CHAPTER 21

Science and Technology: Pharaonic

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1 Modern Expectations and Ancient Sources: Labeling the Past

Speaking about "science" in ancient Egypt requires a preliminary discussion of the meaning of this term. If we strictly adhere to the canonical idea of science as a universal and objective truth, then not much would be classified as such prior to the seventeenth century or, according to some scholars, even the early nineteenth century (Cunningham 1988). When dealing with the ancient world and with non-Western cultures, however, it is necessary to adopt a more flexible approach, which is also more respectful of their intrinsic historical development. Every culture legitimately developed its own way of defining, controlling, and predicting natural events which often mixed magic, science, and religion; the separation between rationality and magic, and the subsequent prominence given to the former, is uniquely European (Selin 2000: vi). The criteria for defining and studying science in history tend nowadays to avoid absolute standards and to acknowledge instead the importance of the locally specific nature of knowledge. In this way, the importance of local differences is re-evaluated rather than dismissed because they do not correspond to universal concepts (Turnbull 2000; Rochberg 2004: 14–15).

As far as ancient cultures are concerned, from the time of Aristotle onwards "natural philosophy" may act as an alternative definition for science in several fields relating to the observation and understanding of the physical world. In applying this discussion to ancient Egypt, however, this approach would not have been particularly useful, for two main reasons. First of all, mathematics should have been treated separately, since it is not regarded as part of natural science. Secondly, the concept of natural science is Greek, and is, therefore, as anachronistic for ancient Egypt as the term "science" in its strictest meaning (Grant 2007: chapter 1, see also 160). The choice was, therefore, made to organize this chapter on the basis of our modern terminology. Our aim is to communicate among ourselves, and, therefore, the adoption of a recognizable classification system is fully legitimate, but this is applicable under one strict condition: that we do not forget that the ancient point of view might have been (slightly or significantly) different. This must be true both for technical and methodological issues. For example, our approach, understanding, and appreciation of ancient measuring instruments are often hindered by our modern, extremely high expectations of their accuracy (Symons 2000).

In general, it is important to bear in mind that only in a few cases do we know if and how the ancient Egyptians systematically organized their knowledge, and whether they recognized a certain field as a distinct discipline. The absence of sources should be treated with extreme care: implying that the absence of "treatises" means that no corresponding disciplines existed may be as dangerous as implying that sources, now-lost, could revolutionize our perception of the ancient culture. The preservation of the ancient sources, especially in case of fragile papyri, is very uneven and depended, in many cases, on pure chance. The discovery of new sources would certainly improve our knowledge, but this expectation should not be used as an alibi to dismiss the value of the documents that have already been found (as happened in the past, for instance, with mathematics). This chapter will, therefore, contain a brief survey of what we know of how the ancient Egyptians dealt with various fields. As we shall see, the categories of "science" and "technology" may act as complementary guides: when one cannot stretch any further, the other will lead us to explore the complexity of ancient knowledge.

2 Mathematics

The sources and uses of mathematics

Our knowledge of ancient Egyptian mathematics relies on a limited number of documents that may be classified as mathematical texts (Robson 1999: 7). Other texts such as building records and administrative accounts, although not strictly mathematical, may reflect mathematical knowledge and provide important evidence on how mathematics was used (e.g. Simpson 1963; Posener-Kriéger 1976).

The main mathematical texts include the Rhind, Moscow, Kahun, and Berlin 6619 papyri, a leather roll held in the British Museum, and two wooden tablets kept in the Cairo Museum. These all date to the second half of the Middle Kingdom, and the majority come from illicit digs, not from recognizable and documented contexts. They were all found in the second half of the nineteenth century and were all published for the first time between 1900 and 1930 (Peet 1923a; Chace, Bull, and Manning 1929; Struve 1930; Griffith 1898; Schack-Schackenburg 1900 and 1902; Glanville 1927; Daressy 1906; Peet 1923b).

The surviving mathematical documents appear to be school texts, designed to teach mathematics to young scribes (Ritter 2000: 120). Their contents can be classified into two categories: table texts and problem texts (Imhausen 2002). Table texts are ready made collections of mathematical *data* that may be consulted to perform calculations; problem texts, on the other hand, are sample problems, ranging from recurring tasks such as measuring the area of fields, calculating the volume of a granary, and dividing loaves of bread among men, to exceptional events such as calculating the slope of a pyramid.

Notation and mechanisms

The Egyptian mathematical system was decimal and expressed any number by combining the hieroglyphic signs for the numbers 1, 10, 100, 1,000, 10,000, 100,000, and 1,000,000. The system (with some exceptions, Roero 1994: 32) was additive: the number 7, for instance, was indicated by seven signs each meaning 1; the number 40 by four signs each meaning 10; a number such as 253 was expressed by two signs indicating 100, plus five indicating 10, plus three indicating 1; and so on.

Beside integers (whole numbers), the Egyptians made large use of unit fractions, that is, fractions with 1 as a nominator and any number as a denominator (with the exception of $\frac{2}{3}$). However, they would never use the same fraction twice, that is, $\frac{2}{5}$ would never be expressed as $\frac{1}{5}+\frac{1}{5}$, but preferred strings of unit fractions listed in decreasing order: $\frac{2}{5}$, for instance, may be expressed as $\frac{1}{2}+\frac{1}{15}$, but also as $\frac{1}{3}+\frac{1}{16}+\frac{1}{240}$ or as $\frac{1}{4}+\frac{1}{7}+\frac{1}{140}$ and by six more combinations of three unit fractions each (cf. Gillings 1972: 53–4). The scribes took full advantage of the existence of more than one combination and generally chose the most "convenient": for instance, even numbers were definitely preferred to odd numbers, and short sequences were favoured over long series of unit fractions (Gillings 1972: 49). The most convenient results might be listed in tables and thus made available to the scribes who had to perform quick calculations.

