359–385. Since the appearance of this text, which was based on the earliest and best MS, Oxford, Bodl., D'Orville 70, 61v–62v, three further MSS have been discovered: Paris, B.N. lat. 7434, 79v–81r (colophon missing); and Vienna, Nationalbibliothek 5176, 143v–146r (colophon missing), and 5277, 276v–277r (proem. proofs of propositions I–IV, and colophon missing). The text will be republished and related to the sixteenth-century authors in volume IV of M. Clagett, *Archimedes in the Middle Ages*.

The *De sectione conica orthogona, quae parabola dicitur* was published in an altered version by Antonius Gongava Gaviensis in an ed. of Ptolemy's *Quadripartitum* (Louvain, 1548). For a comparison of this printed text with a sixteenth-century MS, Verona, Bibl. Capitolare, cod. 206, 1r–8v, see J. L. Heiberg and E. Wiedemann, "Eine arabische Schrift über die Parabel und parabolische Hohlspiegel," in *Bibliotheca mathematica*, 3rd ser., **11** (1910–1911), 193–208. There is a further copy of this work in Regiomontanus' hand: Vienna, Nationalbibliothek 5258, 27r–38v. Other copies are in Oxford, Bodl., Canon. Misc. 480, 47r–54r, 15c; and Florence, Bibl. Laur. Medic. Ashb. 957, 95r–110v, 15–16c. In both of these the tract is attributed to Roger Bacon.

On the work of Ibn al-Haytham that may be related to *De duabus lineis*, see F. Woepcke, *L'algèbre d'Omar al-Khâyyamî* (Paris, 1851), pp. 73 ff.; and L. Leclerc, *Histoire de la médecine arabe*, I (Paris, 1876), 515. Woepcke translates the title given by Ibn al-Haytham (through Ibn abī Uṣaibi'a) as "18. Mémoire sur la réfutation de la démonstration que l'hyperbole et ses deux asymptotes s'approchent indéfiniment l'une des autres, sans cependant jamais se rencontrer."

M. CLAGETT

JOHN PECKHAM. See **Peckham, John.**

JOHN PHILOPONUS (*b.* Caesarea [?], late fifth century; *d.* Alexandria, second half of sixth century), *philosophy, theology*.

Most of what is known about Philoponus is found in a few remarks made by him and by some of his contemporaries. He gives the dates of two of his books: his commentary on Aristotle's *Physica* was written in 517 and his book against Proclus in 529. One of his last works, *De opificio mundi*, was dedicated to Sergius, who was patriarch of Antioch from 546 to 549. Philoponus was one of the last holders of the chair of philosophy in Alexandria, succeeding Ammonius the son of Hermias. His philosophical background was Neoplatonic; but he was—probably from birth—a member of the Monophysite sect, which was declared heretical in the seventh century.

Philoponus' main significance for the history of science lies in his being, at the close of antiquity, the first thinker to undertake a comprehensive and massive attack on the principal tenets of Aristotle's physics and cosmology, an attack unequaled in thoroughness until Galileo. The essential part of his criticism is in his commentary on Aristotle's *Meteorologica*, in his book *De aeternitate mundi contra Proclum*, and in excerpts from his book against Aristotle's doctrine of the eternity of the world. This last work has been lost, but Philoponus' pagan adversary Simplicius quoted from it extensively in his commentaries on Aristotle's *Physica* and *De caelo*.

