CHAPTER 1

Of Philosophers and the Color Blue

In late 1996, a discovery was made near Rigillis Street in downtown Athens. While preparing the grounds for a new museum of modern art in the Greek capital, workers unearthed the foundations of an ancient building under a sprawling dirt parking lot. Finding ancient ruins under any part of Athens is no surprise, but this was a special case. No major excavation had ever taken place in the area, yet ancient writings indicated that this was roughly the place where, two and one-half millennia ago, the Lyceum had been located. Known to the ancient Greeks as the *Lykeion*, this was a public garden with military marching grounds, a gymnasium, sanctuaries, and groves. Reportedly there were colonnaded walks as well, where the eminent philosopher Aristotle gathered his students for philosophical teaching and discourse. In early 1997, archaeologists from the Greek Central Archaeological Council concluded that the ruins were indeed part of the Lyceum. The news that Aristotle's school had finally been found traveled around the world.

Although the Lyceum is the one place commonly associated with the name of Aristotle (Figure 1.1), for much of his life he was more of a wanderer, and we shall see that his philosophy benefited from the experiences he gathered "on the road." Aristotle was not a native of Athens. He was born in 384 B.C. in Stagira, a town in northern Greece on the border with Macedonia. His father worked as a physician for Amyntas II, the King of Macedonia, and while this intimates the privileged conditions under which Aristotle was raised, it also foreshadows his precarious position between two neighboring countries that were not always at peace. At the age of seventeen, Aristotle was sent to Athens to become a pupil at the Academy of Plato, a famous philosopher who himself had been a pupil of Socrates. Aristotle remained at the Academy for twenty years and eventually became an assistant to his famous teacher. When Plato died in 347 B.C., Aristotle left Athens and went on to travel and study around the

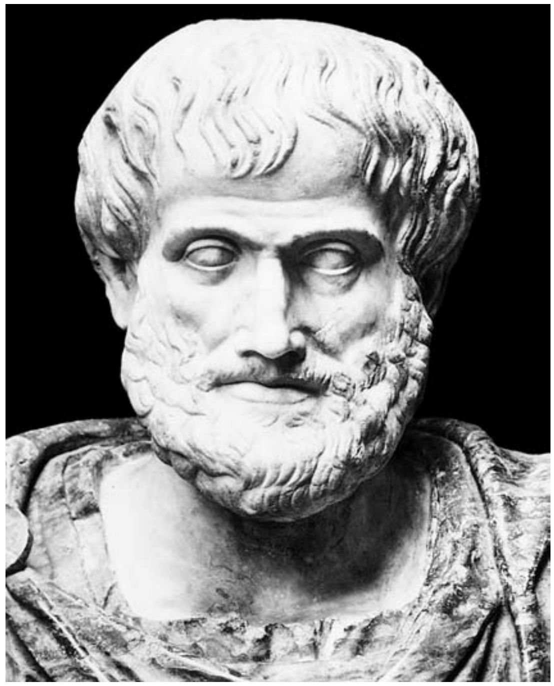

Figure 1.1 Bust of Aristotle in the Museo Nazionale, Rome. Courtesy of Bildarchiv Preussischer Kulturbesitz, Berlin.

Aegean Sea and Asia Minor (modern Turkey), pursuing mostly biological studies. During long stays on the islands, he became keenly interested in marine life, making some observations himself and gathering others from fishermen, farmers, and physicians. Then he returned to Macedonia, where he was called to teach Amyntas' grandson, Prince Alexander, who would later be known as Alexander the Great. Only in 335 B.C., when Athens fell under Macedonian rule, did Aristotle return to Athens. He founded a philosophical school in the Lyceum, which soon emerged as a competitor to the Academy (Figure 1.2).

A few years after the discovery of the ruins on Rigillis Street, more and more archaeologists came to view the identification of the ruins with the Lyceum as premature. The building turned out to be a villa from Athens' Roman period, dating from the second century A.D., approximately four centuries after the death of Aristotle. Thus, the colonnaded walks where he strolled remain as yet undiscovered. However, modern scholars agree that the Lyceum must have been situated nearby.