The general preference for even numbers finds a clear explanation in the mechanism underlying the majority of ancient Egyptian mathematical operations: halving, doubling, taking 2/3 of a quantity, multiplying and dividing by 10 were basic actions of many mathematical procedures. The list of the results of 2 divided by the odd numbers from 3 to 101 (which occupies the entire *recto* of the Rhind papyrus) corresponds, in fact, to the doubling of unit fractions with odd denominators, that clearly posed more problems to the scribes than any even number (Clagett 1999: 18; Ritter 2000: 126–7 and 129).

Problem texts provided solutions for specific cases, but could also be consulted as general examples on how to approach similar issues (Clagett 1999: 94). Starting from the *data*, the scribes solved these problems by following a defined sequence of steps, in which each result was employed in the following operation (Imhausen 2003). The study of their algorithmic structure helps understanding similarities and differences with the later development of Egyptian mathematics (Imhausen 2002: 158–9): whereas some aspects clearly evolved over the centuries (Silverman 1975), others remained a constant down to the Graeco-Roman Period (Rihll, ch. 22).

Metrology and geometry

As the centuries passed, among the various units of measurement used by the Egyptians (Hannig 1995; Schlott-Schwab 1981) some survived almost unchanged, some appeared and disappeared (e.g. Žába, Verner et al. 1976: 83), and some changed their value (e.g. Imhausen 2003: 156). The basic unit of linear measurement was the cubit ("royal" and "small") and its subunits, the palm and the finger. The small cubit corresponded to the length of the human forearm and was equal to 6 palms (c. 45 cm), whereas the royal cubit corresponded to 7 palms (c. 52.3 cm); each palm (c. 7.4 cm) was divided, in turn, into 4 fingers (c. 1.8 cm). The royal cubit was the basic unit of measurement used in architecture, as many standing monuments clearly attest (Arnold 1974a: 29–31; Arnold 1991b: 10–1; Rossi 2004: 96–147); cubic cubits appear in building records reporting on the foundations of standing buildings and on the works done in rock-cut tombs (Simpson 1963: 124–6; Koenig 1997: 9). Agricultural fields were also measured on the basis of the cubit: their dimensions were generally expressed in *khet* (equal to 100 cubits) and their areas in *setat* (also indicated with the Greek term *aroura*), equal to one square *khet* (100 × 100 cubits; Clagett 1999: 12–3; Imhausen 2003: 66–7; see also Arnold 1991: 252).

The mathematical sources contain problems of calculation of rectangular, triangular and trapezoidal areas, that may well reflect the actual practice of land-surveying. The calculation of the area of a circle as large as a field, on the other hand, is likely to represent a theoretical case (Gillings 1972: 139), most probably meant to complete the series of examples on how to calculate the area of the most common geometrical figures.

The main unit of measurement for capacity was the *heqat* (corresponding, at least in the Middle Kingdom, to c. 4.8 litres), with its multiples and submultiples ranging from the tiny *ro*, equal to $\frac{1}{320}$ of *heqat* (c. 0,015 litres), to the *khar*, corresponding to 20 *heqat* (that is, c. 96 litres; Clagett 1999: 14–5; Imhausen 2003: 58). Beside the intrinsic commensurability of these units and subunits, an important aspect was the relationship existing between the *khar* and the cubic cubit: the former was known to be equal to $\frac{2}{3}$ of the latter, and this proportion allowed scribes to shift easily from capacity to volume, and the opposite. A common problem assigned to a scribe, in fact, was calculating the volume of a granary and establishing how much grain could be stored inside, or the opposite.

In general, the subjects of the surviving mathematical problems clearly reflect the type of tasks that a Middle Kingdom scribe was likely to be assigned in his working life. They also reflect the various uses of mathematics which played an important role in several contexts: the administration of the community was based on an equitable distribution of goods; large-scale production of food had to be strictly regulated from the initial step of land-surveying to the final act of storing grain; and the construction of important monuments required a constant control of the workforce and of the geometry of the building (cf. Rossi 2009). The respected scribe, well fed and well taken care of by his community (cf. Lichtheim 1976: 167–8), owed part of the success of his profession to the mathematical documents at his disposal. As the first lines of the papyrus Rhind state, they contained "accurate reckoning for inquiring into things, and the knowledge of all things, mysteries [. . .] all secrets" (Clagett 1999: 122).

3 Astronomy

The sources: from religious symbols to computers

Our knowledge of ancient Egyptian astronomy relies on a variety of sources, including religious texts, funerary decorations, and building records. Matching the ancient data to the sky itself, however, is not easy. Religious texts and representations describe the sky in symbolic terms that may or may not reflect distinct celestial bodies or astronomical events. For instance, whilst many stars and constellations were specifically associated with minor deities (Wilkinson 2003: 90–1), an important and single entity like the sun might be identified with three different deities depending on the time of the day (Quirke 2001; Müller 2001; Mysliwiec 2001; O'Rourke 2001). Other sources may not be accurate enough to match our modern expectations: our knowledge of the ancient Egyptian star tables, for instance, is entirely based on artistic representations of ancient time-keeping methods, not on actual working instruments (Symons 2000: 112).

Achievements and problems in the study of ancient Egyptian astronomy may be summarized as follows: our understanding of mechanisms and notation has certainly improved over the years, but the identification of the majority of the stars mentioned in the ancient sources remains an unsolved problem. The introduction of computer-generated models that help to reconstruct the ancient sky has had a significant impact but has not produced results that have met with the general consensus. In general, it is interesting to note that a better comprehension of the ancient sources has weakened, rather than reinforced, some earlier undisputed assumptions, thus opening the way for further research.

The sun, the moon, and the stars

Orientation in time and space is a basic need of every society, and in ancient Egypt the sky provided abundant material for this purpose. The most obvious rhythm and the first basic spatial distinction were provided by the sun which every day rises in the east and sets in the west. For more sophisticated goals, such as keeping a calendar and establishing with precision the four cardinal points, the ancient Egyptians appear to have turned to the night sky and to the more complex movements of various celestial bodies.