Philoponus' philosophy of nature was the first to combine scientific cosmology and monotheism. The monotheistic belief in the universe as a creation of God and the subsequent assumption that there is no essential difference between things in heaven and on earth, as well as the rejection of the belief in the divine nature of the stars, had already been expressed in the Old Testament and was taken over by Christianity and later by Islam. The unity of heaven and earth had been accepted as a fact, but Philoponus was the first to interpret it in the framework of a scientific conception and to explain it in terms of a world view differing from myth or pagan beliefs. His point of departure was a criticism, supported by physical arguments, of Aristotle's doctrine of the eternity of the universe and the invariable structure of the celestial region. The physical basis of Aristotle's dichotomy of heaven and earth was his assumption that the celestial bodies are made of the indestructible fifth element, the ether. As early as the first century B.C. an attack on the concept of ether was made by the Peripatetic philosopher Xenarchus. His book *Against the Fifth Element* is lost, but fragments are extant in quotations by Simplicius in his commentary on Aristotle's *De caelo*. No doubt Xenarchus' book was also known to Philoponus; but from a remark by Simplicius it appears that Philoponus' arguments against the ether went much further than those of Xenarchus, particularly those concerned with his physical proofs in favor of the fiery nature of the sun and stars. Aristotle had claimed that "the stars are neither made of fire nor move in fire" (*De caelo*, 289a34) and that the celestial stuff "is eternal, suffers neither growth nor diminution, but is ageless, unalterable, and impassive" (*ibid.*, 270b1). Heat and light emitted from the celestial bodies are produced, according to him, by friction resulting from their movements, a case similar to that of flying projectiles. This is what makes us think that the sun itself possesses the quality of fire, but even the color of the sun does not suggest a fiery constitution: "The sun, which appears to be the hottest body, is white rather than fiery in appearance" (*Meteorologica*, 341a36).

Philoponus denied Aristotle's statement regarding the color of the sun and emphasized that the color of a fire depends on the nature of the fuel: "The sun is not white, of the kind of color which many stars possess; it obviously appears yellow, like the color of a flame produced by dry and finely chopped wood. However, even if the sun were white, this would not prove that it is not of fire, for the color of fire changes with the nature of the fuel" (*In Meteorologica*, 47, 18).

Philoponus expressed this idea elsewhere, explicitly comparing celestial and terrestrial sources of light: "There is much difference among the stars in magnitude, color, and brightness; and I think the reason for this is to be found in nothing else than the composition of the matter of which the stars are constructed. . . . Terrestrial fires lit for human purposes also differ according to the fuel, be it oil or pitch, reed, papyrus, or different kinds of wood, either humid or in a dry state" (*De opificio mundi*, IV, 12). If the different colors of the stars indicate their different constitutions, it follows that stars are composite bodies; and since composite things imply decomposition and things implying decomposition imply decay, one must conclude that celestial bodies are subject to decay. But, Philoponus argued, even those who believe the stars to be made of ether must assume them to be composed of both the matter of the fifth element and their individual form, different for each star. "However, if one abstracts the forms of all things, there obviously remains the three-dimensional extension only, in which respect there is no difference between any of the celestial and the terrestrial bodies" (Philoponus, *apud*: Simplicius, *In Physica*, 1331, 10). Thus, anticipating Descartes, Philoponus arrived at the conclusion that all bodies in heaven, as well as on earth, are substances whose common attribute is extension. Against the objection raised by Simplicius that no change can be observed in the celestial bodies, Philoponus adduced arguments from physics, stressing that the greater the mass of a body, the slower its rate of decay. Furthermore, the slowness of change is a function not only of the mass but also of certain physical properties, such as hardness; moreover, it is well known, for instance, that different animals have different life spans and that some parts of them are more resistant than others to change.

The monotheistic dogma of the creation of the universe *ex nihilo* by the single act of a God who transcends nature implied, for Philoponus, the creation of matter imbued with all the physical faculties for its independent development according to the laws of nature, a development that he conceived of as extending from the primary chaotic state to the present organized structure of the universe. This deistic conception of a world that, once created, continues to exist automatically by natural law, was completely foreign to the classical Greek view, which never considered the gods to be "above nature" but associated them with nature, reigning not above it but within it. The shock created by this conception of Philoponus' is reflected in the words of Simplicius, who is bewildered by the idea of a god who acts only at the single moment of creation and then hands over his creation to nature.

Philoponus' anti-Aristotelian views were not restricted to problems of cosmology and to the removal of the barriers between heaven and earth. He also took strong exception to some of the main tenets of Aristotle's dynamics. According to Aristotle, movement is not possible without a definite medium in which it can take place; thus, statements on the movement of bodies must always be related to a certain medium. Aristotle asserted, for instance, that in a given medium the velocities of falling bodies are proportional to their weights, and that the velocities of a given body in different media are inversely proportional to the densities of these media. Furthermore, one of the many reasons given by Aristotle for denying the existence of a void was that it would be like a medium of zero density; and thus the velocity of a falling body *in vacuo* would reach infinity, regardless of its weight. Philoponus, in opposition to Aristotle, did not exclude the feasibility of movement in a void. However, against the view held by the Epicureans (proved to be correct), he assumed that in the void Aristotle's law of the proportionality of the velocities and weights of falling bodies would be exact. Against Aristotle he stressed that the impeding influence of a medium on a falling body consists in an additional increase of the body's time in motion over and above that of the natural motion *in vacuo*, depending on the density of the medium. This additional time will be directly proportional to the density of the interfering medium. In a lengthy argument Philoponus refuted Aristotle's statements and emphasized that experience shows that "if one lets fall simultaneously from the same height two bodies differing greatly in weight, one will find that the ratio of their times of motion does not correspond to the ratio of their weights, but that the difference in time is a very small one" (*In Physica*, 683, 17).

