# THE CAMBRIDGE MEDIEVAL HISTORY

VOLUME IV

## THE BYZANTINE EMPIRE

PART II

## GOVERNMENT, CHURCH AND CIVILISATION

EDITED BY

J. M. HUSSEY

WITH THE EDITORIAL ASSISTANCE OF

D. M. NICOL AND G. COWAN

CAMBRIDGE

AT THE UNIVERSITY PRESS

1967

CHAPTER XXVIII

# BYZANTINE SCIENCE

When the course of Byzantine history is surveyed as a whole, it will be seen that long periods of partial or complete neglect of the sciences alternated with periods of intensive activity. Thus, the sciences flourished under Justinian I, then again under Theophilus and Michael III, under Constantine VII Porphyrogenitus and Constantine IX Monomachus and finally under several of the Emperors of Nicaea and the house of Palaeologus, whose members, despite their political preoccupations, did not confine their patronage merely to those practical branches of science indispensable to the health of the national and private economy.

Byzantium is important in the history of science, and especially that of mathematics and astronomy (the two subjects about which there is more information, though the situation is similar for the other sciences), not because any appreciable additions were made to the knowledge already attained by the Greeks of the Hellenistic era, but because the Byzantines preserved the solid foundations laid in antiquity until such time as the Westerners had at their disposal other means of recovering this knowledge. It must be admitted, however, that the theoretical discoveries of the great figures of classical mathematics (Archimedes, Apollonius, Diophantus) were only understood by a few, whereas calculations and measurements with a practical bearing (as in logistics and geodesy), and the subjects of the Quadrivium (arithmetic, geometry, astronomy and music), found their way into educational curricula, both because of their practical importance in ordinary life and also as a preparation for courses in philosophy; both geometry and logic start with definitions, postulates and axioms.

Chronologically considered, Byzantine history shows three main periods of scientific activity, each of which opens with a spectacular, or at any rate a high, level of achievement, followed just as regularly by a perceptible decline. The beginning of the first period (from Justinian I to Michael II) saw the activity of Eutocius and Isidore of Miletus, who were responsible for preserving the work of Archimedes and Apollonius. But soon afterwards interest in higher education evaporated, and all the available energy was caught up in the state's struggle for existence in the face of external foes or consumed in ecclesiastical conflicts. However, intolerance towards the pagan schools and the Nestorians had the effect of sending eastwards to Syria and Persia a number of refugee scholars who were learned in antique science; under the Sassanids there was a cultural centre, with a medical school, at Jundishapur (in Chusistan), to which the Nestorians came after their expulsion from Edessa in 489, and the Neoplatonists from Athens in 529. The opening of the second period (from Theophilus to Alexius V) is marked by the appearance of Leo the Mathematician at the university of Bardas; without Leo, the revival of mathematical studies in the West based on Greek texts is well-nigh inconceivable. For it must be remembered that the Arabs, who by the end of the ninth century had already mastered the corpus of Greek science, could only influence the West through Latin and Hebrew translations. The cultural efflorescence of the reign of Constantine VII Porphyrogenitus was also beneficial to scientific studies, and mathematics and astronomy, chiefly as subjects of the Quadrivium, were once more sedulously cultivated at the university of Constantinople reorganised under Constantine IX Monomachus (1045). But the internal and external weakening of the state once more took its toll of the sciences, so that the period of interregnum between the Macedonians and the Comneni has nothing to show in the way of mathematical activity. Even the succeeding period, covering the revival of the Empire under Alexius I Comnenus up to the time of the Latin conquest, can boast of only a few names to prove that intellectual endeavour was not wholly absent. In the third period (1204–1453) there was a marked revival from the time of John Vatatzes onwards. In the thirteenth and fourteenth centuries mathematicians such as Pachymeres, Maximus Planudes and Theodore Metochites discovered once again the paths leading back to the ancients. From the beginning of the fourteenth century, Greek astronomical lore which had formerly been known only to the Arabs and the Persians began to return to Byzantium, where there is also evidence of Eastern medical and pharmacological knowledge at this period.

## I. MATHEMATICS AND ASTRONOMY

### (*a*) *Justinian to Michael II* (527–829)

There could have been no mathematics in Christian Byzantium but for the scientific work already accomplished in the pagan universities. The great classical thinkers had lived in Alexandria, and it was at Alexandria that their works were assembled and studied. Hypatia (died 415) was the last of the line of commentators who helped to preserve Hellenistic learning for the West, where the heritage was to be received centuries later by way of Byzantium and the Arabs. In the Academy of Athens, on the other hand, pride of place in mathematical studies was given not to the higher mathematics but to those branches which were regarded as necessary to the understanding of problems in philosophy and natural philosophy, such as the elements of geometry, 'Platonic figures' and neoplatonic arithmetic, which were studied by Proclus, Simplicius and others in conjunction with the writings of Plato, Aristotle, Euclid or Nicomachus. Byzantium was added to Alexandria and Athens as a centre of learning when Theodosius II in 425 revived an educational institution which had existed there in the time of Constantine. Admittedly, mathematics was not the central feature of the curriculum: there were thirty professors of languages and law and only one of philosophy. However, there is evidence that lectures were given on the subjects of the Quadrivium.[1] The school clearly had a good reputation, since Armenian students and scholars went there to study as well as to Athens and Alexandria. Subjects of practical application, such as logistics and surveying, were probably taught by private teachers; an edict of 425 makes a clear distinction between such private teachers and the professors of the state academy.

Close relations existed between these three schools, which were all within the Empire; there is even evidence of a conference being held. Proclus, born in 410 at Byzantium, studied at Alexandria and in Athens, where he succeeded his master Syrianus as head of the Academy. One of his pupils in Athens, Ammonius (died before 510), revived the school of Alexandria, which had sunk into insignificance after the death of Hypatia. Among Ammonius' followers in Alexandria were Simplicius and Damascius, who both worked later in Athens, migrating to Persia when the Academy of Athens was closed by Justinian in 529. Another of Ammonius' pupils in Alexandria, the monophysite John Philoponus, was one of the greatest scholars of this period of transition from Hellenistic to Byzantine science. Some of his mathematical and astronomical work has survived, a commentary on Nicomachus and a treatise on the astrolabe. In a commentary on Aristotle, John Philoponus dealt with quadrature of the circle and duplication of the cube.

Another pupil of Ammonius was Eutocius (born *c.* 480 in Ascalon), who, under the inspiration of his master, devoted himself to the study of classical mathematics; we are indebted to him for commentaries on some of the works of Archimedes. In his commentary on Book I, *On the Sphere and Cylinder* (dedicated to Ammonius), Eutocius gave a detailed account of all earlier solutions of the problem of duplication

[1] H. Usener, *De Stephano Alexandrino* (Bonn, 1880), pp. 5f.

of the cube,[1] and in doing so preserved certain precious fragments of ancient Greek mathematics, taken partly from the lost *History of Mathematics* of Eudemus (*c.* 340 B.C.). He was also successful in recovering a lost text of Archimedes (on the geometrical solution of the cubic equation) from an old Doric version. His commentary on Archimedes' *Measurement of a Circle* provides examples, otherwise rare, of Greek arithmetical methods. Eutocius also wrote a commentary on Archimedes' *Plane equilibriums* and on the first four books of Apollonius' *Conics*,[2] which he dedicated to his friend Anthemius of Tralles, the first architect of St Sophia. It is not known whether they became friends in Alexandria or whether Eutocius actually lived at Constantinople later in his life; in either case, Eutocius must have the credit of having introduced classical Greek mathematics into Byzantium.

Anthemius (*ὁ μηχανικός*, architect and engineer) can also be counted as a mathematician. In his work on the burning-mirror he outdistanced Apollonius on several points; he knew of the directrix-focus property of the parabola and the method of constructing ellipses known as 'the gardener's', and also described the construction of ellipses and parabolas from their tangents.

Serious work in mathematics and mechanics was also undertaken in the circle of Isidore of Miletus, who became responsible for the building of St Sophia after the death of Anthemius in 534. Under his direction, Archimedes' writings on measurement of a circle and on spheres and cylinders were published, together with Eutocius' commentaries; one of Isidore's pupils was responsible for the so-called 15th Book of Euclid's *Elements*, whilst Isidore himself was the inventor of a pair of compasses for drawing parabolas, and the author of a commentary on the lost '*Καμαρικά*' (*On the Construction of Vaults*) of Hero, with its stereometrical and mechanical problems which were necessarily of interest to any architect. There is no clear evidence of a connection between Isidore and the state university.

The university was closed by Phocas (602–10) but revived as an oecumenical academy under his successor Heraclius (610–41) through the Patriarch Sergius. The direction of philosophical and mathematical studies was given to the scholar Stephen, summoned from Alexandria to Constantinople about 612, the author of an astronomical treatise *An explanation of Theon's method of handy tables by means of individual examples* (*Διασάφησις ἐξ οἰκείων ὑποδειγμάτων τῆς τῶν προχείρων κανόνων ἐφόδου τοῦ Θέωνος*).[3] Stephen also lectured on

[1] Archimedes III, ed. J. L. Heiberg (2nd ed. 1915), pp. 54ff.
[2] Apollonius II, ed. J. L. Heiberg (1893), pp. 168ff.
[3] Ed. H. Usener, *De Stephano Alexandrino*, pp. 38–54.

Plato and Aristotle and on the Quadrivium. This division of mathematics into the four branches, arithmetic, geometry, astronomy and music, which together with the Trivium comprised the seven liberal arts, was defended by Ammonius (against Proclus), although it originated at a much earlier date.[1] Later the Quadrivium was continued as the foundation of all mathematical instruction in the curriculum of the Byzantine and also of the western schools, where it was introduced through the writings of Martianus Capella and of Boethius, who was responsible for the name Quadrivium.

Little is known of the later activities of the oecumenical academy of Constantinople up to the time of its dissolution by Leo III the Isaurian in 726, and still less is known of scientific work in the following century up to the revival of learning under Theophilus. It is said that the Armenian Ananias of Shirak came to Constantinople towards the end of the seventh century to study philosophy, but found there no teacher of the subject; if this is true, it shows how deeply this branch of secular learning had declined. On the other hand, it is probable that the subjects of the Quadrivium continued to be taught and it is certain that there was never any interruption in the teaching of elementary arithmetic (logistics) and of geometry (geodesy), which at that time was regarded only as a branch of arithmetic; prescriptions were used without recourse to proof. These elementary subjects, indispensable to the life of the community, may perhaps have been taught privately or in church schools, which the Third Council of Constantinople (681) ordained that the clergy should establish 'per villas et vicos'. There are some collections of geometrical and stereometrical prescriptions for everyday use (they occur in a number of manuscripts from the ninth century onwards), many of which are ascribed to Hero; they are in reality only meagre extracts, in quality far below Hero's authentic writings. The knowledge of mathematics and mechanics necessary in building must have been handed down in the guilds of masons, just as merchants and craftsmen must themselves have undertaken the education of the rising generation. A few textbooks of logistics have survived from that period. The sixth- or seventh-century papyrus *Akhmīm*, found in Egypt,[2] contains an

[1] Proclus, following Geminus (*c.* 70 B.C.), distinguished eight branches of mathematics, two of which were on an elevated and advanced level (theoretical arithmetic and geometry) while six were lesser ones, concerned with the *αἰσθητά* (logistics, geodesy, optics, music, mechanics and astronomy). Varro in his scheme of education drawn up in 32 B.C. added medicine and architecture to the subjects later to be known as the seven liberal arts. After Apuleius (*c.* A.D. 150) and Martianus Capella (first half of the fifth century) Roman schools usually followed a plan of instruction based on the seven liberal arts, and this division must also have been the plan followed in the early Byzantine schools.

[2] Ed. J. Baillet, *Mém. miss. arch. française*, IX, 1 (Paris, 1892).

arithmetic book which includes amongst other things tables of fractions, exercises in division of fractions, and partnership rules. There is a wooden tablet from Cairo of the same period which gives tables of fractions and calculations of interest.[1] To logistics belong also the puzzles so popular as mathematical entertainment, which could be solved by algebra or arithmetic; a collection of these was made by Metrodorus (late fifth or early sixth century).[2] A similar collection 'for retailing at feasts' was made by the Armenian Ananias, who may have become acquainted with puzzles of this kind during his stay in Byzantium.