From the point of view of an observer, the stars slowly and constantly rotate around the north celestial pole. This point corresponds to the direction of the axis of the planet Earth and is currently marked by Polaris, the North Star. Four millennia ago, however, the axis of our planet pointed in a slightly different direction, and the north celestial pole was not marked by any star. The entire sky rotated around a dark spot: whilst the further stars periodically disappeared under the horizon, those lying closer to the center of rotation never set. In ancient Egypt, because of their constant presence, the circumpolar stars earned the appellative of "the Imperishable Ones".

Stars were grouped in constellations, divided into southern and northern groups (Neugebauer and Parker 1969: 183–202); New Kingdom sources mention about a dozen in each group but only a few can be identified (Wilkinson 2003: 91). Five "stars that know no rest" (five planets) moved independently against this "fixed" background (Neugebauer and Parker 1969: 175–82), and so did the moon. Among the stars that set and rose, the most important was the bright Sirius, called Sopdet by the Egyptians and Sothis by the Greeks. The moon and Sirius played a fundamental role in the organization of the ancient Egyptian society: the phases of the former and the annual cycle of the latter lay at the basis of ancient Egyptian time-keeping system.

Time keeping

The oldest calendar appears to have been based on the lunar cycle. The interval between equal phases of the moon (the synodic period), however, is about 29.5 days, and lunar months therefore last either 29 or 30 days. This irregularity, noted already in earliest times, might have prompted the Egyptians to turn to the more regular solar calendar. The old lunar system survived in parallel and was used to fix the dates of some religious festivals (Parker 1978: 708).

Finding a match between lunar and solar dates is a difficult task: first of all, the precise sequence in which 29- and 30-day periods alternated is unclear (see, for instance, Parker 1950; Krauss 1985; Luft 1992). Moreover, the first day of the lunar month corresponded to the disappearance of the last lunar crescent, an event that could easily be missed in situations of imperfect visibility. Moreover, the irregular lunar calendar could not be precisely linked to the most important natural event of the year, the Nile flood. Another celestial body, however, appeared to fit this requirement: Sopdet (Sirius), which "disappeared" (that is, rose when the sun was already up in the sky and was thus invisible) for a period of 70 days. Her first visible rising at dawn, called "heliacal", took place at the end of June, in the same period when the inundation reached Upper Egypt.

To the early third millennium BC date the earliest representations of the star-goddess Sopdet as well as, probably, the introduction of a civil calendar which divided the solar year into 10 months of 30 days each, plus 5 extra days, called "epagomenal" (Wilkinson 2003: 167–8; Shaw 2000a: 10–1; Parker 1950). Originally, the beginning of the solar year is likely to have corresponded to the heliacal rise of Sirius. The true length of the year, however, is a few hours longer than 365 days and in fact nowadays, to keep the calendar in place, every four years we assemble the extra hours into an extra day. The ancient Egyptians were fully aware of this shift (they called it "the wandering year") but maintained this time-keeping system unaltered for millennia. It took about 1,460 years to the civil calendar to complete the cycle, and to start again in correspondence of the helical rising of Sirius. This event was celebrated during the reign of the Roman emperor Antoninus Pius in AD 139, thus suggesting that the same correspondence must have taken place around 1320 BC and 2780 BC (Parker 1952; Ingham 1969; Krauss 1985).

The 70-day period of invisibility of Sirius may have also played an important role in the compilation of the earliest diagonal star tables. There are three types of tables, previously known as "star clocks", that were thought to correspond to three stages of a linear evolution of the same system; recent research, however, casts a new light on their function.

The earliest examples of diagonal star tables date to the Middle Kingdom. They record the rising of the stars called "decans" during the course of one night. Every ten days one of the twelve decans disappeared, and a new one appeared, and thus the list "shifted" upwards and sideways, giving to the table a distinctive diagonal pattern. By the time the solar year had passed, 36 decans had appeared and disappeared in the night sky; the five remaining days were marked by a specific group of additional stars (Symons 2007). These tables appear to have been time-keeping systems: the columns represent stars and the rows time-periods, but not necessarily hours, as previously believed (Depuydt 1988). For this reason, the misleading word "clock" has been abandoned in favor of a more neutral and objective definition as "table" or "list".

Spotting a rising star may be difficult, and this led scholars to believe that a "natural" evolution of this method would be looking instead at the transit, or culmination, of stars (that is, their maximum height in the sky; Frankfort 1933; Neugebauer and Parker 1960: 32–42, 113–15). Recent research, however, suggests that the so-called "transit star clocks" of the New Kingdom, rather than being "clocks", are simply embellished lists of stars that share a common characteristic: a 70-day period of invisibility. This span of time, equal to the period of invisibility of Sirius, corresponded also to the time that conventionally elapsed between death and burial of an individual. When someone died, the corresponding disappearing star was chosen: her heliac, rising, 70 days later, marked the time when the burial would take place. As such, these lists may be precursors, rather than successors, of the diagonal star tables (Symons 2002).

Finally, the Ramesside "star clocks" consist of stars placed within a grid, drawn above a kneeling, full-faced figure. According to the traditional interpretation, two people, the observer and the "target figure", would seat facing one another, along a north-south direction. The observer would look at the position of the stars in relation to the "target figure" and, by comparing it with the table, would be able to tell the time (Neugebauer and Parker 1964). This interpretation, however, is based on a number of conjectures, and several questions remain open (Symons 2000).

Astronomical orientation of monuments

From earliest times the first act in the construction of important temples was a foundation ceremony, during which the king performed a ritual version of the basic building operations (Wilkinson 2000c: 111–12, 139; Engelbach 1934; Montet 1964; Weinstein 1973: chapter 1). During the action of outlining the building plan on the ground the king was said to be "looking at the sky, observing the stars and turning his gaze to the Great Bear". In other passages, the "stride of Re" and the "shadow" are also mentioned in connection with the same action, thus suggesting that the orientation of the buildings might be achieved either by using the stars or the sun (Arnold 1991: 16).