Philoponus had his doubts about the essence and the causes of the natural motion of light and heavy bodies. For instance, he wrote that one cannot agree with Aristotle that air tends to move only upward. Air may move downward for some physical reason, such as the removal of earth or water beneath it; in this case it will rush down, filling the void thus

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created. On the other hand, it may well be that the so-called natural motion upward has a similar cause, if there happens to be an empty space in the upper region.

Of special importance is Philoponus' criticism of Aristotle's theory of forced motion. He rejected the main contention of the Peripatetics that in every forced motion there must always be an immediate contact between the mover and the body forced to move in a direction other than that of its natural motion. In particular Philoponus denied Aristotle's hypothesis that besides the push given to a missile by the thrower, the air behind the missile is set in motion and continues to push it. He argued convincingly that if string and arrow, or hand and stone, are in direct contact, there is no air behind the missile to be moved, and that the air which is moved along the sides of the missile can contribute nothing, or very little, to its motion. Philoponus concluded that "some incorporeal kinetic power is imparted by the thrower to the object thrown" and that "if an arrow or a stone is projected by force in a void, the same thing will happen much more easily, nothing being necessary except the thrower" (*ibid.*, 641, 29). This is the famous theory of the impetus, the precursor of the modern vectorial term "momentum" or scalar term "kinetic energy." The impetus was rediscovered by Philoponus 700 years after it had been conceived of by Hipparchus (see Simplicius, *In De caelo*, 264, 25). In the physics of medieval Islamic philosophers and Western Schoolmen the concept of impetus was developed further, mainly as a consequence of a tradition following Philoponus.

Philoponus returned to his idea of the impetus in his anti-Aristotelian theory of light, which he developed in the guise of an interpretation of Aristotle's doctrine that centers on the basic categories of potentiality (*dynamis*) and actuality (*energeia*). According to Aristotle, light is the state of actual transparency in a potentially transparent medium; by such an actualization any potentially colored body found in this medium becomes actually colored and thus visible. Light is therefore a static phenomenon whose emergence and disappearance are instantaneous and have nothing to do with locomotion. Philoponus raised the fundamental question of how Aristotle's view can be compatible with both the laws of geometrical optics, developed in the Hellenistic period, and the thermic effects of light, which are so strongly enhanced by its concentration through burning glasses. He emphasized that light must be a directional phenomenon and that visual rays move in straight lines and are reflected according to the law of equal angles. However, at the same time he pointed out that these rays are not projected from our eyes to the luminous object, as was formerly assumed, but that they move in the opposite direction, from the luminous object to the eye. He clearly stated the principle of reversibility of the path of light for the case of reflection: "It makes no difference whether straight lines proceed from the eye toward the mirror or whether they are reflected from the mirror toward the eye" (*In De anima*, 331, 27). Making this assumption, Philoponus interpreted Aristotle's term *energeia* (actuality) as a kinetic phenomenon proceeding from the luminous object to the eye. He attempted to reconcile Aristotle's conception of light as actualization of a state with geometrical optics by identifying the visual rays with the *energeia* light, interpreting *energeia* as "force" and conceiving the emission of light in terms of the doctrine of impetus. Light is "an incorporeal kinetic force [*energeia kinetikē*]" emitted from the luminous object, similar to the force imparted by the thrower to the body thrown (*In Physica*, 642, 11).

