CHAPTER TWO

Practice and Experiment: *The Conquest of Matter*

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EGYPT

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In his book *Isis and Osiris*, the Greco-Roman philosopher Plutarch, writing about 100 CE, proposed a synthesis between Platonist philosophy and Oriental wisdom (Pleše 2005), explaining the presence of natural elements in Egyptian thought in passages dealing with physical myths. In the first excerpt (Plutarch, *De Is. et Os.* 36, 365C: Froidefond 1988: 209), the first element is the humid substance, or "emanation of Osiris" (*Osiridos aporroēn*; Plut. *De Is. et Os.* 36, 365B: Froidefond 1988: 208–9), equivalent to the Egyptian "humours of Osiris" (*redjou Ousir*; Pantalacci 1982; Kettel 1994; Nardelli 2017: 408). This element and the other three elements (earth, air, and fire) would have had the power to autoregenerate. A second excerpt relates a war that had broken out between Zeus-Amon (Breath or Air) and his brother Apophis (Dry or Igneous, different from the Sun). Osiris (Moist) chose to side with Zeus. After defeating Apophis, Zeus not only adopted Osiris as his son but also gave him – a perfect example of *interpretatio Graeca* – the name of Dionysus. Thus, according to this excerpt, it would follow that the association of Air and Moist prevailed over Dry and Igneous, with Earth in the background. In a third excerpt from the same book (Plut. *De Is. et Os.* 7, 353E), the sea of the Egyptians, considered isolated from the rest of the world, was perceived as a foreign, corrupt, unhealthy, salty body like that represented by Apophis-Typhon.

Plutarch's conception was not isolated in Egyptian thought. Manetho of Sebennytos, an emblematic character created during the Ptolemaic period that probably inspired Plutarch's discussions, evokes a system in which five elements were symbolized by divine names. Thus, Fire was Hephaestus (Ptah), Water Ocean (Noun) or Nile (Hapy), Air Athena (Neith), Earth Demeter (Isis), while a fifth element, Spirit, was Zeus (Amon; Waddell 1980: 196–7).

However, if Plutarch's and Manetho's views were meant to show that the traces of elements mentioned in Egyptian thought were equivalent to those found in Greek philosophy, this did not necessarily imply that this notion corresponded exactly to that of the Egyptians. Whereas the ancient Greek philosophers argued for a terrestrial realm consisting of four elements (Fire, Water, Air, Earth), ancient Egyptians preferred a nomenclature consisting of elements of the universe over which the gods had an influence, for instance: "Sky, Earth, Water, Mountains" (*Wb* V, 213, 4; Barucq and Daumas 1980); "Sky, Earth, Hellish world, Water, Ether" (Cauville 2009; *Edfou* IV 309); or "Sky, Earth, Hellish world, Mountains and Oceans" (Agut-Labordère and Chauveau 2011: 23, 26).

The concept of kingdoms, in the Western sense of mineral, vegetable, and animal, is hard to discern here, as the Egyptian priests thought in terms of up to five classifications. Moreover, the ancient Egyptian classification of kingdoms was a more extensive and variable one, like the one depicted on a bas-relief engraved on the plinth of the door of the East sanctuary of Amon-Rē's temple in Karnak (Aufrère 1991: 307–9). According to the caption, this bas-relief represents animate beings in prayer before the king of the gods, Amon-Rē, represented in its solar form circulating in the celestial vault. The gods (*netjer*), the humans (i.e. the Egyptians; *remetj*), the plebaians (*rekhyt*; Griffith 2006), the trees (*nehet*), and last, combined in a pair, the herbs (*sem*) and stones (*iner*) appear successively. The last three are shown with both arms.

The priests of Amon-Rē – the king of the gods – in Karnak conceived a nomenclature consisting of five classes of kingdoms over which he reigned: divine, human, servile (perhaps also animal), ligneous, and herbomineral. On the basis of an identical growth process, the last two represent a double paradigm, recalling for us that the Middle Ages inherited a tradition of giving the same status to herbs and to stones. While there are even more extensive models for classifying beings, which differ from one document to another (Meeks 2012), this vision is significant for classes of substances considered, religiously speaking, as noninert and endowed with a life of their own, being the subjects of a particular ontological conception.

