the need to explain how things got the way they are. In this sense he does not need to be an evolutionist.

Teleology is the belief that there is purpose in nature. The belief exists in many variants differing in the coverage of natural phenomena and processes, the four main levels of coverage being organs, individuals, communities, and the world as a whole. Of the four, only the first two interrelated levels are relevant to the subject matter under discussion here. In the case of organs, it is the complexity of their structure that invites thoughts about their function and thus their purpose. In the case of individuals, it is the complexity of their development from an undifferentiated material. In both cases, the phenomena and processes give the impression of being goal-driven, an impression that there is a purpose or predetermined end (*telos* in Greek) which they strive to attain. The purpose seems to be an organ best adapted to its function and an individual best fitted for the environment in which it lives. An analogy with a human-made product—a house, say—forces itself to one's mind. The construction of a human dwelling requires building material, a blueprint designed by an architect, and workers to carry out the work. The analogy makes one think: Who is the designer of organs and individuals in the organic world? There are two theoretically possible answers to this question. First, there is no designer behind the construction of an organism and its organs; the organism constructs itself in accordance with natural laws. Most biologists think, however, that this explanation is believable only in combination with the theory of evolution by natural selection. According to this theory, the complex design evolves in small steps, each step being the outcome of a process, in which many random variants are rejected and only those that improve the adaptation of the organism to a particular environment (and an organ to a particular function) are allowed to persist. The second, nonscientific, answer invokes a supernatural forces or agents as being responsible for the design of organisms and their organs. The first answer is the "good" teleology accepted by modern biology. The second answer is a "bad"

teleology, which some biologists attribute to Aristotle and his followers. Aristotelian scholars argue, however, that careful reading of Aristotle's works does not support the attribution. As we have tried to explain, he admits that the generation of individual organisms is driven toward a specific end, but he argues that the process is self-propelled, rather than being guided by a supernatural force.

Where Modern Genetics Meets Old Aristotle

At this point we might want to ask two questions: What is Aristotle's Form really? And what does it correspond to among the things that we now, more than 2300 years after Aristotle, recognize as reality? The principal assumption of Aristotle's theory of hylomorphism is that reality has a dual nature, consisting of matter and Form. Matter is the stuff of which an object is composed and Form is the way matter is organized. Modern science, especially biology, assumes essentially the same duality in that it distinguishes between the material structure of things and function determined by this structure. In biology there are sciences devoted to the study of structure (biochemistry, anatomy, morphology) and those investigating function (physiological sciences). Both Aristotle and modern science hold the stuff for material and the activity it displays for immaterial, but not in the sense many religions view immaterialness, that is, in the sense of spiritualness. By assuming immaterialness as a part of reality, neither Aristotle nor modern sciences violate the basic tenet of reality's physicalness. For both the manifestation of physicalness is the intimate association of the Form and function with matter (stuff). In this respect, one other parallel between Aristotle and modern science is the abundance of aliases for the immaterial component. Perhaps the closest that modern science comes to Aristotle's Form is the term *information* (note the obvious etymological relatedness of these two terms), especially in regard to the phenomenon which Aristotle calls "generation" and which modern science splits into heredity and reproduction. First in physics and then also in biology, information came to be a measure of order, applicable to any structure and any system.[48] It quantifies the instructions needed to produce a certain organization. Its counterweight is *entropy*, which is a measure of disorder.

In modern genetics one now speaks commonly of heredity as of genetic information. The physical carriers of genetic information are the DNA and their twins, the RNA molecules. The two kinds of nucleic acid are strings (two in the case of DNA and one in RNA molecules) of repeated subunits called *nucleotides*. There are four types of nucleotides, whose names are abbreviated to single letters A, C, G, and T (or U). It is the order of these "letters" that stores the information in the DNA molecules analogously to the letter order and grouping in forming words, sentences, and chapters in a book. All the information necessary for building, for example, a human being and keeping it alive is contained in 23 pairs of very long DNA molecules (chromosomes). The two strands of a DNA molecule enable it to duplicate itself and then pass a copy from each of the two parents to the offspring in the act of reproduction. It has been suggested[49] that Aristotle's concept of the Form prefigures the existence of DNA molecules. Aristotle, of course, knew

nothing about molecules and the concept of information was alien to him, but he correctly grasped the essence of reproduction by postulating that something immaterial (the Form, the information) stored in a material substance (matter) was all that was required to give rise to a new individual in the process of generation. His grave mistake was that he reduced the female's contribution to a default situation. Only when the transmission from the male failed in part or as a whole, did the female get a chance to have things her way. In this he followed an ancient Greek belief that reality arose out of the interplay of two primal principles, the formative-male and receptive-female principles.[50]

The parent-to-offspring transmission of information is one aspect of generation, in which Aristotle prefigures modern genetics; another is the development of an embryo into a new adult individual. Modern genetics still struggles to get the whole picture of this very convoluted process. The essence of the process as it is now known is this. When the DNA molecules of the male and the female find themselves together in the same cell, the fertilized egg, the deciphering of the information encrypted in them begins. In a complex biochemical process, the first messages are transcribed into RNA from specific sites of the DNA molecules, and the messenger RNAs are translated into proteins, which fall into two categories. In the one category are proteins necessary for the growth and differentiation of the arising embryo. In the second are RNA and protein molecules that target new sites on the chromosomes and activate them to produce a second-generation RNA and protein molecules. These fall again into two categories—the effector and regulator molecules. The former join the teams that build the developing embryo, whereas the latter return to the chromosomes and find new sites to activate. And so the process continues step by step, in each step some of the previously activated sites being shut off, while new sites are activated, until all the informative sites along the chromosomes have been visited and used at the right moment when their contributions toward the development were called for.