The careful study of some buildings confirmed that the sun was involved in their design: the funerary complex of Khafre appears to have been aligned along the rays of the setting sun at the equinoxes (Lehner 1997: 129–30), and the temple of Abu Simbel was designed so that twice a year the sun would reach the innermost sanctuary (Wilkinson 2003: 226). Stars appear to have been the target of other monuments: the inlaid eyes of the statue of king Djoser placed in the *serdab* at the back of his pyramid were fixed on the circumpolar stars, and it is possible that the so-called air-shafts of the pyramid of Khufu pointed in the direction of specific stars (Lehner 1997: 90 and 112–14).

Other cases are less straightforward. The astronomical orientation of pyramids, for instance, is the subject of a heated debate that opposes supporters of solar and the stellar alignment (Isler 2001; Žába 1953). Within the latter group, there is no agreement on which stars might have been used (see Maravelia 2003 for a summary of the discussion triggered by Spence 2000), nor on which method might have been used to fix the four cardinal points (Edwards 1993; Dorner 1981). Because of the lack of clear textual evidence and the need to test the theoretical methods in the field and to combine computer-generated models with practical observations, the discussion inevitably remains open.

4 Medicine

The sources: papyri, bodies, and art

In ancient Egypt medical knowledge was recorded and transmitted by means of written documents, listing problems and relating solutions. About a dozen papyri survive, dating from the Middle to the New Kingdom. Like the mathematical papyri, they were all found between the end of the nineteenth and the beginning of the twentieth century, and many of them come from illicit digs. They have all been thoroughly studied, translated into German, and systematically published between 1954 and 1973 (Grapow et al. 1954–73); some of them have been translated into English and French (Allen 2005: 70–115; Breasted 1930; Stevens 1975; Jonckheere 1947; Iversen 1939; Barns 1956).

Among the most important documents, the Edwin Smith Papyrus contains a systematic list of cases, nearly all referring to victims of trauma; the Ebers Papyrus, the Hearst Papyrus, and the Berlin Papyrus contain collections of medical cases of various kinds. Gynaecology is the subject of the Kahun and Calrsberg VIII Papyri, whilst Chester Beatty VI deals with rectal diseases. The Ramesseum papyri contain gynaecological, ophthalmic, and paediatric problems, and the papyrus held in the British Museum contains mainly magical spells.

Another important source of information on ancient medicine is represented by human bodies, in particular by well-preserved mummies (Ikram and Dodson 1998). The ancient Egyptians appear to have suffered from the same diseases as we do today, ranging from toothache to cancer, and to have incurred several types of trauma relating to their professions or to warfare (Halioua and Ziskind 2005). Modern techniques, such as X-rays and CT-scan (computed tomography), provide plenty of information on the life and death of the people, commoners and kings whose bodies have been found (Halioua and Ziskind 2005: 53–65; see also Balout et al. 1985; Forbes 1993; Hawass 2005; Forbes, Ikram, and Kamrin 2007).

Finally, artistic representations may also offer important information on traumatic events and medical conditions, including dwarfism, spinal deformities, and various types of hernia (Nunn 1996: 57, 79, 93, 166; Reeves 1992a: 32–48). Artistic conventions, however, should not be taken too literally: the most controversial case is the Pharaoh Akhenaten (whose body has not been found), usually represented with physical features that may either depend on the development of an artistic canon or as signs of chromosomal or genetic abnormality (Nunn 1996: 83–4; Reeves 1992a: 46–48).

Diagnosis and prognosis

The medical papyri provide important information on the subjects that nowadays we call anatomy, physiology, and pathology. Although the meaning of some specific terms remains unclear, the ancient names of several parts of the body have been identified, including bones and internal organs (Nunn 1996: 46–7 and 50). By combining the information coming from various medical situations, it is also possible to reconstruct how the body was thought to function.

The Egyptians believed that the air was drawn through the nose into the lungs, reached the heart and from there started to circulate in the body through a system of vessels, called *metu*, which contained also blood, mucus, urine, and semen. It was clear that food and drink went down into the stomach and then at some point reached the anus, where also the *metu* was thought to converge (Nunn 1996: 54–6). Emotions were associated with the heart, whilst the brain did not attract particular attention. However, the role of the spine in the transmission of information from the brain to the various parts of the body appears to have been appreciated (Allen 2005: 91). The basic concepts of the reproduction system were clearly understood; fertility, pregnancy, and contraception occupy large sections of the medical papyri (Halioua and Ziskind 2005: 69–75, 175–8). Trauma, infections, and various diseases required the intervention of doctors, although in some cases also priests and magicians acted as healers (Nunn 1996: 113–21; Halioua and Ziskind 2005: 7–12).

The Edwin Smith Papyrus provides information on standard medical procedure, very similar to the modern process, which consisted of examination, diagnosis, prognosis, and treatment. The doctor examined the patient, asked questions, and checked abnormal signs; then he formally pronounced a sentence stating what he had detected. The prognosis was chosen from three stock phrases: "an ailment which I will handle", "an ailment I will fight with", and "an ailment for which nothing is done" (Allen 2005: 70). The first sentence corresponds more or less to our favorable prognosis and the second to an uncertain prognosis. The third sentence was used when no practical treatment was known, including cases with an unfavorable prognosis. In general, apart from a few desperate cases, a treatment was then prescribed.

Treatments

No medical instruments dating to the Pharaonic period can be unequivocally identified, but the medical papyri suggest that doctors made large use of linen bandages and splints, and of swabs made of raw flax (Vogelsang-Eastwood 2000: 294). When necessary, they used at least three types of knives, made of metal, flint, or reed

(Nunn 1996: 24, 164–5). In some cases, it is clear that the "knife treatment" involved cutting and cauterising at the same time (Reeves 2001: 49–50).

Doctors also prepared drugs that could be administered to the patients through mouth, anus, or vagina, or as external applications or fumigations. The origin of the main components might be mineral, vegetal, or animal. Among the minerals, natron, common salt, and malachite were probably used for their septic and anti-bacterial properties (Nunn 1996: 145–7). The identification of many herbs and plants which were used to prepare medicaments, on the other hand, is hampered by several factors: the nature of the ailment may be uncertain; some unidentified plants may have become extinct; it may be unclear which part of the plant was used; finally, their pharmacological effects may be unknown (Germer 1993; Manniche 1989: 64–5).