Even when Philoponus accepted Aristotle's tenets, he was most remarkable in the originality and ingenuity of his exposition or amplification of Aristotle's physical doctrines. Sometimes he posed questions never raised before, anticipating much later developments; and some of the solutions he offered are evidence of the great acuity of his mind. Conspicuous examples are his discussion of the functional dependence of one set of variable quantities on another and his clear recognition of the course of a function—in modern language its first derivative. Assuming with Aristotle that the physical properties of a substance ultimately depend on the mixture of the four elementary qualities—hot, cold, dry, and moist—he asked how a reasonable explanation can be given of the fact that one of the physical properties of a given substance may remain practically unaltered while the other is undergoing a visible change. Two examples are the sweetness of honey remaining constant while its color changes from yellow to white and the color of wine remaining the same while its taste changes to sour. If all the properties derive from the primary qualities, one should expect them to change together with the qualities. Philoponus' answer is given in what can be defined as a verbal description of a graphic representation (unknown before the late Middle Ages). He explained that every physical property is a variable depending on the four primary qualities, so that if the qualities are diminishing, the physical properties are also being reduced. However, the rate of change is different for each of the properties; and thus, "if the mixture of the independent variables is slightly varied, the sweetness of the honey, e.g., will not alter appreciably, but its color may change completely" (*In De generatione et corruptione*, 170, 32).

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Another very acute remark of Philoponus' is his comment on Aristotle's statement in the *Physica* that "all things that exist by nature seem to have within themselves a principle of movement and of rest" (Aristotle, *Physica*, 192b13). Many Aristotelian commentators have pondered the question of how to include the heavens in this definition of nature, since they are never at rest but move eternally in a circle. Philoponus answered this question by interpreting the uniform and circular motion of the celestial bodies as inertial motion: "Rest is found in all things. For the perpetually moving heavens partake in rest, because the very persistence of perpetual motion is rest" (*In De anima*, 75, 11). Elsewhere he repeated his definition of inertial motion, adding that "the celestial bodies are, if I may say so, motionless in their motion" (*In Meteorologica*, 11, 31).

The concepts of potentiality and actuality, which Aristotle used extensively in his physical treatises, were occasionally supplemented, from the second century on, by a term expressing the capacity of a body to actualize a certain property or state that exists only potentially. The Greek word for this was *epitedeiotes*, meaning "fitness," "appropriateness," or "suitability"; it was sometimes used as a synonym for potentiality but later came to signify the sufficient condition for actuality, thus restricting potentiality to a necessary condition for actuality. In several of his writings Philoponus makes frequent use of this meaning of "fitness," occasionally in order to amplify Aristotle's doctrine of the basic requirements for physical action, whereby it is supposed that both the thing acting and the thing acted upon must be alike in kind but contrary in species. One of the examples given by Aristotle is the change of color, which he regarded as a process in which the object acted upon changes into the acting object by assimilation. Philoponus, commenting on this, remarked that such processes require the fitness of the active object to accomplish the assimilation. The black ink of a cuttlefish, he said, will overpower the whiteness of milk; but the black of a piece of ebony, when put into the milk, will not affect its color because of its lack of fitness. In the same way, brass or silver or similar metals will resound for some time after having been struck—i.e., they are capable of turning potential sound into actual sound—because they have a fitness for producing sound, in contrast with wood or other nonmetallic substances.

On another occasion Philoponus made use of the concept of fitness in order to defend against Aristotle's criticism Plato's doctrine of the soul as the mover of the body. Aristotle in his *De anima* argued that if Plato were right, it would be possible for the soul that had left the body to enter it again, and thus resurrection of the dead could be feasible, although it had never been observed. Philoponus emphasized that the soul keeps the body moving only so long as the body has the mechanical fitness to be worked on, and it loses that fitness when death occurs. Characteristically, he adduced mechanical similes for his view: "A stick pushed against a door cannot move it when it has not the fitness necessary for being moved. . . . It will not do so when fastened by nails or when the hinges are loose. Everything set in motion by something else generally needs a certain specific fitness" (*In De anima*, 108, 24). One interesting aspect of Philoponus' treatment of this problem is the way in which, anticipating Descartes, he looked at the human body as a mechanism capable of functioning only if its parts have the necessary mechanical fitness.

Philoponus' Neoplatonic background, depending largely on Stoic conceptions, is also evident in his manner of discussing a problem that in modern terms can be defined as resonance; it also shows his keen powers of observation. He described the ripples produced in the water in a metal cup when the cup is brought into a state of vibration. He assumed that these vibrations are not transferred directly to the water but that the air enclosed in the metal acts as an intermediate agent. This assumption shows influences of the Aristotelian theory of metals (*Meteorologica*, III, 6) as well as of the Stoic doctrine of *pneuma*.