The question then arises: What determines the order in which the different sites are activated? A popular answer was: a genetic program.[47] It assumed that the DNA contained a program specifying the order of activation and that the order was the result of the program's unraveling, similarly to the unfolding of a computer program. This explanation collapsed, however, when the complete DNA sequences of several different species were determined and no such program was found in them.[51] At this point, some researchers (those who had a healthy respect for history) remembered Aristotle. You may recall that he faced the same problem in his theory of generation. He solved it by postulating a progression similar to the operation of mechanical toys of his time. We do not know what the toys looked like, but presumably they were cleverly constructed automata operating on the principle of a chain reaction. In it, the first stimulus triggered a reaction, which then triggered another reaction, and so on, resulting in the puppet's performance of a small act. This is, in principle, how now some geneticists imagine the molecular control of embryonic development. In each step of the cascade described above, the regulatory molecules are specific for those sites of the DNA molecules that need to be produced to trigger the next step of the progression. But how could have such an

enormously complex chain reaction arisen? Aristotle did not have to answer this question because in his eternally existing universe, things just happened to be the way they were. Modern science, however, does believe in the beginning of the universe and in the evolution of the organic world. And it has a powerful theory of evolution by natural selection, which accounts for the complex phenomenon of embryonic development by postulating a stepwise accumulation of complexity.

How Does Mendel Fit into All This?

Modern genetics, a discipline in which 5-year-old articles are considered too ancient to be cited, has rediscovered Aristotle. A clear sign of the rediscovery are articles with titles like "Aristotle and modern genetics"[52] or "Genomic metaphysics."[53] Behind the resurrection is not only the realization that Aristotle's views are relevant to some of the ethical issues the discipline raises but also in relation to some of the new genetic findings. What is now happening in genetics is nothing less than a conceptual (the Kuhnians might say paradigmatic) shift. After a century of focus on the study of single or simple character inheritance, genetics is turning to the examination of an organism as a whole and to the development of individual organisms. This was the focus that characterized ancient Greek philosophers and physicians, with Aristotle at the forefront. Their interest was in the generation, the rise of an individual animal from what then appeared to be amorphous emissions of sexual organs. Their interest in the transmission of individual characters, such as the color of the eyes, the shape of the nose, or the texture of the hair, was not strong enough to compel them to coin a separate name for the phenomenon.

When later, in the Middle Ages, the West European civilization assimilated—through the Romans, Arabs, and Jews—much of the Greek culture, it took over also the Aristotelian concept of generation in its entirety, including the views of sexual reproduction, species, and heredity. This tradition then persisted without any significant modifications until the nineteenth century, when the three parts of this package split and became the subjects of separate studies. Mendel, whose studies on heredity founded the genetics of the twentieth century, therefore started essentially from a counter-Aristotelian platform, although, ironically, it was Aristotle who introduced the *symbebekota*, the accidental qualities or characters, as a distinct component of reality. It was Mendel, however, who liberated the characters from the generation package and gave them a life of their own. By doing so, he effected the first great paradigm shift in the study of heredity since Aristotle. A second shift appears to be under way now, and although it sometimes gives the appearance of being counter-Mendelian and pro-Aristotelian, when it is completed, it will probably be a synthesis of the two. It is our aim in this book to unravel how the first shift came about, and to do this, we needed to describe the base from which the new paradigm issued. May we be forgiven if we have been a bit overzealous in our enthusiasm for Aristotle!

References and Notes

[1] *"Never, Telemachos, you will be feeble or thoughtless hereafter. If indeed is instilled in you the great force of your father—Such was the man he was to achieve both action and speeches—Then your journey will not be fruitless or lacking fulfillment."* Homer: *The Odyssey*, translated by Rodney Merrill. The University of Michigan Press, Ann Arbor, MI 2005. Book 2, verses 270–273

[2] Peters FE (1967) Greek philosophical terms. A historical Lexicon. New York University Press, New York, NY

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[5] The Greek word *symposion* means drinking together (*syn-*, together, *posis*, drink). It is also the title of one of Plato's dialogues describing a long drinking party, in which the participants debate the nature of love. In general, *symposion* was a social gathering of intellectuals, in which a discussion upon a chosen subject was aimed at collecting the opinions of different authorities

[6] The first definition of a philosopher can be found in Plato's *Symposium*, but the term was introduced much earlier. It was apparently used by Heraclitus and by the historian Herodotus in the sense *philosophoi anders*, men who love wisdom

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[12] Ontology is the knowledge of being (from Greek *ontos*, "being," and *logos*, here "knowledge." The term was introduced in the form of *Ontologia* by the German philosopher Jacob Lorhard (1561–1609)

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