The nomination and determination of the terms in the hieroglyphic system made it possible to identify concepts relating to matter and its transformations. The hieroglyphic system, combining images of sounds and pictures, enhanced a more comprehensive interpretation of their meaning. If the Egyptian words consist of a skeleton of consonants using phonograms (the Egyptians had a wide range of strong to weak consonants represented by uniliteral, biliteral, or triliteral values), a wide range of classifiers, technically called "determinatives," specify the semantic class to which they belong and their concrete or abstract character. In addition, word signs or ideograms combined the two former functions by attaching a sound to a classifier. A vast vocabulary contained references relating materials and substances to elements and kingdoms.

Moreover, by its very nature the hieroglyphic system enabled the reader to visually perceive the texture of the materials. In fact, to make their intrinsic nature more explicit, a range of determinatives provided access to information about the characteristics of the material used, such as its appearance, its state (liquid, dry, solid, or gaseous), its temperature, the mass or texture of the substances used, the mode of packaging, and even their mode of manufacture. In the absence of a rigorous spelling system, each scribe, depending on his degree of language proficiency, could add a panel of semantic nuances. It is therefore important to examine more closely the interpretation of the most common hieroglyphs in order to obtain valuable clues. For example, placed at the end of the phonetic skeleton of a term, one grain or three grains, or even the group such as, indicated their powdery, fragmentary, or granular character. This is the case for a detrital rock such as sand (*sh'ā*), for an oleoresin such as frankincense (*'ānty*), for a mineral substance such as natron (or niter; *neter*), and also for dry fruits. The viscous or oily nature of a substance resulting from an amalgam of products, such as "oil" (*merehet*), was indicated. The same applied to minerals, dyes, chemicals, and drugs. The same classifier could also be used for the word "metal" (*bia*), which could be broken down by the addition of epithets for various types of metals such as "native copper" (*bia-her-khaset.ef*, literally "the metal on its desert"), "Asian copper" (*bia-Setjet*), "black bronze" (*bia-kem*), or iron, which was called "celestial metal" or "metal of the sky" (*bia-en-pet*).

However, if it was important to insist on the weighty nature of a material, the hieroglyph signified this by the squared stone block ready to be transported: . The word "stone" (*iner*) was used more for building stones than for minerals. The exceptional character of a stone block was connoted by a wooden sledge on which was fastened a squared block sliding on a skidding ramp: , a hieroglyph that suggested the idea of a "finding," of a "marvel": (*biaou*), as if it were an exceptional stone block spotted and drawn from a mineral vein. It will be observed that the notion of "weight," "to weigh" – for example, "to be heavy" (*denes*) or "a block of heavy stone" (*oudenet*) – combined two hieroglyphs: the pestle hitting a material in a block of stone (*supra*) or not in stone. The hieroglyph of the stone block could sometimes be represented by a grain, because the word designating "a small stone, a pebble" was indifferently written or (*'ār*).

In those distant times, when mineralogy was not yet a discipline, a wide range of rocks and minerals were all designated by the same hieroglyphic word or (*'āat*), which even embraced resins used to make beads (Aufrère 1991: 101–4). Such rocks and minerals included what we now know as igneous (granite, porphyry, diorite), sedimentary (limestone, greywacke, sandstone, shale), metamorphic (gneiss, quartzite, shale), or metamorphosed (marble, schist, gneiss), as well as minerals (alabaster, calcite, travertine), all of which substances were used to make statues, precious items (coffins, naos), and vases (an exhaustive list of Egyptian mineral products is given by Aston et al. 2000: 21–63).

Concerning metals, there were several signs evoking the shape of the crucible used to melt and pour the molten ore into a mold: , , , etc. Thus, the word "metal" was written , (*bia* or *hemet*), but the writings could vary, showing an ax-head () or a mold and an ax-head (; Aufrère 1991: 449–50).

The designations of liquid substances were frequently accompanied by either the determinative for liquid (), used to represent the word "water" (*mou*) itself, or by various containers made of ceramics or of rocks or minerals, the shapes of which connote the products they contain. For example, the abbreviated word for "oil" (*merehet*) was represented in the form of a cylindrical travertine or alabaster/calcite pot and only used to contain oils or fatty ointments (see Chapter 8). The word "natron" or "niter" (*neter*) was represented by an ideogram combining two hieroglyphs: the sign of the god – a mast () – and a prospector's leather bundle (; Aufrère 1991: 606–7).