During the seventh century the Byzantine era, which fixed the creation of the world at September 5509 B.C., was introduced, an innovation which also soon came into use outside the Empire, to be superseded later by the Christian and Arabic eras.[3]

### (*b*) *Theophilus to the Fourth Crusade* (829–1204)

A second epoch in the history of Byzantine science begins with Theophilus. His taste for splendour and luxury was itself a stimulus to building and the ornamental arts; but he was also anxious to make Byzantium the leading cultural force in the orient, impelled in this ambition, perhaps, by thoughts of rivalling Baghdad where the Caliph al-Ma'mūn (813–33), like his father before him, was seriously concerned to make translations of the Greek works preserved in Syrian monasteries or purchased from Constantinople available to Arab readers. al-Ma'mūn also tried to acquire for his court the man who was to preside over the revival of studies in Byzantium, Leo the 'philosopher' and 'mathematician'. From what we known of Leo's youth—he was born about 800, in Hypata (Thessaly)—it is clear that it was still possible to obtain some education even after the closing of the university in 726. Leo attended a school of grammar in Constantinople; he found a teacher of philosophy and mathematics on the island of Andros, where there was also a library. He later set up as a private teacher in the capital, dealing with all branches of learning. When Theophilus heard that Leo had been invited to Baghdad, he appointed him a state teacher, to lecture publicly at the Church of

[1] See D. S. Crawford, 'A Mathematical Tablet', *Aegyptus*, XXXIII (1953), 222–40; he thinks the *Akhmīm* is rather earlier. In addition to the tables of fractions mentioned by Crawford (p. 223) there are also similar tables from *c*. A.D. 600, published in W. E. Crum and H. I. Bell, 'Coptic and Greek Texts from the Excavations Undertaken by the Byzantine Research Account "Wadi Sarga"', *Coptica*, III (Copenhagen, 1922), 53–7.

[2] Published in P. Tannery's *Diophanti Opera*, II (1895), pp. 43 ff., and with an English translation by W. R. Paton in *The Greek Anthology*, V (1953), Book XIV (Loeb).

[3] On chronological problems see V. Grumel, *La chronologie* (Paris, 1958).

the Forty Martyrs. It was thus only when Leo was already advanced in years that he acquired enough influence to bring about a genuine advance in Byzantine scientific studies. In 863 Caesar Bardas made him rector of the newly established secular university in the Magnaura palace, where Leo, as 'chief of the philosophers', taught both philosophy and the subjects of the Quadrivium. He had as assistants his pupil Theodore, who taught geometry, and Theodegius, who taught astronomy. Amongst those who heard Leo lecture on Euclid were the deacon Arethas,[1] later Bishop of Caesarea, and Constantine (Cyril), the Apostle of the Slavs.

Apart from his work as a teacher of the Quadrivium, Leo merits an honourable place in the history of mathematics on account of his effort to preserve the work of the great classical mathematicians. It was during his time that most of the manuscripts forming the vital link in the line of descent from antiquity were written. The following are known to have been copied in the ninth century: a text of Euclid, written in 888 and at one time in the possession of Leo's pupil Arethas, who himself made a number of notes in it;[2] the now missing manuscript of Diophantus, on which the oldest existing codex (dating from the thirteenth century) is based;[3] two lost manuscripts of Apollonius, from which copies were made in two codices now in the Vatican (tenth and twelfth centuries);[4] and three manuscripts with the *Syntaxis* of Ptolemy, among them the magnificent Cod. Vat. Gr. 1594.[5] There was no full edition of Archimedes, since Isidore's was incomplete. Leo, however, had a collection made of everything still extant. Thus there came into being the archetype, lost during the sixteenth century, which in the twelfth century was in the library of the Norman kings of Sicily and after the battle of Benevento came into papal possession, to be used (together with an older manuscript containing writings on mechanics) by William of Moerbeke in his translation of Archimedes. From Leo's time also dates a manuscript of the short treatise on astronomy, interpretations of Archimedes based on Leo's teaching, as well as the oldest scholia on Euclid,[6] the

[1] See J. L. Heiberg, 'Der byzantinische Mathematiker Leon', *Biblioth. Mathem.* I (2. Folge, 1887), 33–6. A much more important contemporary was Photius, chiefly a theologian and philologist, who only quite incidentally concerned himself with medicine and natural science; there are extracts made by Photius from Nicomachus in Cod. Vat. Gr. 198, fol. 1.

[2] See Euclid, *Elements*, ed. J. L. Heiberg, V (Leipzig, 1888), p. xxviii: *ἐκτησάμην ἀρέθας πατρεὺς τὴν παροῦσαν βίβλον νομισμάτων ιδ̄*. (in Cod. Bodl. Dorvillian., x, 1, inf. 2, 30).

[3] *Diophanti opera*, ed. P. Tannery, II (1895), p. xviii.

[4] Apollonius, ed. J. L. Heiberg, II (1893), p. lxviii (Cod. Vat. Gr. 204 and 206).

[5] See also Cod. Vat. Gr. 1291 and Cod. Paris. Gr. 2389 (from Egypt).

[6] Euclid, ed. J. L. Heiberg, V (1888), pp. 714–5; *ὑπόμνημα σχόλιον εἰς τὰς τῶν λόγων σύνθεσίν τε καὶ ἀφαίρεσιν Λέοντος*. Going far beyond what was then the usual practice

pseudo-Heronian treatise *On measuring* (περὶ μέτρων), and many other texts.

Little is known of the fate of the secular university during the reign of Basil I though it is clear that learning as well as art flourished in the Amorian and early Macedonian periods. Basil I, and to an even greater degree his son, Leo VI the Wise, attached much importance to education.[1] Constantine VII Porphyrogenitus was well known for the stimulus which he gave to arts and sciences. He himself studied mathematics, astronomy, music and 'philosophy the queen of all', and appointed distinguished teachers, and there were clearly still notable scholars to be found. Constantine's intellectual endeavours (the compilation of comprehensive encyclopaedias and collections of excerpts) were also beneficial to mathematics. The *Suda* contains numerous biographical notices, the sources for which must have been available in the libraries of the time. The number of manuscripts originating in the tenth century shows that mathematical works were then being studied and sought after in the bookshops; these included the edition of the *Elements* of Euclid in Cod. Vat. Gr. 190[2] (based on a pre-Theon text) and other manuscripts of Euclid,[3] Eutocius,[4] Ptolemy,[5] and Nicomachus.[6] The famous Archimedes palimpsest which also contains the *Method* dates from this time.[7] Constantine Cephalas' edition of the *Anthologia Palatina*, with mathematical epigrams from two older collections and scholia which go back at least to Metrodorus, also dates from the tenth century, as does a *Geodesy* of a surveyor known as Hero of Byzantium.

After the death of Constantine VII Porphyrogenitus in 959 there followed almost a century in which scientific studies were neglected as far as imperial patronage went and the Emperors were occupied with the extension and consolidation of the Empire. Basil II, whose reign marked the highest point of Byzantine power, was notorious for his hostility to learning, but in spite of this scholars were still to be found, and the fruits of their work were seen in the marked intel-

by which letters were used for numbers (see J. Tropfke, *Geschichte der Elementarmathematik*, II (3) (1933), pp. 46 ff.), Leo employed letters in calculations such as $\alpha . \beta = \delta$ ('ὁ μὲν ὑπὸ α, β ἔστω ὁ δ'), or $\alpha = \beta . \gamma$ ('ἔστω ἀριθμὸς ὁ α τοῦ β πολλαπλάσιος κατὰ τὸν γ').

[1] For one of his mathematical puzzles see Nicomachus, *Introductio arithmetica*, ed. R. Hoche (1866), p. 151.

[2] The Euclid manuscript, which probably originated in Syria (see Euclid, VI, p. vi, ed. H. Menge, 1896) contains also the *Data* with Marinus' commentary on it, and Theon's memorandum on Ptolemy's tables.

[3] Cod. Flor. Laurentian. 28, 3 (*Elements* and *Phaenomena*); Cod. Vat. Gr. 204 (*Data*, *Optica*, *Catoptrica* and *Phaenomena*).

[4] Cod. Vat. Gr. 204 (commentary on the *Conics* of Apollonius).

[5] Cod. Marc. Gr. 313 (*Syntaxis*).

[6] Cod. Gottingensis Philol. 66.

[7] Cod. rescriptus Metochii Constantinopoli S. Sepulchri monasterii Hierosolymitani 355.

lectual activity of the mid-eleventh century. Moreover, private teachers and the church schools had seen to it that the subjects of the normal curriculum were still taught, as is shown by the Quadrivium of an anonymous writer (perhaps Gregory the Monk or Romanus of Seleucia) of the year 1008.[1]

Mathematics took on a new lease of life when Constantine IX Monomachus reorganised the university in 1045 with a faculty of law and a faculty of philosophy. The Emperor himself exhorted the young to the study of philosophy and mathematics. At the head of the faculty of philosophy was set the versatile genius Michael Psellus. He lectured not only on philosophy and the subjects of the Trivium but also on those of the Quadrivium. But he did not consider this the most essential part of his work. Like Plato and Proclus, he saw in mathematics the connecting link between material objects and ideas, a means of leading students into the realm of abstract thought. He also devoted some time to the mathematical portions of Aristotle. His treatise on numbers (*περὶ ἀριθμῶν*) betrays the influence of neoplatonic and oriental number mysticism. Among his surviving writings is an astronomical treatise on the movements of the sun and moon, their eclipses, and Easter calculations.[2] There is also a letter on the nature of geometry, scholia on Nicomachus (written by 'Soterichus') and a letter on the algebraic terms used by Diophantus, of whom he possessed a manuscript (perhaps the only one in existence at the time).

One of Psellus' pupils, and his successor as 'chief of the philosophers', was John Italus; he also lectured on the Platonic theory of ideas, on Aristotle, Proclus and Iamblichus. In 1082, under Alexius I Comnenus, Italus, who had taught 'the foolish wisdom of the heathen', was condemned as a heretic. The secular university continued, though it henceforth appears to be to some extent under the supervision of the Patriarchs; the first evidence of this is furnished by Nicholas Mesarites (*c.* 1200).[3] Now, as formerly, the Quadrivium (which had formed part of the education of Anna Comnena) was taught, and there is even evidence that it figured in the teaching of

[1] See A. Diller, 'Byzantine Quadrivium', *Isis*, XXXVI (1945–6), 132; this Quadrivium was published twice in the sixteenth century under the name of Michael Psellus (in 1533 and 1556). There is a modern edition by J. L. Heiberg in *Det Kgl. Dansk. Vidensk. Selsk. Hist.-fil. Medd.* XV, 1 (Copenhagen, 1929).

[2] In Cod. Vindob. Phil. Gr. 190; cf. *GBL*, p. 622.

[3] In the description of the courses given at the Church of the Holy Apostles there is no mention of astronomy, and medicine appears in its place (see A. Heisenberg, *Grabeskirche und Apostelkirche*, II (Leipzig, 1908), 17 ff. and 90 ff.). The Patriarch had the last word on debatable points: he was 'an arithmetician greater than Nicomachus, a geometer greater than Euclid and a musician greater than Ptolemy' (A. Heisenberg, *op. cit.* p. 95).

the patriarchal school, which had clearly somewhat extended its curriculum.[1]

That the study of the ancient authors had certainly not ceased is shown by the number of manuscripts originating in the eleventh and twelfth centuries and containing works of Euclid (the *Elements*, *Data* and *Phaenomena*), Proclus, Marinus, Ptolemy, Apollonius, Serenus and Hero. One eleventh-century manuscript[2] provides not only the genuine *Metrica* of Hero but also the compilations known as the *Geometrica* and *Stereometrica* as well as the pseudo-Heronian *Geodesy* and similar writings of Didymus and Diophanes.[3] Cod. Paris Suppl. Gr. 607 of the same period contains Hero's *Dioptra*, and the *Definitions* of Hero contained in Cod. Paris. Suppl. Gr. 387 (*c.* 1300) are also authentic and taken from an eleventh-century compilation.[4]

During the twelfth century, political and economic relations between Byzantium and the West had their effects on scholarship. In the reign of Manuel I (1143–80), who was well disposed towards astronomical and astrological studies, Aristippus conveyed a manuscript of Ptolemy (the *Almagest*) to Sicily, where it was probably translated by Adelard of Bath. At about the same time Leo's archetype of Archimedes and other Greek manuscripts reached the Norman court, to be translated by William of Moerbeke. Admittedly, there was little in mathematics that Byzantium could learn from the West at that date; however, it may well be that the Byzantines gained from the West their knowledge of Arabic numerals, which appeared in Byzantium for the first time in a twelfth-century scholium on Euclid.[5] It is noteworthy that Leonardo of Pisa (b. *c.* 1170), whose career marks the beginning of the renaissance of mathematics in the West, and who introduced Arabic numerals and methods of calculation with his *Liber abbaci*, is known to have visited Byzantium. As he himself tells us,[6] he became acquainted with a number of

[1] Michael Italicus (second quarter of the twelfth century) taught not only grammar and rhetoric but also 'the mathematics' (the Quadrivium including mechanics, optics, catoptrics, metrics, the theory of the centre of gravity) and theology; see H. Fuchs, *Die höheren Schulen von Konstantinopel im Mittelalter*, pp. 37 f. See also a letter written by the prolific writer Theodore Prodromus to Michael Italicus, *περὶ τοῦ μεγάλου καὶ τοῦ μικροῦ*, ed. P. Tannery, *Mém. sc.* IV (1920), 207–22.