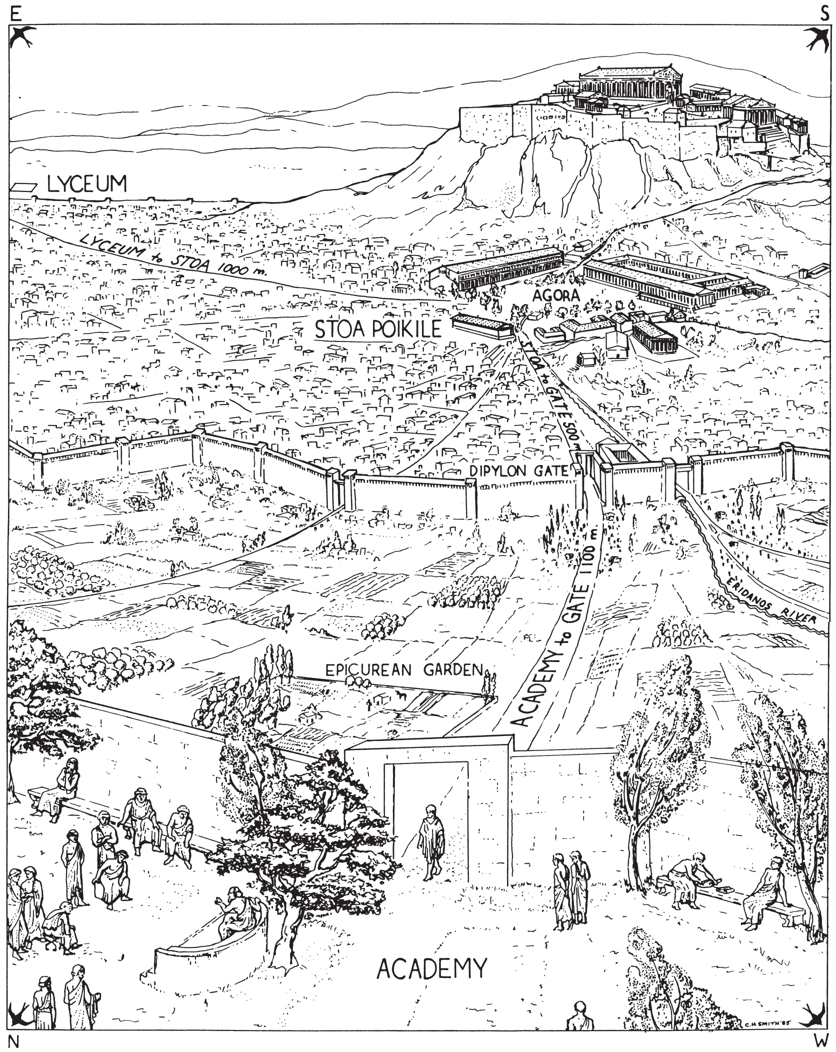

Figure 1.2 Sketch of Athens in the classical Greek period (fourth century B.C.), showing the locations of the important philosophical schools. Courtesy of Candace H. Smith.

Aristotle lived at a time when Greek thinking about nature was changing rapidly. For countless centuries, natural phenomena had been explained solely as the actions of the gods, most notoriously Zeus himself, the father of them all. But starting in the fifth century B.C., scholars at centers of learning began to debate questions such as whether, and how, planetary motion could be understood by means of mathematics, and which substance might fill the space between the stars. Meteorological phenomena drew their attention as well, perhaps because the caprices of weather and the devastation caused by storms were of particular concern to an agrarian society.

In Greek meteorology, two traditions are discernible from that time. One dealt with the prediction of weather, mostly in the form of farmers' rules and almanacs. Throughout antiquity, poetry was an important medium for conveying information, including technical data and instructions, and poems containing rules for predicting the weather were geared toward farmers and sailors as the groups most directly affected by its vicissitudes. The *Phaenomena* of Aratos, a poem of more than a thousand lines, is the most famous example of this genre.[1] Another tradition concerned itself with explanation, attempting to understand the phenomena observed in nature within the framework of a comprehensive theory. There were various schools that followed different approaches and came to different conclusions. Some claimed that the gods did indeed have a marked effect on nature as it was perceptible to man. Others, however, notably the members of the so-called Milesian school, refrained from attributing any perceptible action to deities. This was new. The Milesians assumed that the universe was made of one basic substance, but were unable to agree on what that substance was. Thales surmised that it was water, while Anaximenes claimed that it was air.

Faced with such a variety of conflicting ideas, Aristotle grew uneasy. He envisioned a systematic philosophy that would provide a framework for unambiguously interpreting natural phenomena. Given this background, we must not be surprised that he considered the problem of sensory perception particularly important. After all, our knowledge of nature relies on trust in our perception—whatever we feel, smell, hear, taste, or see. In particular, light and color make the world perceptible to our eyes, vision perhaps being the central mode of perception. Aristotle deals with the senses in several books, especially *On the Soul* (De anima) and *On the Senses and their Perceptions* (De sensu et sensibilia).

As we may infer from Aristotle's devotion to biological studies, natural history was one of his favorite pursuits. And indeed, he was interested in the study of meteorology and weather as well. Once more he realized that contradictory opinions and teachings abounded and that a new doctrine was needed. Yet he also realized that meteorology was a particularly difficult field of study. Meteorological phenomena, Aristotle realized, were halfway between the perfect regularity of the heavens and the irregularity encountered on Earth. Nevertheless, he tried to come to grips with the phenomena observed in the sky and to explain their colors. His book *Meteorology* attests to these efforts.

WERE THE GREEKS BLUE-BLIND?

When we search the works of Greek authors for clues to how they perceived the color of the sky, we are confronted with a mystery. Vacationers are familiar with the intense blue of the Greek sky and the Aegean Sea. It stands to reason that this color would be mentioned, for example, in Homer's *Odyssey*. But that is not the case: a blue sky is mentioned only rarely in Greek literature. Homer, in the third book of the *Odyssey*, describes the ascent of the sun god Helios thus:

> And now the sun, leaving the beauteous water surface,
> sprang up into the brazen heaven
> to give light to the immortals and the mortal men on the earth . . .[2]

Homer's sea is not blue either. When Odysseus was taken captive by the nymph Calypso and thought longingly of his wife Penelope and of his distant home of Ithaca, Homer wrote:

> Him I saved when he was bestriding the keel and all alone,
> for Zeus had struck his swift ship with his bright thunderbolt
> and had shattered it in the midst of the wine-dark sea.[3]

Elsewhere in the *Odyssey* Homer describes the sea as black, white, gray, dark, and purple. Upon further reading, we discover that other Greek authors also write about the sea and the sky without describing them as blue-colored.