More than half of the medicaments that appear in the medical papyri contain animal substances. Fresh meat was applied to wounds, fat was widely used to prepare greasy mixtures, milk was probably mainly used as a convenient vehicle; blood and bile also appear, together with excrements of various animals, including cat, ass, birds, lizards, crocodile, fly, and even man (Nunn 1996: 148–50). The most important ingredient of animal origin, however, was honey: applied externally or ingested, it was used either as a vehicle or as a medicament in itself, thanks to its anti-bacterial and anti-fungal properties (Zumla and Lulat 1989).

Finally, amulets and magic spells were also prescribed to help the healing process. The Edwin Smith Papyrus, the most systematic and pragmatic among the medical documents, contains only eight magic spells, but other sources indicate that magic was widely used either alone or alongside the practical treatment and was deeply intertwined with the latter. It would be unwise to underestimate the role of magic in the healing process: the expectation of being cured or relieved of pain would have been strongly enhanced by the use of amulets and incantations, and would certainly have had a positive effect on the patient (Nunn 1996: 96–112).

5 Biology

Botany

Clear and unmistakable evidence of the deep knowledge that the ancient Egyptians had of herbs, plants, flowers and trees can be found in several contexts. Human consumption of plants and vegetables relied on long-established experience: cereal cultivation and processing, as well as beer- and wine- production, reveal a deep knowledge of both the ideal conditions of growth for the plants and the necessary steps to isolate, process, and preserve the edible parts (Murray 2000a; Samuel 2000; Murray, Boulton, and Heron 2000); spices and various herbs were common ingredients of cooking recipes (Murray 2000b), and plants and flowers of various types were used to prepare cosmetics and perfumes (Manniche 1989: 44–63).

The physical characteristics of many plants and trees were also aptly exploited: the peculiar fibres of the papyrus made it particularly suitable for turning into a writing surface (Leach and Tait 2000: 227–38); resins of various origins were used as adhesives and were also employed in the mummification process (Serpico and White 2000: 430–51); thanks to their flexibility, palm leaves and grass were the most common materials for making baskets and mats (Wendrich 2000: 254–5); finally, about thirty different types of wood were used to produce a variety of objects from small pieces of furniture to large beams to be used in architecture (Gale, Gasson, Hepper, and Killen 2000). Finally, plants, flowers, and trees were also widely used for decorative purposes: gardens were an important part of private houses as well as of royal estates, and in some cases of religious complexes as well (Manniche 1989: 7–21).

Whilst the practical applications of the curative and structural characteristics of plants are relatively well-known, it is unclear whether there was a common theoretical background behind them, as no treatise or complete written document specifically referring to our modern concept of botany has been found from the Pharaonic period (Manniche 1989: 7). This means that we do not know if and how exactly the Egyptians classified plants. Modern research focuses on the identification of plants mentioned or represented in the ancient sources (Manniche 1989: 67 onwards) but has received important contributions from the growing field of archaeobotanical studies (for instance, Wetterstrom and Murray 2001).

Zoology

The ancient Egyptian knowledge of the animal world clearly emerges from their artistic representations (te Velde 1980: 76). A detailed and careful study of artistic evidence dating from the Predynastic Period onwards has allowed the identification of over seventy species of birds (Houlihan 1986), twenty of fish (Brewer and Friedman 1989), and about one-hundred of mammals (Osborn and Osbornová 1998). A parallel, minor source is represented by hieroglyphs which include tiny but detailed representations of over one hundred animals and over sixty parts of animals (Gardiner 1957: 458–77). It is important to remember, though, that artistic representations such as scenes of daily life painted on tomb walls were meant to accompany the dead into the afterlife and not necessarily to be a faithful reproduction of the real world (Janssen 1990: 48); therefore, they may contain mistakes or incorrect representations of some details (Osborn and Osbornová 1998: vii).

The study of zooarchaeological remains provides information on the actual life and death of the ancient animals and, indirectly, also on their role in ancient society (Ikram 2005a). By combining various sources, it is possible to gain a relatively detailed picture of the animals that lived at the time of the Pharaohs (Houlihan 1996). In some cases, e.g. the cat, it is even possible to follow its role in society and religion from the earliest times to the Graeco-Roman Period (Malek 1993). Also in this case, as with botany, we do not know if and how the ancient Egyptians classified animals, beyond – one would imagine – the obvious, visible distinctions between flying creatures, fishes, herbivores *vs.* carnivores, etc.

As with human bodies, preparing an animal mummy implied a good knowledge of the internal structure of dead bodies. There is also evidence that the Egyptians had a clear idea of how live animal bodies functioned or malfunctioned: the way in which sick animals were cured suggests that a parallelism between human and animal organisms was clearly perceived (Petrie and Griffith 1898: 12–4; Ghalioungui 1983).

In general it was evident to the ancient Egyptians that life (human, animal, and vegetal) always depended on the same basic rules. The fundamental role of sun, air, and water, for instance, is clearly acknowledged already in the earliest myth of the creation of the world (Quirke 1992: 21–50): no systematic written descriptions of flora and fauna have survived (if they ever existed), but the clear understanding of the basic mechanisms regulating the life of all creatures still emerges, even if indirectly, from the symbolic realm of religion.

6 Earth Science

Geography

The ancient Egyptians knew very well the territory that they inhabited: from earliest times the annual cycle of the inundation had determined the best locations where villages and towns could develop (Butzer 1976), and people had learned to exploit the changing conditions of the river. The landscape was not as static as it is today but changed dramatically from winter to summer – and so did the available space and the possible activities.

Navigation was the most important method for transporting people and goods. Whilst during the dry season this was mainly a north-south business, the inundation greatly increased the number of destinations that could be reached by boat to the east and to the west. A good example of how the Egyptians exploited this substantial change is the choice of the locations to build some of the massive Old Kingdom pyramid complexes (Lehner 1997: 58, 82–3, 142, 231).