[2] Cod. Constantinop. palatii veteris no. 1.

[3] Ed. J. L. Heiberg, 'Mathematici Graeci minores', *Det Kgl. Dansk. Vid. Selsk. Hist.-fil. Medd.* XIII, 3 (Copenhagen, 1927), 3 ff. and 25 ff. There is a French translation by P. Ver Eecke, *Les opuscules mathématiques de Didyme, Diophane et Anthémius* (Paris-Bruges, 1940).

[4] See Hero, ed. J. L. Heiberg, IV (1912), p. iv.

[5] Euclid, ed. J. L. Heiberg, V (1888), p. xix.

[6] The *Liber abbaci*, ed. B. Boncompagni (Rome, 1857), pp. 249 ff.: 'Questio nobis proposita a peritissimo magistro Musco Constantinopolitano in Constantinopoli.' Other examples (pp. 188, 190, 203, 274 and 276), as well as the measures used, point to Byzantium.

arithmetical and algebraic problems from his contact with several Byzantine teachers, which is evidence that such studies continued to be cherished among them.

(c) *The Latin Empire to the fall of Constantinople* (1204–1453)

During the rule of the Latin Emperors there is no evidence of intellectual activity, whether of a general or a mathematical nature, in Constantinople itself. Baldwin planned a university there, but it never materialised. The private teachers migrated, irreplaceable manuscripts were destroyed or scattered. Only the practical subjects seem still to have attracted attention; and at this time also the new Arabic numerals and methods seem to have slowly started to spread. An arithmetic book in which they are used, dating from 1252 (*ἀρχὴ τῆς μεγάλης καὶ Ἰνδικῆς ψηφοφορίας*) later came into the possession of Maximus Planudes.

The court of Nicaea, on the other hand, whither most of the Greek scholars had fled, became, especially during the reigns of John Vatatzes and Theodore II Lascaris, a centre of Greek intellectual life, in which the leading figures were Nicephorus Blemmydes (*c.* 1197–1272) and George Acropolites (1217–82). John Vatatzes founded a school of philosophy in Nicaea (under the direction first of Hexapterygus and later of Blemmydes) and also other schools, with libraries, in various towns. In the Nicaean Empire there was a serious attempt at making education comprehensive to a much greater degree than it was in the West at the time, though it must be admitted that in mathematics it was again the practical branches that primarily received attention; had it not been so, the mathematics professors of the time of John Vatatzes—like the teachers of philosophy, with their renowned disregard of money—would have received no payment from the state.[1]

Blemmydes, a doctor's son born in Constantinople, founded a school at Ephesus; he was the tutor of the future Emperor Theodore II Lascaris (the best educated Basileus since Leo VI), who established at Nicaea a school of grammar and rhetoric and himself discussed scientific—including mathematical—problems. The most important of Blemmydes' and Hexapterygus' pupils was George Acropolites, statesman and humanist (also a tutor of Theodore II). Michael VIII Palaeologus, who undertook the revival of the schools and hospitals

[1] Zachariae von Lingenthal, *Jus graeco-romanum*, Synopsis minor VI (1931), pp. 495 f. —always assuming that von Lingenthal is right in saying that the 'Synopsis minor', ascribed to Michael Attaleiates, belongs to the period of Vatatzes; see his *Geschichte des griechisch-römischen Rechts* (3rd ed. 1892), p. 40.

of Constantinople after the restoration of 1261, appointed Acropolites head of the reopened state university at St Sophia, which was much under the influence of the Patriarch, Germanus III. In addition to the university, and connected with it (probably as a school of preparation), was a grammar school, held in the orphanage of St Paul's Church, where the normal general curriculum (ἐγκύκλιος παίδευσις) was taught. Acropolites lectured on mathematics after Euclid and Nicomachus,[1] as part of a course on philosophy. Of his successors as *hypatus* in his chair of philosophy, John Pediasimus (fl. *c.* 1310) showed a special interest in mathematics. He wrote scholia on Cleomedes and Ptolemy, a geometry consisting of excerpts from 'Hero' and also *Some Observations*, consisting of explanations of musical points, such as the numerical names of the intervals. According to his own account, the gifted scholar and historian, George Pachymeres (born 1242 in Nicaea, died *c.* 1310), a pupil of Acropolites, also taught at the university, despite his preoccupation with his ecclesiastical and secular offices. Like all philosophers, he was interested in Euclid and Nicomachus, he knew the Arabic system of numerals, and was the author of a Quadrivium much superior to the others (*Handbook on the Four Sciences*); in the arithmetical section he clearly demonstrates his close knowledge of Diophantus, at that time something very unusual. Pachymeres also lectured on the mathematical portions of Aristotle; one of his pupils made a set of notes on these lectures.

Maximus Planudes (*c.* 1255–*c.* 1310), who was a monk from Nicomedia, taught neither at the state university nor in the patriarchal school but in a public institution connected with a monastery with a library. He edited and commented on Diophantus' *Arithmetic* and revised the *Anthologia Graeca*. His *Arithmetic after the Indian method* (*c.* 1300), which was based on the similar book of 1252 mentioned above, shows that the new numerals and methods were still spreading.[2] It seems that before the time of Planudes there was a monk called Neophytus who used the Arabic numerals but employed the zero merely as a 'kind of exponent' or index for representation of the value of the digits,[3] so that his work represents no real advance over the arithmetic in which the numerals were alphabetical.

George of Cyprus (identical with the Patriarch Gregory (1283–9))

[1] George (Gregory) of Cyprus gave an account of the teaching he received from Acropolites (printed in *MPG*, CXLII, 25).

[2] Although the western Arabic Gobar digits are used in an arithmetic book of 1252, Planudes used the east Arabic forms; this points to influences by way of Persia-Trebizond-Constantinople. See P. Tannery, 'Les chiffres arabes dans les manuscrits grecs', *Mém. sc.* IV (1920), 199–205. Planudes received the book from George Beccus.

[3] The zero was denoted by a dot, or small circle, placed over a numeral, one dot indicating that the numeral was multiplied by ten, two dots by one hundred, three by one thousand, and so on [I am indebted to G. J. Whitrow for this note].

taught at the same monastery as Planudes, and was stimulated by his teacher Acropolites to the study of Euclid and Aristotle. Manuel Moschopulus, who wrote a treatise on magic squares, from a purely mathematical rather than mystical standpoint, was a pupil and friend of Planudes.

In the first half of the fourteenth century, a period very favourable to the pursuit of serious studies, the tutelage of the sciences at Byzantium passed into other hands. Among those who now came to the fore were some high officials of the civil service, who gathered round them a number of pupils to whom they handed on the intellectual achievement of the ancient world. Among such officials was Theodore Metochites (*c.* 1260–1332), who was deposed from the position of Grand Logothete in 1328, a man of wide education with a deeply ingrained love of learning. In his description of his course of study, he mentions that mathematics had for many years been in a perilous situation, lacking both teachers and students.[1] The only parts of Euclid and Nicomachus still studied were those relevant to philosophy, but did not include the tenth book of the *Elements* or the *Stereometry* or even the *Conics* of Apollonius or those of Serenus. Metochites eventually found a teacher to initiate him into the *Syntaxis* of Ptolemy; this was Manuel Bryennius, professor of astronomy and author of a book on harmony. He later studied Euclid (including the *Stereometry*, *Optics*, *Catoptrics*, *Data* and *Phaenomena*), Theodosius, and also, 'with much toil', Apollonius.

Metochites was the author of an introduction to Ptolemaic astronomy (*The Elements of Astronomy*), a treatise on the mathematical (harmonic) form of philosophy, and of many commentaries on Aristotle. The revival of higher mathematics at this period is attested by the numerous manuscripts of the thirteenth and fourteenth centuries, many of which certainly emanated from the circle of Manuel Bryennius and Theodore Metochites. Among them are included all the authors instanced by Metochites in his account of his studies (Euclid, Theodosius, Apollonius, Ptolemy), and many others (Eutocius, Theo, Pappus, Proclus, Geminus, Marinus, Autolycus and Aristarchus). Thus, while there is only one twelfth-century manuscript of Ptolemy's *Syntaxis* there are many surviving from the thirteenth and fourteenth centuries, including two with scholia 'by Bryennius', as Demetrius Cydones records.[2]

Metochites was responsible for introducing the encyclopaedic scholar and historian Nicephorus Gregoras (b. *c.* 1295 at Heraclea in Pontus, died *c.* 1360) to the study of astronomy and of the Greek

[1] C. N. Sathas, Μεσ. Βιβ. ι, πϛ′ f. (Venice, 1872), pp. 139–95.

[2] Cod. Paris Gr. 2390 and Cod. Flor. Laurentian. 28, 1.

mathematicians such as Nicomachus. Nicephorus Gregoras gave some private lessons at the Chora monastery, but he chiefly lectured before the learned audience of the court of Andronicus II. He was the author of a moderate work on the formation of square numbers, of two essays on the astrolabe and of various other astronomical writings, in which he sets out his own ideas (as also did Plethon, *c.* 1355–1452). His proposals for a reform of the calendar in 1324 went unregarded. By 1328 he seems to have stopped teaching, to resume his courses later, after his victory in a disputation with the Calabrian monk Barlaam (died *c.* 1350), a man well versed in scholastic dialectics, who had been appointed by John Cantacuzenus as teacher of theology and exponent of Aristotle; this success seems to have been due to Gregoras' superior ability as a mathematician. About 1358 Gregoras seems to have been living on Mt Athos, where there is evidence of an interest in mathematics and Aristotelian physics at this period. Many of the manuscripts found at Mt Athos have notes written in by Gregoras himself, which show that he was expert in the subjects treated. Barlaam, mentioned above, was the author of a commentary on the second book of Euclid's *Elements* and also of a work on logistics, in which calculations with vulgar and sexagesimal fractions and with ratios are taught. The fourteenth-century Cod. Marc. 310 contains an astronomical treatise by Barlaam on solar eclipse.

Another contemporary was Nicholas Rhabdas (fl. 1351); he knew Diophantus and was familiar with the 'Indian' methods of calculation. In two letters in which he employs the old numerical symbols Rhabdas expounds finger-symbolism and methods of arithmetic (including roots) and so brings together examples of problems in political arithmetic (rule-of-three, mathematical puzzles), which give us some insight into the old problems of logistics. Similar examples of arithmetical problems—some of them identical—appear in Cod. Paris. Suppl. Gr. 387 of the year 1303 as *Ψηφοφορικὰ ζητήματα καὶ προβλήματα* (Arithmetical questions and examples).

There was also a revival of astronomy in the first half of the fourteenth century. In this case the stimulus came from Trebizond, with which Byzantium had always maintained political, economic and cultural relations. Trebizond was the terminus of the important trade-route leading out of Persia. Gregory Chioniades (who died in Constantinople at the end of the thirteenth century) had made contact with Persian and Arabic science whilst living at the court of Trebizond; he travelled to Persia, learned the language, collected books, particularly on astronomy, and brought them back to Trebizond, where he founded a kind of academy. Cod. Vindob. Theol. Gr.

203 contains letters from Chioniades, including many addressed to the mathematician and *protonotarius* and *protovestiarius* Constantine Lukytes (not Lykytes), to whom he probably left his library. There is also a free translation (dated 1323) of a work of a Persian astronomer writing in Arabic (Shams al-Bukhārī, died *c.* 1339), known as Σὰμψ μπουχαρής. A cleric of Trebizond, Manuel (otherwise unknown), was the teacher of the physician, astronomer and geographer George Chrysococces. Manuel based his instruction on the books collected by Chioniades, which he translated. Chrysococces was himself the author of a *Commentary on the Persian Astronomical System* (1346), and of other astronomical works. Thus by a circuitous route the learning of Greek antiquity returned to Byzantium.