Scholars have recognized since the beginning of the nineteenth century that there is a mystery here. Between 1858 and 1877, the British statesman William Gladstone published several articles and books in which he speculated that the ancient Greeks may have had deficient organs for color perception.[4] In other words, he surmised that they were blue-blind. Yet while the color blue is mentioned only rarely in the literature, we have learned since then from archaeological research that, next to yellow, blue was one of the most frequently used colors in Greek painting. The Greeks were not blue-blind.

Careful linguistic study has resolved this riddle by revealing that to ancient Greeks, including Aristotle, luminosity was more important than hue in characterizing color. For example, the Greek words *melas* and *leukos* can be translated not only as "black" and "white" but also as "dark" and "light." The use of the color term *kyanos* is equally ambiguous; it is usually translated as "blue" and gave rise to our modern color term cyan (a green-tinged blue). *Kyanos* referred to a dark color in general and was used to describe emeralds, but it could also manifest itself as a blue, and could even mean black. The difference between black and blue, then, was not so crucial to the Greeks. It was much more important to them that blue bordered on black or dark, and that both of them constituted the dark end of a scale of colors. If we keep this meaning of the word *kyanos* in mind, then much that is found in Greek literature becomes clear. In a book on precious stones, Aristotle's pupil Theophrastus describes the (blue) lapis lazuli as *kyanos*-colored. Homer's *Iliad,* on the other hand, could describe not only the color of steel but also the (probably black) hair of King Priam's son Hector as *kyanos*. A cloak could also be *kyanos*-colored: "a dark-hued veil, than which was no raiment more black."[5]

ILLUMINATING THE "TRANSPARENT"

The oldest-known statements by the Greek philosophers include thoughts about the nature of light (*phos*) and color (*chroma*). In a poem from the early fifth century B.C., the poet Alcmaeon of Croton had already claimed the opposition of light and dark to be the origin of the colors. This assumption, like the color theories of Empedocles and Democritus, remained a speculation in natural philosophy. Empedocles related the four basic colors—black, white, red, and *ochron* (probably a yellow or dull green color)—to the four elements earth, water, air, and fire. Democritus, the originator of Greek atomic theory, interpreted colors as properties of the surfaces of objects and claimed that smooth surfaces appeared white, whereas rough surfaces appeared black.

Plato, a pupil of Socrates, tried to explain the properties of light and color as functions of our perception. He assumed that the eyes emit visual rays that join together with daylight to form a luminous medium. This medium was supposed to convey a material effluence emitted by visible objects into our eyes so that we could perceive these visible things. Plato attempted to reduce sight to a mechanical sensation like touch, explaining the multitude of colors as the result of the different sizes of the particles emitted by the objects. If they were larger than the particles of the visual rays, then the object would appear black; if they were smaller, then we would see white. He described in great detail the combinations that were supposed to produce the multitude of colors we see, and used the rules proposed by Democritus. But in the end, Plato began to have misgivings and gave up, because he feared that attempting to understand colors was tantamount to meddling in the workings of the Demiurge, the creator of the world.

Aristotle did not let such compunctions hold him back when he first began to study the visual process in depth, probably around 340 B.C. In contrast to Plato, he doubted that our eyes could emit visual rays, surmising rather that they passively receive the rays from visible objects; Aristotle was a proponent of the intromission theory of vision. Like the proponents of the extramission theory of vision, he presupposed the existence of a medium that conveys visual impressions, making objects perceptible to our eyes. Aristotle devoted a great deal of attention to this medium, which he called the "transparent" (*diaphanos*). For him, the "transparent" was a property of all media that are more or less translucent. It was that

> which is visible, only not absolutely and in itself, but owing to the color of something else. This character is shared by air, water, and many solid objects; it is not qua water or air that water or air is transparent, but because the same nature belongs to these two as to the everlasting upper firmament.[6]

Aristotle explained that light would come about if fire (one of the four elements) were found in a transparent medium (like air or water). In contrast, darkness would mean the absence of fire. Colors would then only be visible when acting on a transparent medium. Only in the light would there be color, because darkness is colorless. Aristotle claimed that color is a property of all objects and of the medium that surrounds them, but not of light. This corresponds to our everyday experiences with vision, because we think we see colors on the surfaces of the objects around us. Interestingly, Aristotle did not see light as propagating itself with a certain finite speed. Rather, he imagined that a luminous body changes the entire transparent medium from a state of potential transparency into a state of actual transparency in no time, the perception of light reaching the observer's eye instantaneously.

But how do colors arise? In his treatise *On the Senses*, Aristotle names three possibilities. First, the surroundings can produce a color impression in the eye by means of tiny black and white particles:

> One possibility is that white and black particles alternate in such a way that while each by itself is invisible because of its smallness, the compound of the two is visible. This cannot appear either as white or as black; but since it must have some color, and cannot have either of these, it must evidently be some kind of mixture, i.e. some other kind of color. It is thus possible to believe that there are more colors than just white and black, and that their number is due to the proportion of their components.[7]

The colors can be arranged on a scale ranging from light to dark according to their differing proportions of black and white. Relatively dark colors, like blue, contain mostly black and only a little white, while for lighter colors, like yellow and orange, the proportion of white predominates (Figure 1.3). This derivation of all colors from the complementary