The valley, with its relatively uniform but flexible landscape, did not hold many secrets; the case with the deserts was different since in these areas long distances separated settlements and sites of interest. A preliminary knowledge of the territory was essential to travel safely across desert areas, and natural landmarks might prove particularly useful to maintain the right direction. The only geographic map that survives from ancient Egypt dates to the New Kingdom and represents, in fact, an itinerary across the Eastern Desert, namely a section of Wadi Hammamat leading to the gold-mining settlement of Bir Umm Fawakhir (Harrell and Brown 1992). It contains the drawing of a track running along a sequence of *wadis* bordered by high mountains, the profile of which is drawn flat on either side of the track. Annotations in hieratic provide further information on locations and directions. Originally interpreted as a description of an area meant to identify the settlement (Murray 1942; Goyon 1949), the map is better interpreted as an itinerary to reach it (Baud 1990). As such, it may be considered a precursor of the later Roman *itineraria non tantum adnotata sed etiam picta* ("itineraries not only annotated but also illustrated", cf. Brodersen 2001).

It is possible that similar topographical maps existed to support other long-distance expeditions, even before the New Kingdom. There is evidence that the Egyptians traveled far into the deserts from the earliest times (Ikram and Rossi 2004). From the Old Kindgom we have Khafre's mining expeditions to Gebel el-Asr, in Nubia (Shaw and Bloxam 1999; Shaw 2000b) and the deposits of jars found along the track linking Dakhla to the Gilf el-Kebir (Kuper 2003) as well as Harkhuf's accounts of his travels which prove that the Egyptians knew several itineraries to reach the southern land of Yam (Yoyotte 1953; Edel 1955; Dixon 1958; Spalinger 1979a). No evidence of how these routes were recorded survives, but annotated drawings would have been the most logical and convenient method.

Geology

The ancient Egyptians quarried and mined about fifty different types of stone, and used them for various purposes, ranging from making beads, amulets, and vessels of varying size to building large architectural monuments (Aston et al. 2000). Their sources, scattered all over the Valley and the deserts, differ significantly from one another, as some stones could be found on the surface, whereas others had to be searched for underground. In this case, the Egyptians must have been able to identify the most likely geological environment where deposits of those materials might be found. The same must have happened with metals: the ancient prospectors evidently relied on their ability to combine the information provided by the land formation, the color of the rocks, and even the local flora: acacia trees, for instance, often grow near deposits of copper and lead (Ogden 2000: 148).

7 From Science to Technology

Chemistry

Chemistry is a particularly clear case where the lack of written sources indicating the existence of a specific theoretical knowledge cannot obscure the fact that, in practice, the ancient Egyptians did apply countless chemical processes in several fields. As we shall see below in the section on metals, glass and faience, modern chemical and physical analyses of ancient artefacts provide clear information on this subject. The results might have been achieved by means of repeated experiments; whether or not the reasons behind the mechanism were investigated or understood is unclear and, in a way, might be even irrelevant: the Egyptians knew how to obtain the desired result and transmitted their practical knowledge from generation to generation. In this respect, whereas the category of "science" cannot provide a satisfactory systematization of the ancient corpus of knowledge, the term "technology" is an adequate label. Technology implies knowledge, practical if not theoretical, and in many cases better represents the general idea that the ancient sources give us of the Egyptian attitude: the practical result was the main concern, whilst reasons and mechanisms appear to have attracted little attention.

New studies on ancient technology

The study of ancient Egyptian materials and technology has gained increasing importance. About one hundred years ago the majority of Egyptologists were mainly concerned with artistic and linguistic issues, and the realms of science and technology attracted little attention. For many years the analysis of materials and artefacts was basically confined to a few publications which functioned as sole references until recently (Lucas 1926; 1962). In the last twenty years, on the other hand, the application of modern scientific and technological methods to the study of ancient artefacts has allowed the rapid accumulation of detailed and accurate knowledge, with a distinctive multidisciplinary character. A wealth of new *data* and information is now available and keeps accumulating at a brisk pace (Nicholson and Shaw 2000).

An important role in this new wave of studies is played by the growing field of experimental archaeology: a re-enactment of the ancient process is sometimes the only way to understand fully the mechanisms of the ancient technological process and to verify what the final result would have been (see, for example, Samuel 1997 on brewing beer; Ikram 2000 on preparing and consuming biltong; Ikram 2005b: chapter 2).

8 Building Houses and Monuments

Light materials and mudbricks

Mats, reeds, soil and wood were basic building materials from earliest times (Davies 1929; Rizkana and Seeher 1989: 40; Debono and Mortensen 1990: 17–20). Because of the fragility of these materials, the archaeological remains of the earliest architecture are extremely rare; important information may nevertheless be gathered from other sources. The earliest use of intricately woven colored mats and screens, for instance, survived as a common decorative pattern on later mudbrick and stone walls (Wendrich 2000: 257–8 and 263). Seemingly, the appearance of the earliest sacred spaces and some details of their building techniques may be partially reconstructed from some archaic hieroglyphic signs which contain miniature representations of these lost buildings (Badawy 1948: 41–65).

The use of mudbricks although attested as early as the beginning of the Gerzean Period, became suddenly widespread at the beginning of the First Dynasty (Kemp 2000: 79). Domestic and military architecture were almost exclusively built of mudbrick throughout ancient Egyptian history, but religious and funerary architecture also made extensive use of this building technique (Spencer 1979). Mudbrick was also used to build ramps used in the construction of stone monuments (Arnold 1991: 79–98). Mudbricks were made of clay, silt, and sand, often with the addition of straw or chaff, mixed in proportions which might vary depending on various factors, above all the local availability of the various components. The mixture was poured into moulds and then allowed to dry in the sun; the use of fired bricks was probably avoided due to the cost of fuel and the need for a stronger mortar (Kemp 2000: 79-83). The dimensions of bricks vary considerably but generally retained a 1:2 proportion between width and length, due to the intrinsict geometry of bricklaying (Spencer 1979: 147–8, pl. 41).