Still under the Persian influence were Isaac Argyrus (*c.* 1310–after 1371) and Theodore Meliteniotes (fl. 1360–88). Argyrus, a pupil of Nicephorus Gregoras, probably also lived in Constantinople; in 1367 he wrote a treatise on the astrolabe, possibly based on a similar work by his teacher. He is also regarded as the author of two astronomical treatises (1371) and of two computi. The following mathematical works of his have survived: an essay on square roots, scholia on Euclid (six books of the *Elements*) and on the arithmetic of Planudes in Rhabdas' edition, a new edition of Nicomachus' commentary by Proclus and Philoponus and finally an unpublished geodesy in the style of the pseudo-Heronian compilation.

Theodore Meliteniotes, the *megas sacellarius* and chief instructor, one of the teachers at the patriarchal school in Constantinople, studied Euclid and, besides the astronomical writings coming from Trebizond, also once again read Ptolemy and Theo in the original. His *Astronomy* in three volumes (Ἀστρονομικὴ τρίβιβλος) of 1361 is the most comprehensive and learned work of this kind in existence. It cannot be clearly established whether this depended on a similar work of Argyrus or vice versa, since both have much in common and use the same sources. The hesychast Nicholas Cabasilas (born 1322/3 in Thessalonica, died *c.* 1380) also studied Ptolemy and Theo of Alexandria, whose commentary on the third book of the *Syntaxis* (on the length of the year and the mean velocity of the sun) he tried to reconstruct. A friend of Cabasilas (and also of Nicephorus Gregoras) was Demetrius Cydones (died 1397/8), who is known as one of the first translators from Latin into Greek. His scholia on Euclid have survived, as have also those of John Cabasilas (a relative of Nicholas).

There is little to be said on mathematical studies in the last decades before the fall of the Empire. Nothing more is heard of Archimedes, Apollonius and Diophantus. However, as is shown by the numerous array of new manuscripts still being written, an interest was taken in the elementary Quadrivium, which was still taught within the framework of 'the seven branches of learning' as they are called by Joseph Bryennius, who was teaching at the patriarchal school in 1396;[1] attention remained focused on geodesy and logistics. An arithmetic book with numerous exercises similar to those in Cod. Paris Suppl. Gr. 387 of 1303 is preserved in Cod. Vind. Phil. Gr. 65;[2] throughout this work calculations are made using the new Arabic decimal methods, although it is occasionally obvious that the scribe had not reconciled himself to these numerical forms, since he uses in their place the Greek alphabetical numerals from 1 to 9 and a symbol for zero; calculations can be conducted quite satisfactorily in this manner since the form of the ten symbols is unimportant.[3]

Private, public and ecclesiastical libraries still had a rich store of books, which were much coveted and bought by the increasingly large number of Latins who had come to Constantinople to learn Greek and to gain acquaintance with Greek culture. It was men such as Filelfo and Bessarion of Trebizond (fellow-students at the feet of Chrysococces), and George of Trebizond, himself the director of a school, who took Greek manuscripts back with them to Italy. The study of such manuscripts and of earlier arrivals in Italy, taken together with the Latin and Hebrew translations made from Arabic editions, brought to its full flowering the mathematical renaissance in the West which had begun with Adelard of Bath, Leonardo of Pisa, Jordanus Nemorarius and William of Moerbeke.

## II. PHYSICS (MECHANICS)

The Greek concept of physics did not coincide with our modern ideas of physical science as the theory of the forces in nature. The Greek idea was much more comprehensive, especially in respect of particular

[1] His library included, amongst other things, a geometry in fifteen books (obviously Euclid's *Elements*), Nicomachus' arithmetic, the *Great Syntaxis*, and also a book on music (Manuel Bryennius and Ptolemy). See A. Papadopulos-Kerameus, *Varia Graeca Sacra* (St Petersburg, 1909), pp. 295f.

[2] J. L. Heiberg, 'Byzantinische Analekten', *Abhandl. z. Gesch. d. Mathem.* IX (1899), i, 163–9. In iii, 172–4, Heiberg publishes a series of various digit forms (Indian and Herodian) from Cod. Marc. Gr. 323. For Byzantine arithmetical problems in western textbooks see K. Vogel, *Die Practica des Algorismus Ratisbonensis* (Munich, 1954), pp. 206ff.

[3] In Cod. Vind. Phil. Gr. 65 the decimal fraction is already in use, for the writer says that this is the method which has been current 'since the Turks have been ruling our country'. Clearly we can see here the influence of al-Kāshī, the inventor of the decimal fraction system described in his *Key to Arithmetic* (Samarkand, 1427). See H. Hunger and K. Vogel, *Ein byzantinisches Rechenbuch des 15. Jahrhunderts* (Osterreiche Akad. der Wissenschaft, phil.-hist. Kl. Denkschriften, Bd. 78, Abh. 2, Vienna, 1963).

concepts, such as that of motion (=change). Likewise meteorology was not confined, as it is today, to the study of atmospheric phenomena, but included subjects which are now considered more proper to astronomy, physical geography, geology, or even chemical technology. But above all the fundamental attitude was different; the Greeks achieved their results by means of speculative deductions made on the basis of chance observations and perceptions. The idea that nature by means of experiment might be made to speak for herself was for the most part alien to the Greeks.[1] Scientific results were occasionally achieved, in subjects already amenable to mathematical treatment (for example, mechanics, geometrical optics, acoustics); otherwise, however (for example, in heat, magnetism, physiological optics, meteorology), activity was confined to observation and descriptive writing.

All this applies equally to Byzantium, which has scarcely anything to its credit in the advancement of physical theories, although there was a widespread interest in the application of physics to technical problems. The contribution of Byzantine scholarship in physics, as in mathematics, consisted in preserving the old texts and in making new editions and commentaries; and also in ensuring the dissemination of some knowledge of physics through the teaching of the universities, where Aristotelian physics and meteorology were taught as part of philosophy, while acoustics and optics (which formed a part of geometry) came within the framework of the Quadrivium. Thus was made possible the later transmission of this inheritance, first to the Syrians and the Arabs, and afterwards, particularly in the twelfth and thirteenth centuries, to the West.

There is evidence of serious work in mechanics, mathematically based, in the sixth century, a period of great importance in the transmission of Greek learning. Eutocius, who commented on Archimedes' *Plane Equilibriums*, was familiar with the first book of Hero's *Introduction to Mechanics*,[2] which was to be preserved only in Arabic versions; and it is not surprising to find that Isidore of Miletus, the second architect of St Sophia, was also interested in the works of Archimedes and Hero. And although there are only occasional references in later periods to the teaching of mechanics or centre-of-gravity problems, there can be no doubt that the master-builders themselves took care that the important writings of Antiquity on these subjects should be preserved. This is proved by the fact that the

[1] Ptolemy, with his optical experiments, is a famous exception. For an experiment by which Gregory of Nyssa sought to demonstrate the emergence of the cosmos from the chaos see S. Günther, *Geschichte der Erdkunde* (Leipzig–Vienna, 1904), p. 38.

[2] *Heronis opera*, I, ed. W. Schmidt (Leipzig, 1899), *Supplementum*, p. 68.

Greek manuscripts which reached the West in the time of the Normans and Hohenstaufen included the classic works on mechanics.

There is much richer evidence of a continued interest in Aristotelian physics. In the sixth century there lived two of the greatest commentators on Aristotle after Alexander of Aphrodisias, Simplicius and Philoponus; in a few of his ideas Philoponus even advanced beyond Aristotle. He suggested (on the basis of experiment?) that heavy bodies do not fall more quickly than lighter ones, and the possibility of a vacuum. He also seems to have come closer to the concept of inertia.[1]

Of the Byzantine scholars of the ninth century, Photius, in his *Bibliotheca*, busied himself with a number of physical questions, and Leo the Mathematician concerned himself with technical applications. The school of Aristotelian physics reached its full flowering in the university of the eleventh century, whose moving spirit, Michael Psellus, wrote copiously on physical subjects (such as matter, colour, motion, echo, rain, thunder and lightning) in his *Omnifaria doctrina* and in his other works. He was also the author of a treatise on meteorology, and a commentary on Aristotle's *Physics*. The *Short Solutions of Physical Questions* which go under his name are not really by Psellus; they are in fact the first three books of the *Conspectus rerum naturalium* of his contemporary, Symeon Seth, who, like Psellus in his *Omnifaria doctrina*, makes this work on natural science the occasion for a number of reflections on heaven and earth, matter and form, place and time, soul and spirit, and the five senses. Physics and meteorology were also taught under Manuel I at the academy of Michael, later Patriarch, and probably also at the school of the Church of the Holy Apostles. The dialectical treatment of physics at this school is of interest: anyone who pronounced on the laws of nature themselves (instead of relying on ambiguous premises) was no philospher.[2]

The Greek manuscripts from Byzantium which reached the Norman court in Sicily during the reign of Manuel I included a number on physical subjects. Aristippus (died *c.* 1162) translated the so-called 'fourth book' of Aristotle's *Meteorology*; and he is known to have had Hero's *Pneumatica*, also translated at that time, in his possession. The *Institutio physica* of Proclus (Στοιχείωσις φυσικὴ ἢ περὶ κινήσεως) was at that period in the hands of Adelard of Bath, and seems to have been translated by him. A century later William of Moerbeke was at

[1] See E. Wohlwill, 'Ein Vorgänger Galileis im 6. Jahrhundert', *Physik Zeitschr.* VII (1906), 23–32. The originality of Philoponus was questioned by A. E. Haas in *Biblioth. Mathem.* VI (3. Folge, 1905–6), 337ff.

[2] *Apostelkirche*, ed. A. Heisenberg, p. 90.

work on his numerous translations, which included versions of Hero's *Pneumatica*, Archimedes' writings on mechanics (*De insidentibus aquae* and *De planis aeque repentibus*, the latter with the commentary of Eutocius), and the four books of Aristotle on meteorology (partially a revision of earlier translations) as well as other works of Aristotle. William of Moerbeke also revised an older Latin translation from the Greek of Aristotle's *Physics*, which itself preceded the oldest Latin translation from the Arabic (made by Gerard of Cremona).

Nicephorus Blemmydes, Nicephorus Chumnus, and above all Theodore Metochites, bear witness to the continuance of physical studies in Byzantium in the thirteenth and fourteenth centuries; Metochites included the *Physics* and *Meteorology* in his commentaries on Aristotle (see above, p. 276). His pupil, Nicephorus Gregoras, was also interested in Aristotelian physics. There is a final reference to scientific education at Byzantium during the reign of the Emperor Manuel II (1391–1425), who brought about a brief scholarly revival. Thereafter came the end.

## III. OPTICS

The ideas of the Greeks on the nature of vision and their mathematically formulated view of the paths of light rays are set down in the works of Aristotle, Euclid, Hero, Theo of Alexandria and others, and most fully in the *Optics* of Ptolemy.[1] Ptolemy, working from observation and experiment, achieved sound results in measuring the angle of refraction at the entry of a ray of light into another medium. Only one advance on existing knowledge can be credited to Byzantium, and this falls into the earliest period (sixth century), being the work of the architect Anthemius of Tralles (see above, p. 276). His treatise *On Curious Mechanisms* contains a passage on burning-mirrors. This treats of plane mirrors forming tangents to an ellipse.[2] It was once again the Arabs who, from the ninth century onwards, preserved the Greek legacy. Thus it came about that the original text of the lost *Optics* of Ptolemy reached the West in a Latin translation from the Arabic made by the Norman admiral Eugenius in 1154; he also had in his possession the *Optica* (known also to Aristippus) and *Catoptrica* of Euclid. Both these works were studied by the

[1] The most important works are: Aristotle, *Meteorologica*, Euclid's *Optica* and its revision by Theo of Alexandria; the Pseudo-Euclidian *Catoptrica* of Theo of Alexandria, Ptolemy's *Optica*, the Pseudo-Ptolemaic *Catoptrica* of Hero and the *Optica* of Damianus of Larissa (fourth century A.D.). The earlier authorities make a distinction between optics (passage of light rays in direct vision) and catoptrics (refraction in mirrors); Ptolemy and Damianus, however, include both under the heading of optics.

[2] See T. L. Heath, 'The Fragment of Anthemius on Burning Mirrors and the "Fragmentum mathematicum Bobiense"', *Biblioth. Math.* VII (3. Folge, 1906–7), 225–33.

author of the translation of the *Almagest* made in Sicily *c.* 1160 (probably Adelard of Bath) and were perhaps translated by him. The now lost manuscript of Hero's *Catoptrica* which William of Moerbeke used as a model in Viterbo in 1269 was certainly also among the Greek manuscripts in circulation in Sicily and southern Italy at that date.