The name of a vegetable substance was characterized by the determinative for herbaceous plants (), a species of tree by the silhouette of a sycamore (), and a woody material by a branch (). The combination of two or three determinatives increased the degree of semantic precision of the written word.

Whereas the name of a basic product was culturally unambiguous in its local context, the contents of exotic substances had to be specified by their origin and intrinsic quality. Indeed, their potential liturgical role had to be identified according to appearance, color, and smell. These specifications were frequent in lists of aromatics exported from Punt (i.e. the littoral of southern Arabia and the Horn of Africa) and from Asia. They were in conformity with a mytho-scientific model associating information of a religious and physical nature and their affiliation to a kingdom, a genus, or a species. The mythical origin of a variety of styrax, its appearance, and its smell were thus specified:

> The *gaiu-maa* tree, here is what is said about it. Its "variety" is blackish woody, with a pleasant smell. It comes from the pupil of Rē's eye. Its upper extremity is black, its middle part is grey, and its lower extremity is as clear as the resin

> of the terebinth tree precipitated on its trunk. When its flank is incised, it takes on the golden color of the wing of the oriole. (Gloss :) Concerning the oriole, it is the *tefnyt* bird (the bird of the goddess Tefnut) with striped gold-colored wings. When scratched, the smell is that of the *tishepes*.
>
> (Aufrère 2005a: 256–7; Incordino 2017)

Colors are often named according to the external appearance (liveries) of living creatures or of products with stable colors (Bardinet 2018). Such precision about substances clearly indicates that the exotic unknown was associated with the diversity of the known materials from the Nile valley.

From the Second Dynasty (2925–2700 BCE) onwards, the Egyptians indicated on the funerary steles – and later, in the Middle Kingdom, on coffins – the list of products for daily use of the deceased, some made with different manufacturing processes (Barta 1963). Thus, on the stele of Princess Nefertiabet (Louvre Museum, inv. no. AE 15591), Fourth Dynasty (2625–2510 BCE), pieces of meat and various types of fruits are depicted alongside perfumes, cosmetics such as the resin of the terebinth tree (*senetjer*; Loret 1949; Espinel 2017), high-quality oil (*hattet*) perfumes, different kinds of pigments such as chrysocolla (*ouadj*) and galena (*semdet*), alcoholic fermented beverages (i.e. beer [*sekhepet*] and wine [*irep*]), and bread of different shapes showing the rising of the dough and the nuanced colors of the baking. Naturally, these lists became ever longer as the standard of living of the aristocracy improved.

Furthermore, a literary genre – the *onomastica* – appeared, attested from the Middle Kingdom until the second century CE, in several papyri (*Papyrus Ramesseum*, *Papyrus Golenischeff*, *Papyrus Hood*, *London Leather Roll*, and *Tebtunis Papyrus I*), giving a didactic nomenclature of the universe. The incipit of the book written by Amenope (*London Leather Roll*) refers to this nomenclature in these words:

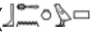
> Beginning of the teaching to clarify the memory, to educate the ignorant and to learn about all that exists: what Ptah created and Thoth copied, the sky and all that concerns it, the earth with what is inside, what mountains spit, what is flooded by the flow, anything that illuminated Rēʻ, all that grow on the back of the earth, everything written by the scribe of the *Sacred Book* in the House of Life, Amenope son of Amenope.
>
> (Gardiner 1947, 1: 1*–3*)

Some chapters of this document allow us to better understand the nature of cereals and other solid and liquid products used to make beverages, but the contents of other chapters – "the earth with what is inside, what mountains spit" – are missing. However, the *Tebtunis Papyrus I*, in which whole sections of Egyptian artisanal culture are fortunately preserved, gives more information. Indeed, in addition to chapters dealing with the diversity of the animal kingdom, other chapters provide information on the characteristics of minerals, on quarries, on mountains and the products of the mines (fr. J, 21,1–22,6; Osing 1998: 107–10), on leatherwork and basketry (fr. N 6,22–9,2; Osing 1998: 120), on wooden utensils, and on various plants (fr N 1–6,21; Osing 1998: 116–20). In the *onomastica*, Egyptians could view the full spectrum of artisanal activities and production.