The ancient Egyptian production of mudbricks must have been massive and constant: the need for impressive quantities such as the 24.5 million mudbricks used to build the core of the pyramid of Senwosret III at Dahshur (de Morgan

1895: 47, n. 3) was probably met by large-scale brickyards, either permanent or specifically set up. Textual and artistic sources on the subject are, however, not numerous and our knowledge depends more on the careful study of the archaeological remains than on any other type of evidence (Kemp 2000: 83).

Stone

Although small-scale quarrying of chert to make tools dates back to 40,000 BP, large-scale demand for stone to produce vessels, statues, and architectural elements arose at the beginning of the Pharaonic period (Aston, Harrell and Shaw 2000: 5–6). Three centuries after the first significant use of stone in the Early Dynastic tombs at Abydos and Saqqara, Djoser chose stone as the sole material to build his funerary complex; the design of many parts of the complex, however, was still deeply influenced by the earliest architecture built of light materials. By the time Khufu built his pyramid just one century later the Egyptians appear to have fully understood the potential of stone and to be perfectly able to exploit it, both structurally and formally. Khafre, Khufu's successor, apart from building the second largest pyramid, inaugurated the tradition of large-scale production of royal statues (Lehner 1997: 84–133). Therefore, in a relatively short time stone had become the most common and most favored building material for any Pharaoh. State expeditions started to be organized to reach specific veins of valuable stones (e.g. Shaw and Bloxam 1999; also Shaw 1998); quarrying techniques developed, as well as efficient methods for transporting the blocks (Aston, Harrell, and Shaw 2000: 17–20), the size of which increased dramatically during the same short period of time (cf. Arnold 1991: 160, 1–2).

Even though quarries have been the subject of detailed studies in recent years (in general Klemm and Klemm 1993; for specific cases Aston, Harrell, and Shaw 2000: 70–7), the exact nature of the tools employed to extract stone blocks remains unclear. Chisels and pounders made of particularly hard stone are likely to have been the most common tools, with or without the help of other materials (Arnold 1991: 33–6; 258–64). In the case of soft stones, the use of copper chisels has been postulated (Klemm 1988); as for hard stones, the old assumption that wooden wedges were used to detach blocks from the bedrock has recently lost consensus (Aston, Harrell, and Shaw 2000: 7). Metal chisels and wooden mallets were certainly employed to dress stone blocks (Arnold 1991: 257–8), whilst the final polishing of vessels and statues was achieved by rubbing their surface with hard stones (Clarke and Engelbach 1930: 197–9).

9 Producing Objects

Pottery

From earliest times pots of various shapes and functions were commonly used to store and transport food, beverages, offerings, and precious materials. Pottery was so ubiquitous and widespread that, in terms of volume, it represents the largest find of any archaeological excavation (Bourriau, Nicholson, and Rose 2000: 144). The importance of pottery as a potential guide through ancient chronology was already understood in the late nineteenth century (Petrie 1901: 4–8; 1920: 3–4); the way in which it was studied, however, remained virtually unchanged for nearly a century, until a wave of modern studies (e.g., Bietak 1968; Nordström 1972; Holthoer 1977) gave life to a new approach to the subject (Arnold 1976; Arnold and Bourriau 1993). Great attention is paid nowadays to recording the properties of the fabric, conventionally divided into "Nile silt" and "marl" clays: the former come from deposits left by the river over the millennia, and produce red to brown pots; the latter come from calcareous deposits and produce creamy white to greenish pots (Bourriau, Nicholson and Rose 2000: 121–2; 129–35).

A careful study of the aspect of the pot or its fragments (see, for example, Bourriau, Nicholson and Rose 2000: fig: 5.4) allows a better understanding of the criteria that guided the choice of the raw material and of the method originally used to shape it. After soaking and trampling the clay (Holthoer 1977: 11–13; Arnold 1993: fig. 3a), a varying amount of coarse material was added in order to improve the resistance of the final product to thermal shocks, a particularly useful characteristic in case the pot was meant to be used as a crucible, a cooking vessel, or a water cooler (Woods 1986; Arnold 1985: 23–9).

The earliest method for shaping a pot was by hand, either with the help of a spatula (cfr. Nicholson 1995), or by joining together coils or rings of clay (for instance, Bourriau 1981: 18), with or without the help of a turntable. Pots might also be moulded, or thrown from a wheel, a technique introduced in the Fifth Dynasty which rapidly became the most commonly used (Hope 1981; Arnold 1993: 41–79; Powell 1995). The pots were then fired either on bonfires, or in the more controlled environment of up-draught kilns, and then left to cool until ready for use (Soukiassian et al. 1990: vii–xii, 49 onwards).

Basketry and textiles

Whenever pots were not specifically required, the ancient Egyptians made large use of baskets. The most important materials for making baskets and mats were palm leaves and grass; reeds, sedges, and rushes were also employed to make brushes, boxes, coffins, pieces of furniture, and sandals (Greiss 1957; Wendrich 2000: 254–5). Baskets for daily use were probably made by women within the household, whereas more elaborate specimens were produced by specialized workshops held by men (Wendrich 2000: 265).

Several basketry techniques dating to the Predynastic and the Pharaonic Periods have been identified, including coiling (the best for producing strong baskets, widely used from the earliest period, carried out in at least nine different patterns), twining (in at least six different patterns), weaving, plaiting, looping around a core, knotless netting, piercing/sewing, and binding. The only tools required to make a basket were a needle and a knife, whereas mats, woven in at least six different patterns, required a relatively simple loom (Wendrich 2000: 255–62).

Basketry and textile techniques are contiguous areas, the main difference being that basketry is made with short and often irregular components, whilst textiles are made of long and uniform yarns (Wendrich 2000: 254). The most common material for making textiles in Pharaonic Egypt was flax, followed by sheep's wool and goat hair. Flax was harvested according to need: the younger the plant, the finer would be the final product. The plants were pulled out of the soil and dried, the seeds were removed, and the inner fibres were extracted and then twisted together to form a long thread. The latter task was not simple and depended on the length of the fibres; it required at least three different progressive steps and might be performed with at least three different techniques (Vogelsang-Eastwood 2000).