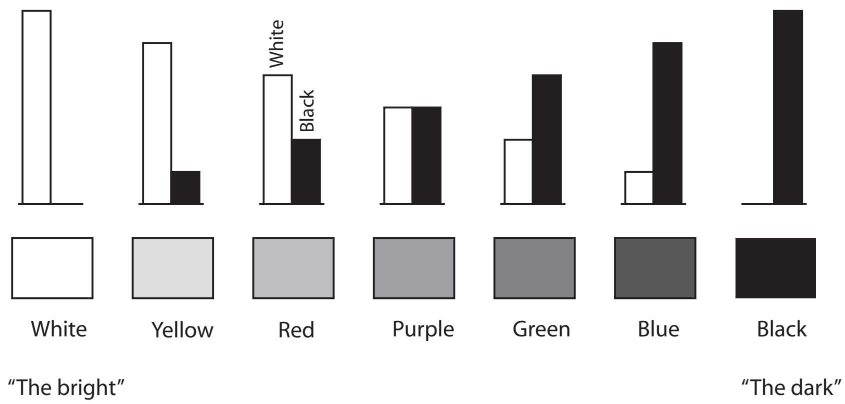

Figure 1.3 The colors produced by black and white mixed in different proportions, according to Aristotle's treatise *On the Senses.*

pair black-white exemplifies a recurrent theme of Aristotelian natural philosophy: pairs of opposites like hot and cold, wet and dry, or light and heavy are commonly employed in ordering phenomena. Aristotle names five colors between white and black: yellow, red, purple, green, and blue. The proportion of white particles decreases in this order; the lightness of these colors therefore also decreases. Blue is next to black and contains very little white. Aristotle thus lists a total of seven basic colors, including white and black. He claims that especially pure colors result when black and white are mixed in proportions of low whole numbers (such as 3:2 or 4:3). Here he is alluding to Pythagoras, who had deduced octaves and the other pure intervals in music from the harmonic relations of tone pitches. This parallel is not coincidental, writes Aristotle, because colors are indeed related to tones.

For Aristotle, the second way that colors can be produced is through the physical permeation of colored substances, from which a mixed color emerges.

New colors may also appear when a luminous color shines through a transparent medium. In *On the Senses*, Aristotle writes:

> Another theory is that they appear through one another, as sometimes painters produce them, when they lay a color over another more vivid one, e.g. when they want to make a thing show through

> water or mist; just as the sun appears white when seen directly, but red when seen through fog and smoke.[8]

This is the third way in which colors can be produced. The effect of smoke and fog is one example; it shows how the air can change the color impression of the sun shining through it. Aristotle identifies a situation in the sky where this transmission of light through a medium has a perceptible effect—namely, the red color of the sun. Could a similar explanation be found for the blue of the sky?

THE SPHERES OF AIR AND FIRE

In searching for an answer, we must consider what "sky" may have meant to the Greek philosopher. More than a century prior to Aristotle's thoughts on light and color, Empedocles had proposed that, in addition to the elements earth, water, and fire, the world was also made up of a fourth element, air. In his book *On the Heavens* (De caelo), Aristotle modifies this idea and divides the world into the terrestrial regions, which he places inside the orbit of the moon around Earth, and the celestial spheres, which are situated outside the lunar orbit. In his view, earth, water, air, and fire are the elements of the terrestrial region. These are characterized by their tendency to occupy certain spaces in accordance with their characteristic natural motions. The heavy elements, earth and water, have a tendency to sink down. The light elements, air and fire, rise up. For Aristotle, the world is finite and has a center. This center is the natural place for the heaviest element, earth. In accordance with their weight, the other elements nestle around Earth in spherical shells and create the spheres of water, air, and fire (Figure 1.4). The sphere of fire, says Aristotle, extends up to the lunar orbit and marks the upper boundary of the terrestrial region. This is the region where everything that comes to be or passes away runs its course: the four elements can transform into one another there. In contrast, he regards the celestial spheres as immutable and eternal. There the moon, sun, planets, and fixed stars move in circular orbits around Earth. Both the celestial bodies

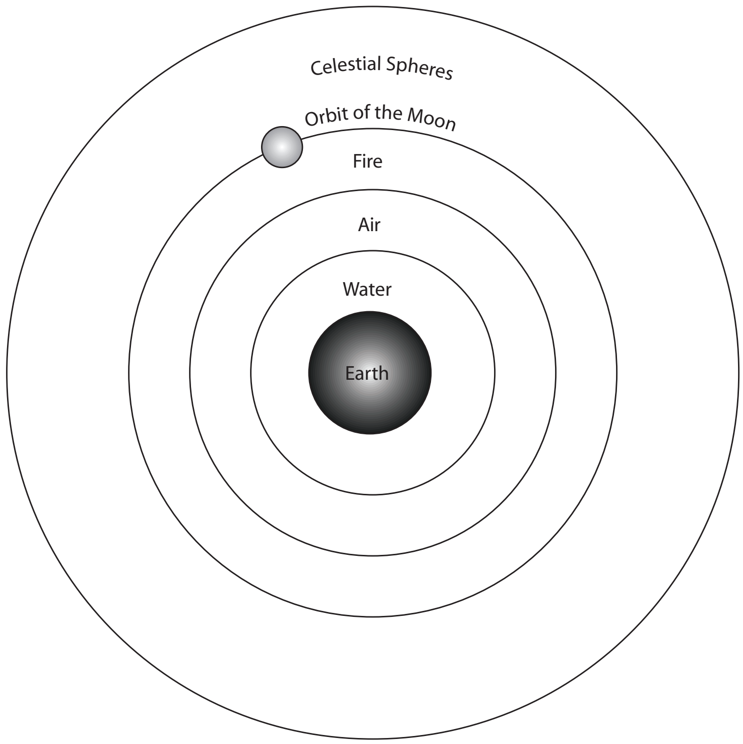

Figure 1.4 In Aristotle's cosmology, the four elements earth, water, air, and fire form concentric spheres around the center of the universe. Outside the lunar orbit, the sun, planets, and stars move in perfect circular paths around this central point.

and the space between them consist of quintessence or aether (*aither*), the perfectly transparent "eternal element of the heavens."