At Byzantium, from the time of Philoponus onwards, there was some interest in the physiological aspects of optics (vision, colour, rainbows, solar coronas and so on) as treated in Aristotelian physics; the subject was discussed both in works on meteorology and in special studies. Psellus made some observations on the subject in his *Omnifaria doctrina*, but there is a more detailed survey in Symeon Seth's note *On Optics* which also contains some remarks on refraction. The classical writings on mathematical optics were still being copied. In addition to the many manuscripts of similar nature from the twelfth and thirteenth centuries and later there have survived a manuscript of Theo's revision of Euclid's *Optics*, written in the tenth century, and a manuscript of his pseudo-Euclidian *Catoptrica*; both have scholia. It is known that Nicephorus Blemmydes, who as a young man experienced the extreme poverty into which scientific education had fallen in Latin Byzantium, learnt optics and catoptrics (together with mathematics and astronomy) at Skamandros (Troas) from a teacher called Prodromus. Pachymeres included an extract from Euclid's *Optics* in the section on geometry in his Quadrivium. In the later period there are only sparse references to mathematical optics; Theodore Metochites (later thirteenth century) refers to it in his curriculum, and Joseph Bryennius (*c.* 1400) had a book on optics ('Ἐποπτικά) in his library.

## IV. ACOUSTICS

The practice of music at Byzantium took on a new lease of life from the time of John of Damascus (eighth century) and was further developed to meet the requirements of the Christian liturgy. One crying need was the development of a form of notation, and from the tenth century onwards the simple system of dots and lines was further improved until a form was evolved which marked not only the notes themselves but also the tone intervals (thus: two higher, five lower) as well as the length of the note, stress, key, rhythm, tremolo and so on.[1] Musical theory, on the other hand, remained where the ancients had left it, both as regards the nature of sound and hearing and the mathematical treatment of intervals. In contrast to the practical thinkers, such as Aristoxenus (fourth century B.C.) who relied on the ear, the Pythagoreans based their mathematical theories on the

[1] See also chapter XXIV by E. Wellesz.

numerical laws of the tetrachord. These Pythagorean doctrines continued to flourish at Byzantium and were taught in the portion of the Quadrivium designated as 'music' or 'harmony'. Michael Psellus concerned himself with questions of acoustics more than once. In his treatise *On the Resounding Hall in Nicomedia* he describes a covered building constructed of four walls set in a semicircle, which had a remarkable echo effect which he sought to explain without reference to sorcery or mechanical devices.[1] In this connection he was led on to discuss thunder and lightning and advances the curious idea that the eye detects it before the ear because it 'protrudes' and is 'not hollow'.[2] His contemporary, Symeon Seth, has a better explanation: sound needs time, whereas sight is independent of time.[3]

At the beginning of the thirteenth century music was being taught at the Church of the Holy Apostles in both its practical and theoretical aspects. In the preparatory school the psalmodists practised with the pupils, with pleasantly harmonious results, and sound and key formed part of the mathematical instruction of the university, together with some discussion of intervals. Pachymeres (d. *c.* 1310) in his teaching of the Quadrivium treated music in great detail, illustrating the intervals (the lengths of the strings in the tetrachord, in the Pythagorean octachord, etc.) with numerous diagrams. His teaching of music was thus much more advanced than that of Gregory the Monk (1008) who discussed it only very briefly in his Quadrivium. Manuel Bryennius made a comprehensive compilation called *Harmonics* which drew on the old theorists and practitioners and also on Pachymeres, only slightly his senior; Bryennius' contemporary Pediasimus wrote *Some Observations* (see above, p. 275). More important was Nicephorus Gregoras (died *c.* 1360) who in music, as in his astronomical studies, went back to Ptolemy, commenting on his unfinished work on harmony and even attempting to complete it. In conclusion, mention must also be made of Joseph Bryennius, whose library, which he bequeathed to St Sophia, contained the works of Ptolemy and Manuel Bryennius on musical subjects.

## V. ZOOLOGY

Byzantine scholars for the most part ignored the deeper questions of zoology such as were treated by Aristotle (the development of organisms, the physiology of organs and their purpose); the most that was done, and that only rarely, was to make a study of Aristotle himself.

[1] ἠχεῖα was used also to denote acoustic vases which might be built into the floor of a theatre to act as resonators.

[2] J. F. Boissonade, *Psellus*, p. 60.

[3] A. Delatte, *Anec. Athen.* II, p. 31.

There is an *Epitome of Aristotle's Zoology* dating from the time of Constantine VII Porphyrogenitus, and a commentary on the *De partibus animalium* is ascribed to John Tzetzes (1100–80). Further evidence of an interest in Aristotle is furnished by the Greek manuscripts used by William of Moerbeke for his Latin translation in 1260 of the *History of Animals* and of the *Generation of Animals*.

On the other hand, there was great interest in practical zoology, the description of animals, their characteristics and diseases, which was often mingled with ancient fantastical and occult ideas. Material relevant to the household and to agriculture and hunting was observed and written up; thus the *Hippiatrica* treats of horses, and the *Geoponica* of domestic animals (including bees), fish, and vermin. Medical writings (see below, p. 288) contain accounts of useful and noxious animals (leeches, poisonous creatures, parasites, worms) and also indicate the value of animal products as food and in making medicaments.

There is a bestiary compiled by Timothy of Gaza dating from the reign of Anastasius I (491–518). During the sixth century Cosmas Indicopleustes travelled widely in Africa and Asia (Arabia and Ceylon); his *Christian Topography* contains descriptions, accurate for the most part, of African and Indian beasts. The introduction of the silk-worm probably from central Asia (Sogdiana) in 553–4 was of great importance for Byzantine, and later also for Italian, industry.

A remarkably detailed work on falconry (*On the Breeding and Care of Falcons*), which used sources different from those drawn on for Frederick II's famous book on the subject, was written by a doctor named Demetrius Pepagomenus during the reign of Michael VIII Palaeologus (1259–82). It has some exact observations concerning the presence of worms in the eyes of falcons. It is uncertain whether Demetrius was also really the author of a mediocre book on dogs (*Kynosophion* or *The Care of Dogs*). Three other anonymous books on falconry also belong to this period: a book on birds (*Wild Birds*) which describes their diseases and their treatment; *The Management of Birds*, written for Michael VIII, and, based upon it, a *Treatise on the Management of Hawks*.

Manuel Philes (1275–1345), a friend of Pachymeres and Maximus Planudes, wrote the *Brief Description of the Elephant*, and a rather mediocre didactic poem *On the Characteristics of Animals* which describes not only authentic birds, fishes and four-legged beasts, but also fabulous creatures (unicorns, jumars). Among his sources was the *Physiologus*, the most important medieval work on natural history. The *Physiologus* is of anonymous origin, and dates from some time during the earliest centuries of Christianity; it found its way into the literature of many nations, though the stream of its Byzantine tradition can only be followed closely from the eleventh century. The zoological portion contains descriptions of actual and fabulous beasts (as basilisks, centaurs, the phoenix, dragons), with religious and allegorical interpretations of their actual or imaginary properties.

## VI. BOTANY

There is little evidence of any scientific study of botany (for example, systematic botany, the physiology and biology of plants) at Byzantium. The high standard of a Theophrastus, who conducted his investigations in the spirit of Aristotle, was no longer maintained. It is true that Basil of Caesarea (*c.* 330–79) shows in his *Homilies on the Hexaemeron* (the Creation) that he had some accurate ideas concerning the way things happen in the world of plants, but from him the tradition seems to have passed to the West (via Ambrose) rather than to Byzantium.

As in zoology, Byzantine interest in botany was confined to descriptions and to its practical applications in agriculture, horticulture, household matters (for example, cooking), medicine and pharmacology. Some information on the subject is to be found in geographical and historical works, in Photius, the *Suda* and Psellus. The *Geoponica* has an account of the useful plants and their cultivation (cereals, vegetables, fruit and olive trees, the vine); the section on viticulture was translated into Latin by Burgundio of Pisa (died 1193), who from 1136 onwards made frequent visits to Byzantium. The number of surviving manuscripts of Dioscorides, some with illustrations (the first dates from *c.* 512), shows the respect in which the memory of this encyclopaedist of the first century A.D., who described about 600 plants, was long held.

Michael Glycas (fl. mid-twelfth century) took some descriptions of plants from the *Physiologus*, which was also known to Manuel Philes (1275–1345), who composed a number of poems on plants, fruits and flowers. Botanical *lexica*, mostly of unknown origin, were also generally current and survive in manuscripts of the thirteenth and fourteenth and later centuries.

## VII. MINERALOGY

In the pre-Byzantine period some attempts were made at treating mineralogy scientifically by defining, systematising and interpreting the data. Theophrastus (late fourth century B.C.) in his work *On Stones* describes many stones (including precious stones) and types of soil, giving an account of the places where they are found and their uses. Some fragments of a work *On Minerals* are also ascribed to him. Straton, rather later than Theophrastus, was probably the author of the so-called fourth book of Aristotle's *Meteorology*, which could be described as the first textbook of theoretical chemistry (see also below); minerals were dealt with in the authentic fourth book (*τὰ μὲν ὀρυκτὰ τὰ δὲ μεταλλευτά*) and, like the meteorological phenomena treated in the first three books, were held to derive from the moist and dry rising vapours. This now lost book (*μονόβιβλος περὶ μετάλλων*) was still known to Olympiodorus and Simplicius and continued to be written about, above all by Philoponus.

Byzantium made no advances in this subject: quite the reverse, since scientific mineralogy was all but destroyed by the superimposition of occult imaginings. Even the knowledge which continued to be gained as a result of mining operations and the observation of nature was no longer regarded as of any theoretical value. There was still an occasional interest in the practical applications of the subject in technology (see below, p. 299), medicine and pharmacology: minerals might be taken in powder form or applied externally. The books produced in later periods, also under the title *On Stones*, deal first and foremost with the magical powers innate in minerals (and especially precious stones, see below, p. 298). The only useful accounts are those to be found in the descriptions which occur incidentally in a few of these writings, some of them lexigraphical in character: for example, the enumeration of stones in Theodore Meliteniotes' poem 'To moderation'.

## VIII. CHEMISTRY

Chemical processes in nature, such as fermentation, coagulation, putrefaction, oxydisation, have been observed at all periods—the Greeks were not alone in this—and some processes are utilised in day-to-day living, in making bread, beer, oil, and vinegar, and in tempering and purifying metals. But chemistry only made its appearance as a theoretical subject with the author of the so-called fourth book of Aristotle's *Meteorology* (Straton, see also above), which sought to explain chemical processes by the combination and dissociation of substances. There can be no doubt that this, the oldest textbook of chemistry, was still known in the time of Philoponus; it also survived in some Aristotelian manuscripts and was among the first works of Greek origin to reach the West. It was translated in the twelfth century by Aristippus and a hundred years later by William of Moerbeke. But Theodore Metochites recognised that this

'Fourth Book' could not have been by Aristotle, as he stated in his commentary on Aristotelian physics.

At Byzantium, however, the chief interest in chemistry was in its practical use in technology (as metallurgy, production of dyes, drugs, glass, chalk) and its household applications; this is evident in numerous, mainly alchemical writings, in which, indeed, unscientific, not to say occult, ideas are frequently uppermost.

## IX. MEDICINE, DENTISTRY AND VETERINARY MEDICINE

As in the other sciences, the main Byzantine contribution to medicine was the preservation of the classical and Hellenistic heritage and its transmission to both East and West. But there was an advance in the field of organisation, which was connected with the Byzantine social sciences: both State and Church concerned themselves to a high degree in everything connected with health: hospitals were organised, the education of doctors regulated and their livelihood guaranteed, and there were even rules for the preparation and safe custody of medicines.

As in the case of astronomy, it can be shown that during the later period some of the classical learning concerning medicine was reintroduced into Byzantium from the East, where Jundishapur was a famous centre of medical studies. In the East itself the only new discoveries concerned *materia medica* and methods of treatment.