Two basic types of looms are known from ancient Egypt: the ground (or horizontal) loom and the vertical (or fixed-beam) loom (Roth 1951; Barber 1991: 83–91 and 113–16). Archaeological evidence shows that textiles were sometimes dyed yellow, orange, brown, blue, and red or with a combination of the latter producing a purple color, but many details on dyestuff and dyeing methods still remain unclear (Vogelsang-Eastwood 2000: 278–9).

Metal, glass, and faience

Metal and glass work are two cases in which the ancient Egyptian ability and competence clearly emerge from the quality and characteristics of the surviving objects; at the same time, though, our understanding of the ancient methods and techniques is still patchy and depends almost entirely on modern chemical and physical analyses, as no ancient sources inform us on how the raw material was found, collected, and worked.

Even if we do not know exactly how hidden metal deposits were located, the Egyptians appear to have been rather systematic in their exploitation (Shaw 1998; Klemm and Klemm 1994). The ores were either treated at or near the mines, or brought to town to specialized working areas. The local availability of fuel must have played an important role in this decision, as high temperatures were required both for smelting the ores and for melting the ingots (Ogden 2000: 148, 157). Copper might be either hammered out into shape or molten and cast into moulds; gold, on the other hand, was either turned into a sheet and then cut, or cast and then refined by hand (Scheel 1989; Ogden 1992).

Apart from using the various metals separately, the Egyptians were also quite skilled in producing alloys with specific physical or aesthetic characteristics. For instance they added lead, oxide, and sulphide ores to copper to lower the melting temperature, and tin or arsenic to increase its hardness (Ogden 2000: 152–5); gold was generally mixed with varying quantities of silver to produce electrum of various shades, or with copper to obtain a reddish color (Ogden 1977; 1993).

Glass, considered an artificial precious stone, was deliberately produced in Egypt from the Eighteenth Dynasty onwards, when the working technique was probably imported from the Near East (Smith 1928: 233; Oppenheim 1973: 263). The main components of glass are silica, an alkali (which would considerably lower the melting temperature), and lime (acting as a stabilizer). The color depended on the addition of other substances, such as cobalt, copper, tin, manganese, antimony, and iron (Nicholson and Henderson 2000: 201–2).

There has been a long debate on whether the Egyptians imported ingots of glass from the Near East and simply worked them into the desired shape, or whether they started from the raw material. In the latter case, it is likely that glass was produced in stages: the components were ground, mixed, and heated to the point of fritting (but not melting), then cleaned of foreign particles and debris. Recent experimental archaeology proved that efficient furnaces might have allowed the glass-makers to avoid the fritting stage (Nicholson and Henderson 2000: 197– 202). Melting would have been the next step; in order to improve the quality of the glass, which would have been full of trapped bubbles of gas, it might have been necessary to grind and melt it several times (Petrie 1894: 25–6). Once the glass was ready, some objects were carved as if they were made of stone; others were probably made by progressively adding powder material into a heated cast; some vessels, on the other hand, were created by thickly covering heated cores of clay with glass powder, and then by removing the interior once the object was cold (Nicholson and Henderson 2000: 202–4).

Evidence from Amarna and Qantir (Nicholson 1995; Pusch 1990) clearly indicates that the same industrial areas hosted the production glass, faience, and blue pigment: these materials share two important characteristics, the necessity for high temperatures and the use of cobalt, a material not readily available which was most probably under strict state control. The overall impression is that glass and faience were part of a more general industry of vitreous materials (Nicholson and Henderson 2000: 204–5). The continuity between glass and faience is mainly due to their extremely similar composition, both being a mixture of silica, lime or soda, and an alkali. Different proportions, though, produce different results: in faience, the larger quantity of silica and the lower firing temperature produce a crystalline material (Nicholson and Peltenburg 2000: 187). The working technique appears to have been significantly different, to the point that faience-making may be considered more similar to stone-working than to glass-making (Peltenburg 1987: 20).

Many details of the faience-making process are still unclear: its paste is difficult to handle, and the binding agent that was used to keep it together is still a matter of debate; shaping might be achieved either by modeling the object by hand and refining it by abrasion, or by pressing the paste into a mould and then firing it (Nicholson and Peltenburg 2000: 188–9). Three different methods of glazing the surface are known (efflorescence, cementation, and application); however, it is often difficult to understand which method was used, not least because the various techniques might be used in combination with one another (Vandiver 1982).

Firing was evidently carried out in kilns, but our knowledge of many important details (such as shape of the kiln, temperature achieved inside, type of fuel that was used, shape and material of the supports that were used inside) is still vague (Nicholson and Peltenburg 2000: 191–2). New excavations focused on ancient working sites are likely to yield important evidence; furthermore, this is a typical case in which experimental archaeology may play a fundamental role in enhancing our understanding of the ancient technological process.

10 Conclusions

Our knowledge of ancient Egyptian science and technology is likely to increase in the near future thanks to a new wave of studies. A careful re-evaluation of the available sources is likely to produce extremely interesting results, and the development of our modern technology allows a growing number of new analyses of ancient remains and artefacts. In general, therefore, our understanding of both fields can be expected to grow dramatically and at a steady pace.

FURTHER READING

On mathematics see Clagett 1999, Imhausen 2002, Ritter, 2000. For astronomy consult Neugebauer and Parker 1960, 1964, 1969, and Symons, 2007. On medicine see Allen, 2005, Ikram, and Dodson 1998, and Nunn 1996. Biology is well covered by Houlihan 1986, Brewer and Friedman 1989, Osborn and Osbornova 1998, Ikram, 2005b, and Manniche 1989. On Earth Sciences see Harrell and Brown 1992. Nicholson and Shaw 2000 provide an excellent introduction to Technology.