When a body moves toward its natural place, Aristotle considers it an instance of natural motion. The impetus for this motion lies solely in the inner nature (*physis*) of the body. When a body does not move toward its natural place, it is a case of forced motion. The impetus for this motion must be an outside mover. Natural motion has the character of a development and is goal-oriented (teleologic).

One might ask why the celestial spheres move if they consist of the perfect fifth element, aether. In his *Metaphysics*, Aristotle answers that their orbit is special, because it is the only thing that is constant and eternal. Yet they have an originator that does not itself move but remains still. Aristotle calls this being the unmoving mover or the first mover. The ultimate cause of motion must be a living god. This god does not move the celestial spheres by means of a physical push but rather by inspiring in them the desire to approximate his perfection by executing a perfect motion.

While he regarded the celestial spheres and their bodies as the object of study for astronomy, Aristotle located the objects of study for meteorology primarily in the spheres of air and fire—that is, between Earth and the lunar orbit. In doing so, he took the Greek term *meteorologica* literally. It is a combination of the words *meta* (over), *area* (air), and *logos* (the study of). Yet for Aristotle, meteorological phenomena, or *meteora*, included not only rain, evaporation, wind, clouds, and rainbows but also comets, the Milky Way, and even earthquakes and volcanic eruptions. If this list of *meteora* appears to us today to be a hodge-podge of phenomena from meteorology, astronomy, and geology, to Aristotle it was a logical grouping. He considered it the task of meteorology to investigate the exhalations of Earth, as well as how the heat of the sun and the other stars influence them. Transformations between the elements earth, water, air, and fire have a special significance here. Because the spheres of air and fire interact with Earth, or are influenced by objects in the nearer celestial sphere, a systematic study must not ignore them. This is the agenda to which Aristotle dedicated his book *Meteorology*.

Like *On the Heavens* before it, *Meteorology* is part of a series of notes for lectures that Aristotle presumably held in the Lyceum. The lectures were meant to present a comprehensive cross-section of the entire natural world. Aristotle does not assume that there is one physics for the entire universe, but rather that the laws within the celestial spheres and within the terrestrial region are independent of each other. He therefore has to find explanations for the phenomena in the latter that do not assume the perfection of the celestial spheres. Aristotle takes pains to place different meteorological phenomena within a systematic structure, but the imperfection of the terrestrial region entails that this task can only meet with a certain degree of success. Definite knowledge is not guaranteed.

Aristotle bases his remarks on observations and reports of *meteora*. His sources are numerous. He made many observations himself, but also heard second- or third-hand reports of rare events from others. Furthermore, he records earlier attempts at explanations, most of which he then vehemently criticizes. Today we profit from this presentational tactic, because many of the writings of Aristotle's predecessors have been lost. It would otherwise be virtually impossible to reconstruct early classical meteorology.

Aristotle conceived of meteorology as a scientific discipline, but not all of his contemporaries thought likewise. His teacher, Plato, characterized the *meteora* as "lofty things," and left it at that.[9] Although geometry and astronomy had already been developed into systematic theories at that time, some disputed that it was possible to study air, or found the idea of doing so laughable. The dramatist Aristophanes, who belonged to Socrates' generation, wrote in his popular play *The Clouds*:

> Why, for accurate investigation of meteorological phenomena, is it essential to get one's thoughts into a state of, er, suspension by mixing small quantities of them with air—for air, you know, is of very similar physical constitution to thought—at least, to mine. So I could never make any discoveries by looking up from the ground—there is a powerful attractive force between the earth and the moisture contained in thought.[10]

We can take this as evidence that more than a small minority were concerned with meteorological phenomena at that time. Otherwise this speech would not have evoked a comic effect among the audience.

EXHALATIONS

In *Meteorology*, Aristotle explains his ideas on the stratification of the spheres of air and fire, as well as their composition:

> We must understand that of what we call air the part which immediately surrounds the earth is moist and hot because it is

> vaporous and contains exhalations from the earth, but that the part above is hot and dry. For vapour is naturally moist and cold and exhalation hot and dry: and vapour is potentially like water, exhalation like fire.[11]

The substance of the spheres of air and fire is the exhalations that rise when Earth is warmed by the sun. Aristotle differentiates between two types of exhalations. One is similar to vapor and can be traced back to the moisture in the earth. It is hot, moist, and heavy. The other is similar to smoke. It comes from the earth itself and is hot, dry, and windy.

The ascent of the exhalations is one stage in the cycle of coming-to-be and passing-away, which is characteristic of the terrestrial region. There, each of the elements can be transformed into the others: water becomes air through evaporation, and air becomes water through rain. These transformations follow laws that result from the composition of the elements. Aristotle assumes that each of the four elements is a combination of the properties wet or dry and hot or cold. Water is wet and cold, whereas air is wet and hot. If you want to change water into air, you have to heat it up. In contrast, air becomes water through cooling (Figure 1.5).