> If we pass a wet finger round the rim [of the cup], a sound is created by the air squeezed out by the finger, which air is ejected into the cavity of the cup, producing the sound by striking against the walls. Experimental evidence for it can be brought in the following way: If one fills a cup with water, one can see how ripples are produced in the water when the finger moves round the rim [*In De anima*, 355, 34].

If the cup itself is held by the hand, no sound is produced, because, as Philoponus explained, "the body struck must vibrate softly, so that the air . . . is emitted continuously into the upper part, striking the walls of the cup and being reflected toward all of its parts" (*ibid.*).

A very ingenious physical illustration was given by Philoponus to explain the perturbation of a system by external forces. He discussed the Aristotelian concepts "according to nature" and "contrary to nature" in the context of explanations given of an illness or a congenital deformity. Such phenomena, according to his view, have to be regarded in a wider framework, as parts of a whole, in order to be considered natural. This is basically the Stoic idea that if something goes wrong, the event or object in question must be seen as a partial phenomenon. In the frame-

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work of a wider system, taken as a totality, the wrong is compensated in some way and the harmony of the whole is restored. Philoponus introduced a more physical notion into this trend of thought. When something "contrary to nature" happens to a physical object, one has to regard it as a perturbation caused by outside factors. The intervention of these factors, taken together with the resulting perturbation, restores the phenomenon as a "natural" one, as something in accordance with nature. Part of Philoponus' example is worth quoting:

> I will give you an illustration that will explain what happens with things contrary to nature: Suppose that a lyre player tunes his instrument according to one of the musical scales and is then ready to begin his music. . . . Let us assume for the sake of this illustration that the strings are affected by the state of humidity of the environment and thus get out of tune. . . . When the player strikes the lyre, the substance of the strings does not perform the melody that he had in mind; but instead an unmusical, distorted, and indefinite sound is produced [*In Physica*, 201, 28].

Philoponus then went on to say that the harmony of the whole is restored by taking into account the climactic changes and the perturbation of the strings caused by them.

On several occasions Philoponus discussed the problem of the infinite. He rejected the use of the infinite in the sense of the unlimited in extension; and in his rejection he went even further than Aristotle, not only denying, as Aristotle did, the existence of the infinite as an actual entity but also excluding the potentially infinite. Aristotle had admitted the possibility of entities that can be increased *in infinitum* without ever reaching actual infinity, but he did this mainly in order to reconcile his doctrine of the eternity of the universe and the infinite duration of the human race with the concept of infinity.

From his opposite position, believing in the beginning of the world at a finite point in the past, Philoponus argued that acquiescence in the existence of the potentially infinite will perforce lead to the admission of the actually infinite. Once one admits the infinite as a never-ending process, he said, the existence of an infinite magnitude existing by itself, or of a number that cannot be passed through to the end, cannot be excluded. From this, in his view, obvious absurdities would follow. A few sentences from his argument may be quoted here:

> If the universe were eternal, it is obvious that the number of men up to now would be infinite, i.e., actually infinite—since obviously they all have actually come into existence—and thus an infinite number would be possible. For if all human individuals have become actual up to now—and we, for instance, will be the limit of the actually infinite number of men who have been before us—then the infinite will actually have been passed through to the end [*In Physica*, 428, 25].

Philoponus went on to say that if we extend this definite limit to a future generation, the infinite will be further increased:

> This increase will tend toward infinity, if the universe is incorruptible, and thus the infinite will be infinitely increased. . . . For each generation, e.g., my own, will have an infinite number of men who were born before it. . . . Since it is impossible for the actually infinite to have been passed through to its end, and for something to be greater and more infinite than the infinite itself, it is impossible for time or for the universe to be eternal [*ibid.*].