The point which marks the transition from Hellenistic to Byzantine medicine coincides with the career of Oreibasius of Pergamum (325–*c.* 400), the personal physician and friend of Julian the Apostate. In his magnificent encyclopaedia (*Corpus of Medicine*) he not only handed down the learning of Hippocrates and, above all, of Galen, but also, by his careful citation of sources, rescued from oblivion much that would otherwise have been lost. All later Byzantine authors base themselves on his work. Only twenty-seven of the seventy books of his *Corpus* (*Synagogai*), together with a fragment of another, have survived; the contents of the lost books can be deduced from a *Synopsis* which he made for his son. It is remarkable that surgery is omitted as being a subject for specialists. Contemporaneous with Oribasius were Philagrius and Posidonius, two doctors who were particularly interested in diseases of the brain, and Nemesius, Bishop of Emesa, whose treatise *On the Nature of Man* was later translated into Latin, first *c.* 1050 by Alphanus of Salerno, and later by Burgundio of Pisa (*c.* 1110–93).

Medical lectures were given at the Theodosian university within the framework of the philosophy course. The philosopher Agapius was summoned thither from Alexandria, the centre of medical teaching and research, to be lecturer in medicine. Aetius of Amida, physician at the court of Justinian I, was also educated at Alexandria. The section on ophthalmics in his encyclopaedic sixteen volumes on *Medicine* (based on Archigenus and Galen) is one of the best of antiquity. A slightly younger contemporary, Alexander of Tralles (*c.* 525–605), a brother of the mathematician Anthemius, stands out for the independence of his opinions, based on his own experience. His work on pathology and therapeutics, in twelve books, was widely known; he was also the author of some monographs, on diseases of the eyes, fevers, and intestinal worms.

The last of the four great early Byzantine scholar-physicians was Paul of Aegina (fl. 640), who stayed on in Alexandria after its capture by the Arabs. Through his textbook on diseases and their treatment (entitled *Memorandum*), based on Galen and Oribasius, he became the teacher of the West on medical matters, and, through his studies on surgery and obstetrics, exerted a great influence on Arab medicine. Another of Paul's contemporaries, also from Alexandria, was Aaron, who deserves mention for his description of smallpox in his *Compendium of Medicine*.

During the reign of Heraclius (610–41) medical lectures were being given at Byzantium by the *protospatharius* Theophilus, and some of his works have survived. Stephen of Athens, a pupil of Theophilus, wrote on the effects of drugs on fevers and on urine, as well as on other subjects. He also wrote commentaries on Hippocrates and Galen as did his contemporary John of Alexandria (fl. *c.* 627–40), who remained in Alexandria after the capture of the city by the Arabs and who, like Paul of Aegina, had a considerable influence on Arab medicine. In fact, John's epitome of Galen (*The 16 Books of Galen*) has survived only in an Arabic translation.[1] Sophronius (Patriarch of Jerusalem in 634) in his 'Letter to Joseph' gives us some incidental information concerning diseases and their treatment at this period, including the fact that doctors who wanted payment were distrusted.

During the next few centuries there was little original work done in medicine at Byzantium. Nicholas, an expert in the medical field of learning, was giving lectures during the time of the Emperor Philippicus (711–13); the Phrygian monk Meletius (somewhere between 600 and 800), the author of an unremarkable work on anatomy, also probably belongs to this period. Much more considerable, especially on the surgical side, is the *Epitome of Medicine* of the early ninth century of Leo, mathematician and 'learned physician' (ἰατροσοφιστής). His treatise *On the Characteristics of Human Beings*

[1] British Museum, MS. Arundel Or. 17.

has also survived, and a still unpublished *Epitome on the Nature of Human Beings* similar to that of Meletius. About the same time, and not, as is often thought, in the eleventh century, lived Nicetas, who collected together a number of older surgical treatises (for example, of Palladius, Soranus, Paul of Aegina). There are also many medical chapters in Photius' *Bibliotheca.*

Among the encyclopaedias produced at the behest of Constantine VII Porphyrogenitus was a *Medicine* by Theophanes Nonnus, compiled from the works of the four Byzantine classical writers on medicine. A work on the pulse, by an otherwise unknown Mercurius, also belongs to the tenth century. To the same century, or perhaps the eleventh, belongs a Greek translation of an Arabic text by Abū Ja'far Aḥmad ibn Ibrāhīm ibn al-Jazzār (died 1009) entitled *Viaticum for travellers*, which contains amongst other things descriptions of the plague, smallpox and measles. A short work of a certain Damnastes *On the Care of Pregnant Women and Infants* also belongs to this period.

The eleventh century is represented by two highly important figures, Michael Psellus and Symeon Seth. That talented and versatile scholar Psellus expressed opinions on a variety of medical topics in both prose and verse. He was the author of a dictionary of diseases, a 'Work on Medicine' (in 1373 trimeters) and another 'On Baths' and also of some humorous verses on scabies, of which he had personal experience. There is also much medical and physiological material in his *Omnifaria Doctrina.* Symeon Seth's most important work is a lexicon of the healing powers of various foods (*Lexicon on the Properties of Foods*), in which the names of a number of oriental drugs are met with translated into Greek for the first time.

The twelfth century is characterised by an intensification of state activity in the care of the sick. John II Comnenus and his wife Irene founded hospitals, laying down precise regulations for their management. The centre of medical teaching was the hospital founded by the Empress in 1136 at the Pantocrator monastery, where Michael Italicus was appointed medical instructor (*διδάσκαλος ἰατρῶν*). In his lectures he expounded Hippocrates and Galen and also used cases in illustration of various diseases. The children of the hospital physicians were also trained to follow the profession. A pupil of Italicus, Theodore Prodromus, gives a good description of smallpox. A certain Callicles is also described as 'teacher of the doctors' at this period. There is a lively sketch from the pen of Mesarites of the conduct and teaching of the school at the Church of the Holy Apostles about the year 1200.[1]

[1] See A. Heisenberg, *Apostelkirche*, pp. 91f.; a translation is published by K. Sudhoff in *Mitteilungen z. Geschichte der Medizin, der Naturwissenschaften und der Technik*, XXIII (1924), 189f.

Medicine also had its share in the revival of studies at the imperial court of Nicaea and at Byzantium under the Palaeologi after the restoration. Nicephorus Blemmydes wrote a little on medical subjects. Nicholas Myrepsus (= *unguentarius*) was court physician (ἀκτουάριος) at Nicaea under John Vatatzes and wrote a work on *materia medica* (Δυναμερόν) which was still influential as late as the seventeenth century. Demetrius Pepagomenus (physician to Michael VIII) wrote a useful book on gout, which was used by a somewhat later writer on the same subject, John Chumnus. Much more important was John Actuarius, court physician to Andronicus III. He is the last great Byzantine doctor of the school of Galen with personal clinical experiences. He wrote a book *Methods of Treatment* (diagnosis, pathology, therapeutics, pharmacology), and a detailed treatise on urine which was of considerable importance in medieval uroscopy. A third work is of significance in the history of pneumatism and psychopathology. It consists of two books on the three kinds of pneuma. The first book deals with the powers of the mind and their disorders, and the second lays down rules of hygiene. He is the first writer to describe the whipworm (*trichocephalus dispar*, a parasite of the human intestine), which he may have himself discovered.

During this period medicine, like astronomy, was clearly subject to eastern influences. Constantine Meliteniotes translated a Persian work;[1] there are two anonymous and undated treatises of Syrian and Persian origin on urine, and Persian influence can also be seen in another anonymous work, on diagnoses made from the blood. There is also a Greek translation of a treatise on urine by Ibn Sīna (980–1037).

Medical teaching at Byzantium ended with John Actuarius and the practice of medicine passed to Jewish doctors. This is explicitly stated by Joseph Bryennius (fl. 1387–1405) who tried to discover the reasons for the decline. But in any case, all the material which was important for posterity was now in other hands. Alexander of Tralles and Aetius of Amida, like Galen, had already been translated into Syrian and Arabic, while the tradition of John of Alexandria and Paul of Aegina was kept alive at Alexandria by the Arabs; but long before the West became acquainted with Arab medicine, Greek medical texts were available to the Latins. Oribasius was translated as early as the sixth century, and the partial translations of the works of Paul of Aegina which originated in southern Italy in the eighth or ninth century seem to have been influential in the early development of

[1] A. P. Kuses, 'Quelques considérations sur les traductions en grec des œuvres médicales orientales et principalement sur les deux manuscrits de la traduction d'un traité persan par Constantine Melitiniotis', *Praktika Akad. Athen.* XIV (1939), 205–20.

Salerno. By the time medical learning at Byzantium had totally declined, the study of the classical works of the Greek medical authorities in the West had already reached its fullest flowering in Italy, France and Spain.

As was usually the case in antiquity and the middle ages, dentistry was not regarded at Byzantium as a special profession. The collected writings of the four great Byzantine medical authorities, Oribasius, Aetius of Amida, Alexander of Tralles and Paul of Aegina, all contain passages devoted to diseases of the teeth and gums and to methods of treatment (extraction, filing, ointments and other remedies). The subject is also treated by many of the doctors of later centuries and by writers on medical subjects.

The Greeks had already much concerned themselves with the care in sickness and health of those animals indispensable to man as food, means of transport and in riding and hunting. Farmers and soldiers were naturally those most interested in the subject. The compendium collection made under Constantine VII Porphyrogenitus entitled *Hippiatrica* (see above, p. 285), composed of more than 400 existing fragmentary writings, included the corpus of knowledge concerning the care of horses and their diseases which had been assembled during the Hellenistic and early Byzantine periods.[1] A principal source was the writings of Apsyrtus, chief army veterinary surgeon to Constantine the Great, who was the author of two books on the treatment of sick animals. One of the best of the veterinary doctors of late Antiquity was Hierocles (*c.* 400); he wrote a book *On the Care of Horses* and is represented by 107 fragments in the *Hippiatrica*, which also contains writings by Theomnestes (fourth century) and others. The *Hippiatrica* also indirectly enshrines the experience in the art of healing animals gained by other peoples: for example, Apsyrtus was acquainted with Sarmathian, Syrian and Cappadocian practices, Theomnestes knew Armenian ways, and it seems that the thirty-six passages attributed to 'Hippocrates' are really the work of an Indian author of the sixth century. The *Geoponica*, also compiled under Constantine VII Porphyrogenitus (see above, p. 286), contained a certain amount on the ailments of horses, dogs, cattle and sheep, goats and pigs.

[1] Cf. Plate 25.

## X. PHARMACOLOGY

Pharmacology as an independent branch of study was unknown at Byzantium; the doctor acted as his own apothecary[1] and did not shrink from travelling far and wide seeking out the substances used as healing agents (plants, ores and so on) in foreign lands, collecting and testing them for himself. The writings of doctors on therapeutics therefore usually include prescriptions for the remedies to be employed. It was only later, with the increased intervention of the state in affairs of health, that some order was introduced into pharmacy and rules laid down for the production and storage of medicines.

The Byzantines were able to make some advances on the knowledge amassed by Nicandrus, Dioscorides and Galen, since they gradually added remedies from the east, from Arabia and Persia, to those obtained from their native flora and fauna.

A large part of the literature of the subject was taken up with works on dietetics, either as separate monographs or incorporated into general medical textbooks, a fact which emphasises the importance attached to correct nourishment in both sickness and health. These treatises describe the characteristics and properties of the various items of diet, and often give advice on their preparation; this subject is in fact dealt with in the first five books of the *Synagogai* of Oribasius. There is a very illuminating letter entitled 'De observatione ciborum', addressed to the Frankish king Theodoric by Anthimus, a Greek physician exiled from Byzantium and living at the court of Theodoric the Ostrogoth. Others to write on the subject of diet were Theophanes Nonnus, Michael Psellus, Symeon Seth and John Actuarius, and there are also a number of anonymous writings. Of all these the most important is Symeon Seth's *Lexicon on the Properties of Foods*. He is the first to mention substances of oriental origin, such as cloves, nutmegs, and hemp-seed (hashish).

Dietary rules were often laid down for the four seasons or even for the different months of the year. One such treatise, by the sophist Hierophilus (twelfth century), has the title *On various foods for each month and their use*; there are a number of different versions. A poem of similar content, 'Verses on the twelve months', was written about this time by Theodore Prodromus.