All these processes clearly happen in what we would today call the atmosphere; they seem to be accurately designated as *meteora*. Other phenomena considered *meteora* by Aristotle may not seem to fit so well into this category, for instance earthquakes and the Milky Way. To explain the latter, Aristotle invokes the action of the celestial spheres. Celestial bodies themselves are not hot, but their motion can inflame and rarefy the air below. This heat adds to that of the friction between the sphere of fire and the celestial sphere, an effect of their different rotational speeds. The resulting heat causes the air to glow, and this is visible in the form of the Milky Way.

Throughout *Meteorology*, Aristotle compares Earth and the cosmos to the human body. An example is his treatment of earthquakes, which draws an analogy between winds internal to the body and those inside Earth, both causing violent motions:

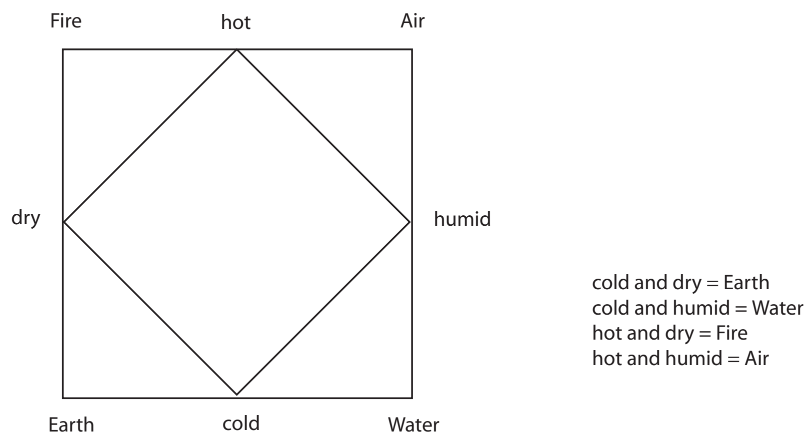

Figure 1.5 Aristotle derived the elements earth, water, air, and fire from combinations of the properties hot or cold and moist or dry.

> We must suppose that the wind in the earth has effects similar to those of the winds in our bodies whose force when it is pent up inside us can cause tremors and throbbings, some earthquakes being like a tremor, some like a throbbing.[12]

Aristotle's use of analogies like this does not mean that he considered Earth or the cosmos to be giant animals, or even to be alive. Instead, it is a sign of his conceding defeat as a scientist: some meteorological phenomena are just too far away or too difficult to understand, so that grasping an aptly chosen analogy is the most one can hope for.

Aristotle is content with describing the macroscopic properties of the four elements and the processes of their transformation; he does not speculate on whether the elements possess specific microscopic structures. This is quite unlike his teacher Plato, who had conceived of the elements as being composed of atoms: tiny, regular, geometric bodies. Plato imagined the atoms of fire to be tetrahedrons, those of water icosahedrons, those of the earth cubes, and those of air octahedrons (Figure 1.6). Aristotle objected to this view, but he agreed with Plato that the elements are inherently colorless.

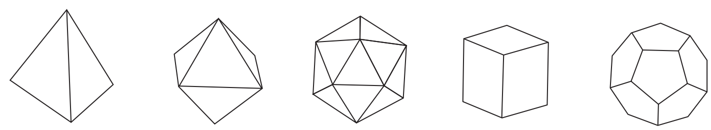

Figure 1.6 Plato conceived of the elements as being composed of atoms: tiny, geometrically regular bodies. He imagined the atoms of fire to be tetrahedrons, those of water icosahedrons, those of earth cubes, and those of air octahedrons. The dodecahedron, the regular solid closest to the sphere, was associated with the cosmos as a whole.

FEELING THE AIR

Aristotle was not alone in drawing parallels between meteorological phenomena and the human body. Throughout Greek antiquity, it was commonplace to construe the nature of air based on knowledge of one's own body. This was not necessarily easy, because air is invisible, has no taste or smell, and we are not able to touch it. All of our experiences with air are indirect and rest on our perception of it via our own bodies, when we breathe and feel the wind. In the sixth century B.C., Anaximenes of Miletus had conceived of air (*aer*) as the basis of the processes of condensation and rarefaction, from which he derived the development of all things. The historian Plutarch reported that Anaximenes had carried out one of the first scientific experiments when he noted that warm air escapes from the relaxed lips of sleepers but cold air comes from pursed lips. Consequently, Anaximenes considered sleep and relaxation as warm, but tension and pressure as cold. It followed that there were two types of air.[13]

Homer had also distinguished between two types of air. He characterized the "clear air aloft under the shining sky" as *aither*, but "dull air, fog, haze near the earth, over which a very tall tree up in the *aither* can loom" as *aer*.[14] The distinction between *aither* and *aer* was maintained for a long time. What was meant by these terms, however, changed again and again, probably most dramatically in the fifth century B.C. Democritus, who lived in the second half of that century, mentioned an old prayer in which believers lifted their hands to that "which the Greeks now call *aer*."[15] Apparently, he did not wish to suggest that they stretched out their hands to the fog or haze. That is why he emphasized that he meant the current usage of the Greeks; he was simply indicating that the ancient people prayed with their hands in the air—that is, up high.

When Empedocles added air to earth, water, and fire as the fourth element, he still alternated between the terms *aer* and *aither*. Later, he decided to use only the term *aer* for air. *Aither* became the substance of the heavens—and remained so for two millennia.