Another argument of Philoponus' against the eternity of the universe is worth noting because it was later used by Islamic philosophers, e.g., al-Ghazālī. It is quoted by Simplicius (who wrote a polemic against it) from Philoponus' lost work against Aristotle. Philoponus, by a *reductio ad absurdum*, set out to prove that a universe without a beginning would necessarily involve the existence of different actual infinities, representing the relative numbers of the revolutions of the planets:

> Since the spheres do not move with equal periods of revolution, but one in thirty years, the other in twelve years, and others in shorter periods . . ., and if the celestial motion were without beginning, then necessarily Saturn must have revolved an infinity of times, but Jupiter nearly three times more, the sun thirty times more, the moon 360 times more, and the sphere of the fixed stars are more than 10,000 times as often. Is it not beyond any absurdity to suppose a ten-thousandfold infinity or even an infinite time of infinity, while the infinite cannot be comprised even once. Thus necessarily the revolution of the celestial bodies must have had a beginning [Philoponus, *apud*: Simplicius, *In Physica*, 1179, 15].

This passage is of interest to the historians of mathematics, since Philoponus, although he rejected altogether the notion of the infinite, here, for the first time in a specific case, made use of infinite cardinal numbers, anticipating modern concepts by more than 1,300 years.

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S. SAMBURSKY

JOHN OF SACROBOSCO. See **Sacrobosco, Johannes de.**

JOHN OF SAXONY (*fl.* France, first half of the fourteenth century), *astronomy*.

Probably from Germany, John Dank, Danco, Danekow, or Danekow of Saxonia was active in science at Paris between 1327 and 1335;[1] but his scientific career may possibly have begun as early as 1297. John of Saxony, who considered himself a student of John of Lignères, composed various works on the Alfonsine tables or works that employed them and a commentary on the astrological treatise of al-Qabisi (Alcabitius).

In 1327 John of Saxony published canons on the Alfonsine tables: "Tempus est mensura motus ut vult Aristoteles. . . ."[2] An exact appreciation of the place of these canons in the history of astronomy is dependent on knowledge of the introduction of the Alfonsine tables among the Paris astronomers. P. Duhem thought that the tables were already known to William of Saint-Cloud in 1300;[3] but his conclusions are based on an unsound subdivision of poorly identified texts (see the article on John of Murs), and it seems unlikely that the tables were known in Paris before about 1320. Their first appearance in medieval science may have been in the *Expositio tabularum Alphonsi regis Castelle*, written by John of Murs in 1321, and in the canons of the tables (1322) by John of Lignères. These canons, however, do not apply to the Alfonsine tables in the form known in the Latin West at the end of the Middle Ages. A short time later, in fact, the Alfonsine tables underwent a considerable transformation affecting both form and substance—the form through substitution of a sexagesimal representation of the mean movements of the planets for the traditional mode employing *anni collecti* and *anni expansi*, the substance through adoption of a double eccentricity for the equation of Venus and Jupiter. It is to this new drafting of the Alfonsine tables that the following canons apply: the undated "Quia ad inveniendum loca planetarum . . ." of John of Lignères; the canons of John of Saxony of 1327; and the canons "Prima tabula docet differentiam . . ." of John of Murs (1339).

It may be wondered why these three astronomers, who very likely worked together, produced texts on the same subject that duplicate one another. Basically, these texts deal with the same tabular material and defend the same principles, particularly in regard to the movement of planetary apogees. John of Lignères's very succinct account deals only with changes of calendar and with determining the mean solar and lunar conjunctions and oppositions and computing the true places of the planets. John of Saxony developed this account; his canons are clearer, and he added chapters on finding a "revolution" (the moment when the sun returns to a previously occupied position); calculating the date and hour of a true conjunction of the sun and moon and of their positions "in quarter aspect"; determining the time of the entrance of the sun into one of the signs of the zodiac; establishing the date of the conjunction of two planets. John of Saxony's canons enjoyed considerable success, attested to by the number of extant manuscripts and by their inclusion in the first printed edition of the Alfonsine tables (1483); the canons of John of Lignères, like those of John of Murs, were never printed.

Produced through the efforts of Erhard Ratdolt, this first printed edition bears, following John of Saxony's canons, the words "Expliciunt canones et quod sequitur est additio." This supplement comprises a general remark on interpolation in the tables of equations, canons of the eclipses, and several chapters —preceded by a separate title page—on the latitudes of the planets. The canons of the eclipses ("Eclypsis solis quantitatem et durationem . . .") are also credited by the manuscripts to John of Saxony. Consequently, they complete the chapter on determining