Medical writers such as Oribasius, Aetius of Amida, Paul of Aegina and Theophanes Nonnus compiled lists of remedies, both household

[1] The first record of a distinction being made between doctors and apothecaries comes from the reign of the Emperor Frederick II (see E. Kremers and G. Urdang, *History of Pharmacy* (Philadelphia, 1951), pp. 555–6).

medicines and those manufactured professionally. Stephen Magnetes (eleventh century) made an alphabetical list. Symeon Seth's book on the properties of various foods, already mentioned, also refers to other remedies. The most detailed *antidotarium* of all, and one whose influence with western apothecaries remained strong until the seventeenth century, was the *Materia Medica* (*c.* 1280) of Nicholas Myrepsus (see above, p. 291); of the 2656 recipes contained therein, about 150 are taken from Salerno (*antidotarium parvum*), whilst others are of oriental origin. John Actuarius' *Methods of Treatment* has two books devoted to the preparation of remedies. With Actuarius, the last important Byzantine physician writing from personal experience, independent works on pharmacology also come to an end. As in the case of medicine and astronomy, Persian influences for a time became dominant. George Choniates composed a book, *Antidotes culled from Persia and translated into Greek*, perhaps based on one of the works brought out of Persia by Chioniades (see above, p. 277). Constantine Meliteniotes (see above, p. 291) translated a similar *antidotarium* from the Persian. But even this Perso-Byzantine renaissance was short-lived; during the succeeding ninety years' long gradual decline, there is no further scientific activity to record, apart from the doings of the scribes, who still continued to copy and compile pharmacological texts and encyclopaedias.

## XI. GEOGRAPHY

The work of Eratosthenes, Strabo and Ptolemy stands as testimony to the noteworthy discoveries already made by the Greeks in geography, both in its physical and mathematical aspects (the figure and measurement of the earth, position co-ordinates, map projection). The Byzantines made little use of such concepts, with the result that they made no further advances in this direction. It is true that a number of thinkers discussed the composition of the earth in their general treatment of natural philosophy: for example, Symeon Seth in the first book of his *Epitome of Physical Treatises*. But it also happened that some discoveries, long well-established, were brushed aside. Thus Cosmas Indicopleustes (see above, p. 216) in his *Christian Topography* rejects the 'extravagant Greek notion' that the earth is spherical; he considers that the universe rather resembles in form Moses' tabernacle. It was important for astronomers to have a knowledge of the position of their observation points and the seven *climata* (or belts of latitude). For this Ptolemy, who was never forgotten, sufficed; his *Guide to Geography*, for example, was in the library of Joseph Bryennius. Apart from Agathemerus (fifth to sixth century), who wrote a very modest *Outlines of Geography*, the only writers on geographical subjects worth mentioning are Nicephorus Blemmydes and Nicephorus Gregoras. Blemmydes, drawing on Dionysius Periegetes (? 2nd c. ? late 3rd c. A.D.) wrote a *Comprehensive Geography* and a small work entitled *Various Accounts of the Earth*, which treats of the size of the earth and its spherical shape, as well as the seven *climata*. Nicephorus Gregoras was the author of some maps and of a commentary on the geography of Ptolemy.

On the other hand, there was great interest at Byzantium in geographical knowledge with a practical bearing or which might be needed for ecclesiastical or political purposes: for example, maps, travel narratives, or lists of place names. The Ptolemaic maps, whose line of descent can be traced back to the third century, had a long life (they are to be found, for example, in a manuscript from Mt Athos of the mid-thirteenth century). Among the early authors who wrote descriptions of their travels was Cosmas Indicopleustes, already mentioned, who is the first to give definite information concerning China. The dates of a certain Marcian of Heraclea, the author of several *Peripli* (voyages), are unknown. A *Periplus Ponti Euxini*, formerly ascribed to Arrian, cannot be earlier than the second half of the sixth century. A series of Greek *portulani* of later date probably originated in Italy; the *Stadiasmus or Voyage in the Great Sea*, however, in a tenth-century Madrid manuscript, is certainly Byzantine.

Of particular importance to both Church and State were the statistical registers of districts and places. Stephen of Byzantium probably compiled his geographical dictionary as early as the reign of Justinian I; fragments of it are preserved in the works of the otherwise unknown sixth-century Hermolaus and in those of Eustathius of Thessalonica (died *c.* 1193). Hierocles' *Handbook*, in which are listed sixty-four provinces of the Empire and 912 towns, also comes from the reign of Justinian, and George of Cyprus compiled a similar work at the beginning of the seventh century. Constantine VII Porphyrogenitus drew primarily on both Hierocles and Stephen of Byzantium for his statesman's handbook *On the Themes*. A concordance of town names (*On Names of Cities and Places*) made by George Chrysococces has also been preserved. Just as in the land and sea itineraries, travellers' narratives and books of pilgrimage, geographical information is also recorded in the descriptive poems (*ekphraseis*) in which the praises of individual cities and landscapes are sung. Apart from these, there are some passages in the works of the historians dealing with ethnographical topics, and some information on plant and animal ecology may be gathered from the authors on biological subjects.

## XII. SUPERSTITION AND PSEUDO-SCIENCES

Superstitious and mystical ideas were deeply rooted in Byzantine popular thinking, as they always have been among the ordinary people at all periods. They were nourished by the fear of illness and death. Incantations against disease, magic formulae, amulets, all might be of some avail. Attempts were made to counteract the uncertainty of mortal destiny by consulting oracles of all kinds or by trying to determine which days were favourable or unfavourable; it was not only a question of predicting illness and death but also of making forecasts concerning a great variety of events likely to arise in everyday life, such as the success of business transactions, the victory of a horse, the flight of a slave, or the arrival of a friend. Predictions were made from the stars, numbers (the numerical value of certain words), geometrical figures, dreams, thunder and much else. When such serious thinkers as Aetius of Amida, who was already Christian enough to use Christian forms of incantation, Alexander of Tralles and even Michael Psellus could indulge in such notions, the extraordinary conjunction of piety and superstition is not to be wondered at. There were others, however, such as Oribasius, Theophanes Nonnus and Nicholas Myrepsus, all of them doctors, who attacked such irrational ideas, and on occasions even the state took action against them; the destruction of alchemical texts ordered by Diocletian (*c.* A.D. 290) entailed the loss of much valuable technological material. In a passage of Graeco-Roman law already cited (above, p. 274, note 1) a strict distinction was made between doctors and those who mingled medicine and astrology (*iatro-mathematikoi*), exorcisers of diseases, who made use of evil practices and therefore should not receive payment.

With the exception of astrology and alchemy, none of these pseudosciences made any contribution to the advancement of knowledge; they must be mentioned, however, since they were then counted as authentic sciences (alchemy was even described as 'the great and holy art'). There was indeed much more to astrology than the making of horoscopes; it was almost a whole philosophy and religion in itself.

According to the astrologers, mankind was subject to numerous influences emanating from the cosmos. Pre-eminent were the seven heavenly bodies (the moon, Mercury, Venus, the sun, Mars, Jupiter, Saturn), to which corresponded the seven days of the week, the seven metals (silver, quicksilver, copper, gold, iron, tin and lead), the seven vowels, colours, tones (intervals), minerals, plants, parts of the body and orders of animals; these heavenly bodies, or the gods identified with them, sent out rays or forces which worked for good or ill on the various parts of the human body, or even on whole groups of men or states, and 'became interwoven with them'. Since the size and distance of the heavenly bodies, and above all their respective positions in the zodiac played an important role, astrological speculations presuppose an exact knowledge of astronomy; they thus served to preserve and also to propagate existing knowledge and even helped towards further scientific inquiry.

Alchemy, which had its origins in the practices of Egyptian goldsmiths and craftsmen of the pre-Christian era, becoming only later (second and third centuries) intermingled with magical ideas and mystical symbolism, also had a double aspect. On the one hand, the texts give technical instructions, mostly quite clear, for metallurgical processes such as the manufacture of alloys and pigments, tempering metals, or glass-making (see below, p. 301); on the other, they are also full of fantastic and valueless notions concerning the sympathetic influences of minerals, the correspondence of metals, plants, animals and parts of the body to the planets or the signs of the zodiac, the Philosopher's Stone and the art of making gold.

Astrology and alchemy flourished greatly in Roman Egypt. It was texts from this period which had a preponderant influence on the Byzantine astrologers and alchemists: Ptolemy's comprehensive *Astrology* (*Tetrabiblos*), the third-century work of Hermes Trismegistus on illnesses influenced by the stars, the treatise of Pseudo-Democritus *Physica et mystica*, in which the magical element predominates, and the *Alchemy* of Zosimus, in which the technical element predominates. The influence of these writings was particularly strong in the early period, but then receded, to be revived to a considerable extent in the eleventh century when the work of Hermes Trismegistus probably became known in Byzantium, arriving by a devious route via Syria and the Arabs.

Among the early commentaries (fifth or sixth century) are those of an anonymous writer and of a 'Christian' philosopher, who even tried to reconcile Christian teaching with astrology. The prophecy concerning Muḥammad and the future of Islam ascribed to Stephen of Alexandria is apocryphal; there is also a much commented on alchemical writing *On Making Gold* which goes under his name. Hopes of finding in it a sovereign recipe for making gold are doomed to disappointment, for it is nothing but a confused hotch-potch of occult ideas. Astrological, alchemical and magical writings were first assembled into a single corpus containing the works of the older authorities and their commentators in the seventh or eighth century, and this collection appears in an extended form in the *Encyclopedia* of Constantine VII Porphyrogenitus.

Michael Psellus and Symeon Seth must be included among the authors of pseudo-scientific works of the eleventh century. Seth wrote on the influence of the heavenly bodies and Psellus on making gold and on other occult matters. Astrology continued to flourish under the Comneni. Theodore Prodromus wrote a poem on the subject. The Emperor Manuel I, in his *Pittakion*, himself defended astrology against a dissentient monk and was supported in his opinions by John Camaterus, the author of two astrological poems, though Michael Glycas, the historian, declared himself in a letter opposed to the Emperor's views.

Further alchemical writings have survived from the time of the Palaeologi, for example, Nicephorus Blemmydes' treatise *On Making Gold* and an *Interpretation of the Science of Making Gold* of a monk called Cosmas. A worthless concoction of John Canabutzes (early fifteenth century) has much alchemical matter (transformation of metals, the Philosopher's Stone). An ancient link between astronomy and music is once again brought to light by Manuel Bryennius.

The magic of stones and plants, which was connected with the planets, played an important role in Byzantine superstition. In Michael Psellus' *On the Properties of Stones*, there are not only descriptions of the external appearance of precious stones but also an account of their sympathetic powers of healing; they were particularly effective as amulets. Special rules and magical rites had to be observed when gathering plants as food or for use as drugs; for example, they should be dug up at night during a full moon.

Numbers and numerical relations were particularly important in the doctrines of the Pythagoreans and Neoplatonists. Some numbers were preferred as being particularly lucky, many had magical properties and influences. Such ideas were kept alive by the Byzantines and even formed part of the school curriculum. Mesarites, for example, describes the teaching on this subject given at the Church of the Holy Apostles; the even numbers were masculine, odd numbers feminine; in months which become uneven when divided by some power of two (περισσάρτιος), for example, in the sixth month, there could be no fear of premature births occasioned by a sudden fright. In the vast corpus of prophetic literature numbers play a large part as the instruments of soothsaying. Oracles were pronounced based on the numerical value of letters (onomatomantics), as, for example, the determination of the sex of an embryo. A text from the early fourteenth century states that those who wished to prognosticate by this arithmetical method what sex a woman's embryo will be should add the value of the letters forming the names of the parents to that of the month of conception and divide the result by three; if the remainder were one, the child would be a boy, if two a girl: there is no mention of what might be expected where there was no remainder. There was even a table for the geometrical figures formed by the combination of stones as they lay in their different 'houses'.

The lowest level of soothsaying was reached with the *Oracle Book* in which a passage from a book selected at random was supposed to give significant information on the subject on which advice was sought. Another method made use of thirty-eight different passages from the Bible: a number from 1 to 38 was chosen, and the corresponding text gave the answer. Oracle books with prepared answers also belong to this category.

Further degenerate forms of soothsaying included catoptromancy (which involved mirrors), lecanomancy,[1] hydromancy, prophecies from wine and oil, prophecies from dream-books, thunder-books and much else. There is no need to go into these further, since such methods had not the slightest affinity with the sciences.

## XIII. TECHNOLOGY

Although there was little discussion of the subject in the ancient world, in many branches of technology advances had been made to the full limit of what was possible in the given circumstances. Life was not from hand to mouth, but was lived with conscious control over the means of subsistence and its preparation as food, habitation and clothing. There was also the possibility of leading a fuller existence than that of mere survival. Here the contributory skills were those of the fine arts (music, painting, the decorative arts, as applied to *objets d'art*), and of architecture and engineering (aqueducts, baths, theatres, centres of worship), together with the talent which went into the devising of tools for scientific purposes (for example, surgical instruments) or for constructing them on a scientific basis (instruments and machines based on mathematical, astronomical, physical or chemical knowledge). Technology also played a part in providing man with defences against his enemies, including disease, and with the means of waging war against them (weapons, fortifications, warships, medicaments). All these activities required the proper preparation of the materials, smooth working of the tools and machines and the creation of the necessary means of transport and lines of communication (trucks, roads, bridges, ships and harbour-works).