Despite the small-scale output of mining operations (Aston et al. 2000: 5–20) and of the harvesting of aromatic plants, as testified to in the texts dealing with mines and temples, extracting any substance of high symbolic and religious value was seen as breaking into a universe with a strong original and divine footprint. Indeed, breaking into the vast, desert-like, and uninhabitable expanses stretching from Egypt to the boundaries of the Red Sea suggested a relationship between the distant geological upheavals in that area and the time when, according to legend, the gods lived on earth. It is reasonable to assume that in order not to offend the gods the extraction of materials from these divine spaces encouraged piety on the part of the prospectors (Aufrère 2008). This was according to a widespread belief that the gods had left, from a poetical point of view, their emanations in mineral veins as well as in gum resins (myrrh and frankincense) resulting from the tapping of the bark of the tree. According to the Edfu texts, these gum resins were considered to be the tears of gods and goddesses taking the form of divine hawks (Aufrère 2017a). Even if it only meant returning the product to the rightful owners of the land, the opening of mineral veins was ritualized to counter unexpected dangers and to obtain the best quality and the highest possible quantity of material (Loret 1928; Kurth 1996; Pantalacci 1996: 87–91; Valbelle and Bonnet 1996).

In extracting and refining techniques there were two distinct phases: in the first, physical means (sieving) were used, and in the second, dealing with ores, a refining procedure exposed the sorted material to a high temperature. Depending on their qualities, the collection of minerals proceeded by sorting and then crushing and washing – as was done for the argentiferous galena of the Gebel el-Zeit (Castel and Soukiassian 1989). Indeed, for obvious reasons of weight, the ores and minerals extracted from the subsoil of the desert adjacent to the Nile valley could not be shipped. The technique of gold extraction is now better known thanks to the study of the Bir Samut mines in the Eastern Desert. The gold ore came from two types of deposits: gold-bearing quartz veins and alluvial gold veins from adjacent wadis. Alluvial gold was simply sieved.

According to Agatharchides of Cnidus (second to first centuries BCE), the gold-bearing quartz was crushed and milled by millstones (Diodorus Siculus, *Bibl. Hist*. Book 3, 12–48; Peremanns 1967; Redon 2016; Faucher 2018). The heavier gold flakes remained on the inclined planes of the washing units.

Archaeology has uncovered traces of important mills dating from the second half of the third century BCE. On account of the lack of local fuel, the purification of the precious metal was carried out in the valley after melting at 1064°C (Rabot and Goncalves 2015). This traditional seasonal way of exploiting the mines, using less sophisticated techniques, peaked twice in the Eighteenth Dynasty (1552 and 1314–1295 BCE), respectively in Samut el-Beda and then in the Greco-Roman period in Samut. Mineral resource maps of the Eastern Desert were kept in the royal and priestly libraries. Preserved today in the Egyptian Museum of Turin, the map of the gold mines (i.e. the map of Wadi Hammamat dating from the reign of Seti I [1294–1279 BCE]), shows the location of the gold and greywacke, also known as "stone of *Bekhenu*" ( *bekhenu*; Goyon 1949; Sauneron 1967: 143; Baud 1990).

As for copper ore, it may have been available in significant quantities in the Sinai desert, in the Eastern Desert, and in Sudan, but there are few documented traces of its exploitation throughout Pharaonic Egypt. Analyses show that the Egyptians were probably supplied with copper and tin from the ports of the Levant, including copper containing a high percentage of arsenic (8 percent; Garenne-Marot 1984; Garenne-Marot 1985). Following the classical reduction process, the objects manufactured with that copper (Garenne-Marot 1984; Garenne-Marot 1985) were rubbed with an ointment made of a mixture of realgar and orpiment, giving them a silvery shine.