SEEING THE AIR

Seen from up close, air is clear, colorless, and seemingly fully transparent. But when it condenses, Aristotle writes in *Meteorology*, it can create different colors in the sky:

> [I]t is therefore to be expected that this same air in process of condensation should assume all sorts of colours. For light penetrates more feebly through a thicker medium, and the air when it permits reflection, will produce all sorts of colours, and particularly red and purple: for these colours are usually observed when fire-colour and white are superimposed and combined, as happens for instance in hot weather when the stars at their rising or setting appear red when seen through a smoky medium.[16]

It thus seems that there are two ways in which colors arise in the atmosphere. One is via the attenuation of light, the other via its reflection. Both ways presuppose condensed air, whereas thin air apparently lets the colors of objects pass through unhindered. The idea that a reflective layer of air is supposed to cause "all sorts of colors" alludes to his theory of the colors of the rainbow, which takes up a substantial part of *Meteorology*. Aristotle explains rainbows as an optical phenomenon that results from the reflection of sunlight off a cloud saturated with moisture, and for which the observer must have the sun at his back (Color Plate 6). In his opinion, a rainbow consists of only three colors, namely (from the inner

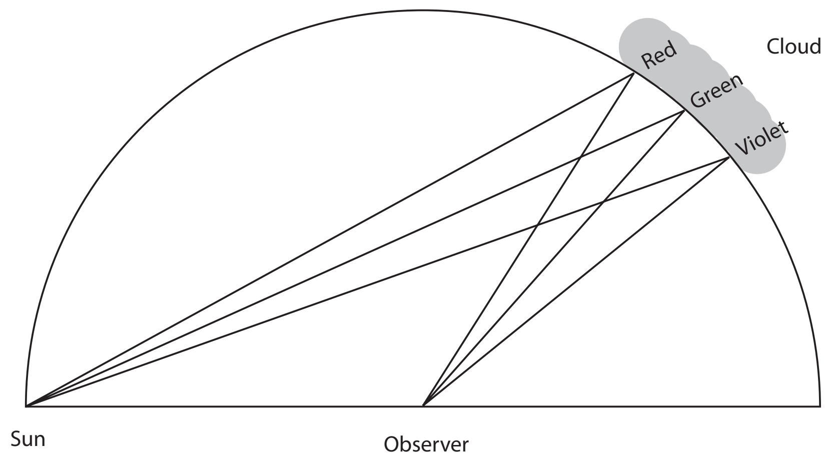

Figure 1.7 Aristotle's explanation of the rainbow.

part of the arc outward) violet, green, and red. Aristotle considers the yellow that appears in the rainbow to be an optical illusion. Since the sequence of the three colors is the same in every rainbow, he infers a universal principle behind it.

To explain these three colors, Aristotle first assumes that the individual vapor particles in the cloud work like small mirrors that reflect the white sunlight. This reflection is one of three causes responsible for creating colors, together with the attenuation of sunlight, as well as the weakening of vision at great distances. Notice that this contradicts his claim that there is no such thing as a visual ray. Aristotle goes on to say that, to a strong eye, reflected colors appear red, to a weaker eye green, and to an even weaker one violet. According to the color scale described in *On the Senses*, then, weaker eyes would see everything in the darker colors, since the degree of lightness decreases over the span of the three colors from red to violet.

Departing from the usual style of *Meteorology,* Aristotle makes use of a drawing to elucidate the relative position of the cloud to the observer and the sun (Figure 1.7). He places the observer in the center of a semicircle and arranges the sun and the cloud along the circumference. He knows that, as a heavenly body, the sun is much farther from an observer on Earth than a cloud, which he locates in the sphere of air. Thus, instead of showing the distances in their actual proportions, his drawing depicts the apparent dome of the sky, in which both the sun and the cloud are located.

Based on this depiction and on what has been said so far, it is not hard for Aristotle to explain the sequence of colors. We can infer from the illustration that the upper front part of the cloud is somewhat closer to the sun than its middle part and especially its bottom. At the same time, the entire front region is equidistant from the observer. The path of the light rays from the sun by way of reflection off the cloud to the observer is thus shortest when the rays are reflected off the upper edge of the cloud, and longest when they are reflected off its bottom edge. It is exactly the same with the visual rays, whose existence Aristotle surprisingly assumes here, and which are supposed to fan out from the observer to the sun and back. Two factors weaken the light and visual rays: their being reflected, and their traveling some distance. The latter attenuation increases with the distance traversed. Since the color red corresponds to the slightest attenuation of the visual rays, and since the path of the rays by way of reflection off the upper edge of the cloud is the shortest, the upper edge of the rainbow has to appear red. The situation with the other two colors, green and violet, is similar; Aristotle explains them on the grounds of increasing attenuation of the visual rays over their longer paths.

This creative application of visual rays with regard to the rainbow would seem like a way to explain any colors whatsoever in the atmosphere. But Aristotle does not settle for such an easy solution; he distinguishes the colors of the rainbow from those of low-lying stars. Seen through fumes, the latter appear red. The best example of this is the rising and setting sun, whose intense red has always fascinated humankind (Color Plate 7). In *On the Senses,* where he vehemently rejected the hypothesis of visual rays, Aristotle already recognized in this color the effect of something light shining through something dark (Figure 1.8). Thus, with or without visual rays, the condensation of the air is a necessary condition for the emergence of colors in the atmosphere.