The outcome of all these endeavours usually owed little to scientific principles, but rather represented the empirical discoveries of anony-

[1] A mode of divination by throwing three pieces of stone into a bowl or basin and invoking the aid of a demon.

mous workmen. A variety of skills, acquired as they were needed in the course of daily life, were handed down within the circle of the family and of manual workers, amongst whom there was very little specialisation at that time. Such work, usually done by slaves, was held in low esteem, and it is understandable that in a society which held that mechanical work led to a lower form of intelligence there were very few writers (among them were Archimedes, Hero and some of those who wrote on siege-warfare) who concerned themselves with technical questions. Even those who did mostly confined themselves to the description of single machines and pieces of apparatus. Pappus of Alexandria, it is true, envisaged the problem as a whole, as the Roman Vitruvius had before him. In the introduction to the eighth book of his *Synagoge* he outlines the intellectual and practical equipment necessary for an architect or engineer (*architekton*). Such a man must be a mathematician and have mastered the subjects of the Quadrivium; in addition he must understand the working of metals, building, carpentry and painting. If he was proficient in all these, then he could be called a creative engineer and architect. Pappus also enumerated the important contributions of engineers who specialised in certain branches; their constructions included levers, catapults, water-raising machines, automata, sundials, water-clocks, and celestial globes activated by water. It will be seen that even Pappus, despite his informative discourses, does not cover all possible branches of technology.

At Byzantium the modest sum of the written knowledge of Antiquity concerning technology was preserved and in some particulars extended: for example, in the fields of apparatus and instrument construction, and of military, pharmacological and chemical technology.

The Byzantines had little written authority to guide them in solving the primary problems of providing food, clothing and shelter; for those who had to deal with these matters, the necessary knowledge was obvious and familiar, and was handed down by oral tradition. Much information concerning both private life and technological activity can be found in a variety of sources, both literary and otherwise. Contemporary illustrations include houses and house-building, baths, furniture, eating utensils, ploughs, weapons, clothing, implements for hunting and fishing, and musical instruments, and there are scenes depicting smiths at work, the harnessing of horses and the taking of land measurements. We can reconstruct something of the different methods of obtaining food (agriculture, hunting, fishing, bee-keeping, horticulture, fruit-growing, viticulture), and the arrangement of the house, with special attention to its heating and plumbing, its kitchen, crockery and utensils, as well as clothing, shoes, and much else pertaining to family life. There are also specialised monographs dealing with the cloth and silk industries. Much information can be gathered from the *Geoponica* concerning the techniques of agriculture, the cultivation of fruit, vines and olives, and their processing (for example, oil-presses), on granaries and methods of preserving (in cellars, casks, brine) and on the ways of procuring materials such as pitch and lime. Of importance also are the chemical techniques used in the household and described by the alchemists, for example, the manufacture of soap and lye, of size for glasses and pots, and methods of making beer.

The *Corpus* of alchemical writings is especially informative on the technical aspects of the fine arts. Here may be found the valuable results of chemical experiment as applied to the creation of useful and ornamental objects, particularly in the fields of metallurgy, dyeing, manufacture of glass and ornaments. The rules for handling metals, which provided instruction for metalworkers and gold- and bronzesmiths, covered soldering, tempering (βαφή), purifying and separating, the production of alloys (for example, white gold) and methods of testing the fineness of an alloy, which was of great importance in the coinage. Admittedly, it was not possible to produce gold from inferior metals by the methods of alchemy, but by tinting and refining some metamorphoses could be achieved so that copper or iron, for example, could be given the appearance of gold. There are further prescriptions from a later period for the production of sheet metal (lead and gold leaf) or metal thread and for making hollow and embossed moulds. The early Byzantine alchemists give recipes for making colours used in painting and textiles (for example, from purple and cinnabar), for inks, and for dyeing wool. This earlier knowledge of colouring techniques is reproduced in the *Painter's Handbook* of Mt Athos. In the *Suda* (*c.* 976; the manuscript dates from the eleventh century) there is also information about the mixing of colours, a practice already in use among craftsmen.

Writings on alchemy are also a rich mine of information concerning the manufacture and treatment of glass. There are directions for making vases and beakers, for glass-painting and for tinting glass, pearls and precious stones, and for the manufacture of cultivated pearls. For their ornamental work Byzantine goldsmiths used not only metals and jewels, but also amber, alabaster and pearls, and were particularly skilled in working gold and ivory and in enamelling. The alchemical works also describe, with diagrams, a number of pieces of apparatus, for example, phials, retorts, distilling apparatus and ovens.

Technology further added to the richness of life by its contribution to architecture, that is, to building on a larger scale than that required for the simplest forms of dwelling. In addition to the churches and the often many-storied private edifices, special mention must be made of the constructions which were of common utility and enjoyment: the roads (with footpaths often built in tiers), bridges and harbour works supplying the needs of transport, aqueducts and canals, baths and theatres. A building edict of the Emperor Leo I of the year 469 restricted the height of houses to 100 feet (29 metres). The 23 metres high and 1170 metres long aqueduct built under Valens in 368 was restored by Justinian II in 567 and is still in being. There was immense architectural activity under Justinian I; its crowning glory was the famous domed cathedral of St Sophia, which was the work of two architects, Anthemius of Tralles and Isidore of Miletus.

Among the greatest achievements of ancient technology, apart from the construction of ordnances, was the invention of tools and instruments based on scientific principles or made for scientific purposes, some of which, indeed, were of service in the arts and entertainment. Some of them are already mentioned by Pappus in his curriculum for engineers and architects (automata, clocks, celestial globes). The classical description in Antiquity of automata, in which simple machines (levers, rollers and so on) work under hydraulic or pneumatic pressure, is that of Hero. The Byzantines further developed these mechanisms, as the men of the Renaissance were later also to find pleasure in doing. Leo the Mathematician made a whole series of them for the Magnaura Palace (as singing birds, or a roaring lion). There is an *Ecphrasis Horologii* on a clock of Gaza from the time of Justinian I. Leontius, an engineer, wrote a treatise *On Preparing a Sphere of Arateia* describing the method of making a celestial globe with the latitude of Byzantium (seventh or eighth century). From what is known of the level of astronomical knowledge at that time one might have thought that Leontius was a contemporary of Leo (ninth century).

Other scientific instruments requiring a finely developed mechanical skill were the dioptra and the astrolabe. Hero had already described the building and uses of dioptra, which were employed in surveying and observing the heavens, and which had a level and a micrometer screw for fine adjustment. Hero the Younger's work on land-measurement (see above, p. 273) is also based on these methods. Philoponus, Nicephorus Gregoras, Isaac Argyrus and others all concerned themselves with the astrolabe, the instrument indispensable to astronomical measurement. Anthemius of Tralles who wrote on burning-mirrors also described a heliostat, which, while remaining at rest, directed the rays of the sun, despite their continual change of direction, always to the same point. In acoustics mention must be made of the numerous musical instruments and of the ἠχεῖα, acoustic resonant vessels which were in use in Asia Minor. It will also be remembered that a number of instruments were evolved by doctors; many were already described by Oribasius. Finally, mention must be made of the most important of all instruments of measure, weights and balances, of writing materials (ink, parchment, paper) and of the apparatus used by the alchemists, already referred to (see above, p. 297).

Defence against the enemy is the special responsibility of the military and in particular of those branches which deal with equipment and armaments, fortifications, intelligence and communications. It is often held that military science can teach men how to organise an army and the tactics and strategy of its deployment. As sciences, however, these branches of learning lack the attributes of an absolute authority which can pronounce infallibly; the subject-matter is too much at the mercy of the prevailing techniques, so that one should speak rather of the 'art' of war, an art which, historical questions apart, scarcely admits of scientific method. But since the Byzantine writers on warfare also deal with technical matters they merit a place here. After the older writers on siege warfare and tactics of the Alexandrian period the first authors to be mentioned are two who are anonymous, one from the time of Justinian I, who wrote *On Strategy*, and another who wrote the *De rebus bellicis*. A number of later works go under the name of the Emperor of the day, who, understandably enough, was usually particularly well disposed to this branch of literature. There is thus a *Strategicon* of 'Maurice' and the *Tacticon* of Leo VI, perhaps the most important of all Byzantine writings on warfare, which includes a section on naval warfare. There is a juvenile work of Leo VI in the *Problemata*, but the *Sylloge* which goes under his name is not by him but is a tenth-century work. Further works include an unimportant essay by Psellus and a number of anonymous treatises such as the *Strategemata* contained in a Milan manuscript, the *Extracts from the Strategica*, a treatise on siege-warfare once ascribed to Hero of Byzantium, and a brief military dictionary. The last of the line of military writers was Nicephorus Uranus, general of Basil II (976–1025), who painstakingly compiled a *Tacticon* from the works of a number of authors.

These works also contain some discussion of military technicalities. These include equipment and armament, hand-weapons, war-engines and ordnance. Pappus had already classed the construction of catapults among the more important duties of an architect. The Byzantines probably made no advances over knowledge already acquired by the Alexandrians and recorded by Hero, Bito and Philo concerning the building of cannon. Siege-engines ('tortoises' and battering-rams), for example, were described by the Anonymous who wrote in the sixth century. Orbicius (sixth century) made a suggestion for mobile battering-rams. There were special firing rules for bow-men.[1] The most important Byzantine weapon, which to begin with was their monopoly and therefore had a decisive influence in their favour, was Greek Fire which is discussed in Leo's *Tacticon*. It appears to have been discovered by Callinicus (*c.* 673), an architect from Heliopolis in Syria. This substance, compounded of naphtha, sulphur and quicklime, was combustible in water and exploded by contact with it, and was launched against the enemy either with lances or by means of pressure (from a siphon). Greek fire was an especially powerful weapon in naval warfare; as is shown in illustrations, the 'siphonarius' stood in the bows and turned the mouth of the siphon in the direction of the enemy. Earthen vessels filled with the fiery material were used as hand-grenades, designed to go off on reaching their target. The tacticians also had to consider the techniques of fortification and siege-warfare. An important role was played by ramparts and walls, for example, the great land-walls of Constantinople. The sixth-century Anonymous discoursed at length on the construction of a town and its defences from the military point of view.

Among intelligence techniques mention must be made of the signalling system and of the optical telegraph of Leo the Mathematician; in naval warfare signalling was by flags, smoke and flashes. Communications were facilitated by military bridges and other forms of transport across rivers, although on land ordinary civil means were used.

Technology also had a part to play in the defence of men against illness, and an important weapon was the manufacture of pharmaceutical drugs, recipes for which are given in books compiled especially for the purpose (see above, p. 293). The information is detailed: thus in a description of a universal nostrum used as a prophylactic (τὸ δωδεκάτεον), the healing effects are first retailed, then the names and quantities of the twelve ingredients and finally the method of taking the preparation: in this case all food was to be dipped in the medicine.

As a conclusion to this survey of Byzantine technology some reference should be made to the methods of procuring the materials required in the work of the household and by all manual workers, whether farmers, builders or artists, and to the tools and apparatus

[1] Given in Leo's *Tacticon* and in the *Sylloge*. See the edition by C. Schissel, 'Spätantike Anleitung zum Bogenschiessen', *Wiener Studien*, LIX (1941), 110–24, and LX (1942), 43–70.

necessary for their preparation. But practically none of the texts deals with these subjects as such. On the other hand, much information is to be gained from a wide variety of sources (the *Geoponica*, the doctors, alchemists, works on siege-warfare), and from such contemporary illustrations and tools as have survived. In addition to the age-old tools of handworkers and peasants (the hammer, chisel, drill, saw, knife, chopper and plough) the Byzantines also knew several simple machines (levers, rollers, cog-wheels, wedges, inclined planes, screws and pulleys) which were used mostly as parts of big machines (capstans, tread-wheels, scooping-machines, weight-lifters and catapults), as is clear from the works of Hero and the writers on military technology. Among individual technical devices mention may be made of Cardan's suspension and the micrometer screw. There is almost complete silence concerning means of transport; though as exceptions may be cited innovations in harnessing horses and cattle, and shipbuilding, which, on account of their military importance, are referred to by many of the authorities. There has been some recent work on these particular topics; but much research on the subject of Byzantine technology still remains to be done.