It is only on the site of Bir Nasb, west of Wadi Nasb, in South Sinai, that this activity is testified to by the presence of slag (traces of reduction of the copper ore) and of multiple batteries of furnaces (3,000 in all) in which the temperature could be brought up to a maximum of 1334°C, a temperature necessary even today to obtain copper from malachite. This quasi-industrial-scale production by Egyptian metallurgists in the Old Kingdom (Fifth Dynasty, 2510–2460 BCE) was due to the availability of local fuel in sufficient quantity (Tallet 2000: 19–22; Castel et al. 2008; Tallet et al. 2011; Tallet 2013–18). However, there is no trace of tin mining in Egypt, despite the presence of an association between gold and tin ore, testified to by a number of bronze objects found in the area of the Eastern Desert. From the Middle Kingdom on, tin was probably imported from the Eastern Mediterranean shores (Garenne-Marot 1984: 107–8), while it was always exported during the Achemenid Period (Briant and Descat 1998: 67).

Apart from a few exceptions, the metal refining and casting processes were carried out in the Nile valley, where fuel, namely charcoal, was readily available. While craftsmen in most towns of the Nile valley met the requirements of daily life, capital cities like Memphis, Thebes, or Pi-Ramses had specialized industrial centers. Archaeology and iconography show this concentration of techniques and work to be of Levantine heritage. Excavations in the area of the temple of Amon at Pi-Ramses revealed the presence of copper casting facilities contemporary with the Nineteenth Dynasty (1295–1188 BCE).

To optimize mass production, craftsmen of all trades such as charcoal producers, potters, tanners, wax sculptors, and molders, all very hierarchical, were comprehensively reconfigured (Pusch 1994; see Garenne-Marot 1985; Hampson 2012: 187–230). The manufacture of weapons (swords, knives, arrows, spears, and chariots of the New Kingdom), requiring the mastery of the art of metallurgy (copper, bronze, and iron), was done in Memphis, renowned for the operations of its arsenal (*Pa-Khepesh*; Sauneron 1954) in the Eighteenth and Nineteenth Dynasties. As imported metals – copper, tin, and bronze – were available only through authorized intermediaries, it was important to recycle and recast worn copper tools and other metal fragments, thus avoiding their theft (Valbelle 1982; Allam 1997: 6: Pap. Geneva, inv. no. 15274 v° 1). In view of their importance, goldsmithing and the welding of other materials (Vernier 1907; Hampson 2012: 141–70) will be discussed in Chapter 8. The solder for gold was made using chrysocolla, but the use of silver-on-bronze welds is suspected (Evrar-Derrick and Quaegebeur 1979: 30).

Large granite and granodiorite blocks (Aston et al. 2000: 65–6) for obelisks or statues (Aston 2000: 35–8) were quarried and worked by thermal expansion of surfaces. First weakened by hot embers and then altered, after thermal shock, these surfaces were hammered with dolerite (microgabbro) balls, often equipped with handles, on the still hot surface, before polishing it. This technique was used in addition to that of the mortises – that is to say, notches specially made to receive bronze wedges, which, when hammered, made it easier to cut granite blocks (Goyon et al. 2004: 285–9; Hampson 2012: 271–90; Gremilliet and Delangle 2017).

The manufacture of ceramics is one of the fire arts that best attests to the mastery of various techniques that spread over time. Two types of materials were used: Nile clay (for ritual and domestic use) and limestone clay (to store food). Blocks of these materials were first crushed (to prevent the formation of air bubbles) and then rehydrated to make a malleable paste. Slips were used to nuance the color of the paste, and vegetal and mineral degreasers were used to strengthen its resistance to heat. The sophistication of turning pottery (by using the potter's wheel instead of more rudimentary methods like turntables) and the control of the entry of air into the ovens led to the production of black and red ceramics. These techniques were invented and applied during Nagada I period (3900–3500 BCE; Arnold and Bourriau 1993; Bourriau et al. 2000).