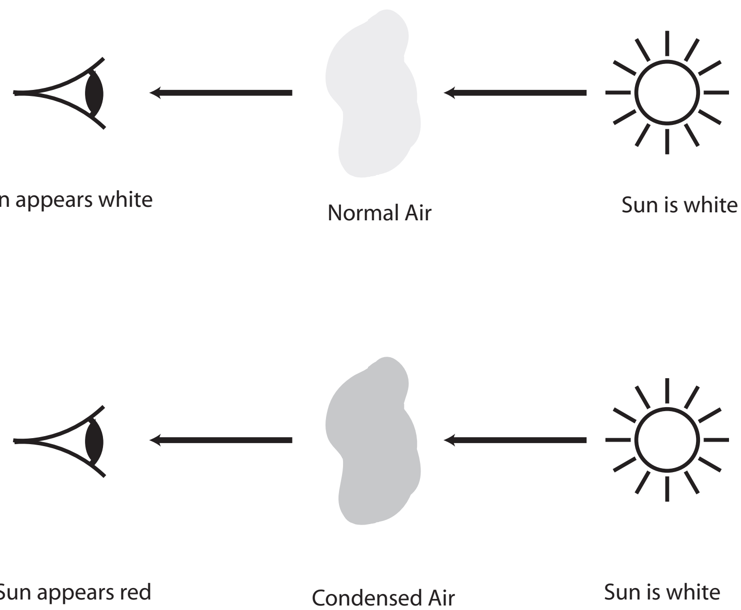

Figure 1.8 Aristotle's interpretation of the effect of condensed air on the apparent color of the sun.

THE PENETRATING DARKNESS OF THE DEPTHS

Aristotle died in the year 322 B.C. Shortly before then he had gone into exile to escape a death sentence. Alexander the Great had died unexpectedly the previous year while on a military campaign. Alexander had subjugated Athens at the beginning of his reign, and so anti-Macedonian sentiments broke out there after his death; these were also directed at Aristotle, as the monarch's former teacher. Aristotle reportedly claimed that he left Athens in order to prevent the city from committing yet another sin against philosophy. Seventy-seven years earlier, the condemned Socrates had been forced to drink a cup of poison.

Even before founding the Lyceum, on his travels in the Aegean, Aristotle had made the acquaintance of Theophrastus of Eresus, who assisted him with his biological research. Theophrastus accompanied Aristotle to

Athens. After Aristotle's death, he was appointed head of the Lyceum and held the position for the next thirty-five years. Theophrastus shared his teacher's interest in meteorology, as can be seen in his work *Metarsiology,* a book concerned with "things in the sky." In the surviving text, Theophrastus distinguishes between phenomena above Earth—to which he assigns thunder, lightning, clouds, rain, snow, hail, dew, frost, wind, and halos—and those below the surface of Earth, which include earthquakes. Theophrastus also dealt with color theory. He is now considered to be the author of the work *On Colors* (De coloribus), which was attributed to his teacher up until the twentieth century.

Even though *On Colors* clearly does rely on the Aristotelian color theory, Theophrastus does not follow his teacher in every detail. Both philosophers agree that the transparent medium is a prerequisite for vision and that all colors result from a mixture of black and white, light and dark. In contrast to Aristotle, Theophrastus places colors in relation to the four elements. Fire (as well as the sun) is golden, air and water are white. Earth is also white, but appears as if "stained" with several colors. While black, for Theophrastus, is a color that can result from some property of a material, it primarily represents the absence of light. He considers sea foam and snow to be proof of the white color of air, interpreting both of them as its compressed states.

We cannot see the colors in their natural purity, writes Theophrastus, because they are always altered by light and shadow. The colors of all objects are influenced, namely, by their illumination, the nature of the medium through which the light rays radiate, and the background they are positioned in front of. Thus the colors of objects appear differently when they are seen in sunlight versus in shadow, in hard or soft light. Media that are dense and transparent appear cloudy, Theophrastus writes, mentioning water, glass, and dense air as examples. The density of these media attenuates the light rays that penetrate them:

> This also happens, one would suppose, in the case of air. So that all colours are a mixture of three things, the light, the medium through which the light is seen, such as water and air, and thirdly, the colours forming the ground, from which the light happens to

> be reflected. But the white and the transparent, when it is very thin, appears misty in colour. But over what is dense a haze invariably appears, as in the case of water, glass and air, when it is dense. For, as the rays from all directions fail owing to the density, we cannot see accurately into their inner parts. But the air when examined from nearby seems to have no colour (for owing to its thinness it is controlled by the rays and is divided up by them, because they are denser and show right through it), but when examined from in depth, the air appears from very nearby to be blue (*kyanos*) in colour because of its rarity. For where the light fails, there, being penetrated by darkness at this point, it appears blue (*kyanos*). But when dense, just as with water, it is the whitest of all things.[17]

Here Theophrastus explains not only the blue appearance of rarefied air. Imagining clouds to be condensed air, he also ponders their white color, as well as the blue of the sea. This blue, as the color of light penetrated by darkness, follows from the color scale described by Aristotle in *On the Senses:* it is adjacent to black. Theophrastus joins his teacher in declaring the density of air to be the deciding factor in creating this color. However, his way of accounting for the interactions that lead to the preponderance of darkness is new. The density of the air accumulates primarily because of its great depth, in which only blue can emerge. This resonates with the daily observation that air is colorless from close up, and only in the sky does the blue color appear. At great depth, darkness predominates because the light rays lose their strength. Theophrastus thus refrains from assuming visual rays and accounts for the darkness of depth solely with the attenuation of light rays.

Theophrastus does not explicitly state that he intends to explain the color of the sky with this argument. Yet there can be little doubt that he did, because in his worldview air is the element of the spheres of air and fire, which in turn are seen in the sky. The great depth of these two spheres, which extend all the way to the lunar orbit, had to suffice to penetrate the sunlight with their darkness.