Plaster, obtained by burning gypsum (Goyon et al. 2004: 70–1), and mortar (plaster mixed with sand) are attested in the construction of the pyramid of Giza. These had previously been used to fill irregularities in graves dug in the rocky walls (limestone or sandstone; Goyon et al. 2004: 71). Plaster was also used for coatings (Goyon et al. 2004: 73–4) and to make funerary masks. Significant deposits of gypsum existed in Northern Egypt and in the Suez Isthmus. Others were exploited in the desert at Umm es-Sawwan, near the Fayoum. The gypsum was extracted using hewn flints (Kemp 2005: 318, fig. 111). Lime is obtained by firing the purest calcite available (e.g. limestone) to a temperature of 1000°C. The increase in temperature leads to the release of carbon dioxide and the formation of the product quicklime (calcium oxide). When water is poured onto the fresh quicklime, it becomes very hot, and hydrated (slaked) lime is obtained. Mortars made of slaked lime with added plaster were not used before the Twenty-Sixth Dynasty (ca. 600 BCE; Goyon et al. 2004: 74). Quicklime was used in Roman times to burn corpses in order to stop an epidemic of plague (third century CE). Traces have been observed in the tomb of Harrua (excavations of Francesco Tiradritti). It is likely that this quality of quicklime was associated by the Egyptians with a divine mechanism.

Several glass-like glazing techniques coexisted. The frit or sintered-quartz ceramic, attested from the fifth millennium BCE to the Late Period, was also called "Egyptian faience." The making of "faience" results from the use of different glazing techniques that varied over time and were used to make several types of objects. Its Egyptian name was *tjehnet*, "brilliant, lustrous" ( ). The process consisted of molding objects (figurines, beads, amulets, seals, instruments) made of a siliceous core of fine ground quartz, slaked lime, copper oxide, and sodium carbonate (natron) and submitting them to high temperatures. During the heating, oxides migrate to the surface, which start to melt and form a glaze while the core remains hard and porous. The copper oxide yields a color ranging from green to blue, depending on the temperature reached (Vandiver 1998). Other oxides were used to decorate the objects. Pigments – some synthesized – were strongly associated with precious metals and noble minerals (Aufrère 1998b; Aufrère and Menu 1998; Mathieu 2009), which they imitated. They required elaborate manufacturing processes (Rouchon et al. 1990; Colinart and Menu 1998).

Since blue could not be made with lapis lazuli or turquoise for reasons of expense, as these were high-value imported products, from the Fourth Dynasty (2665–2510 BCE) on Egyptians produced an artificial blue pigment "synthesized by cooking in a closed cup, a mixture of sand, lime, a copper compound and perhaps an alkaline flux," yielding a product with the modern formula $CaCuSi_4O_{10}$ (Blet et al. 1997: 121; Matoïan and Bouquillon 2000). The manufacturing process of this artificial lapis lazuli blue, now called Egyptian blue, is not mentioned in Egyptian texts. It has successfully been reproduced in the laboratory of the Louvre (Pagès-Camagna 1998). This artificial product was called *irtyu* (; *Wb* I, 116: 11), which, etymologically, signified "the artificial product." However, Egyptian inscriptions also differentiated the "true lapis lazuli" (*khesebed ma'āt*) from "artificial lapis lazuli" (*khesebedj iryt*; Delamare 2007: 18–28). The name "maker of lapis lazuli" (*iru khesebedj*) appeared in the New Kingdom (*Wb* III: 334). While in the Old Kingdom the blue–green range was obtained with the help of copper oxide, it is in the New Kingdom that cobalt blue was invented (Tite et al. 1998). Its use is attested as far away as in Scandinavia (Varberg et al. 2015). It was called "Alexandrian blue" in the Roman period (Delamare 1998a; Delamare 1998b) and *cæruleum* by Vitruvius (VII 12).

Antimony and manganese oxides were used to outline details in yellow and black, respectively. First used in the Middle Kingdom, green glaze ( *hemet*), a name connoting the idea of "crafts," imitated turquoise. Under the reign of Amenothep III (1411–1352 BCE; Tite and Bimson 1989), it was employed to coat minerals such as the soapstone used to manufacture statuettes and beetles to make them resistant to high temperatures.

There is little evidence that glass craftwork could have reached Egypt before the New Kingdom. Small containers made of lapis lazuli-colored glass paste (a material probably called *khesebedj oudjeh*) enriched with a feather-like decoration (plumeti) are attested in the aristocratic milieu as early as the reign of Thutmosis III (1458–1425 BCE), a time that corresponds to the political and economic expansion of Egypt toward the Levant, from where this technique originally came (Lilyquist and Brill 1993). Three glassmaking workshops are known: one workshop in Tell el-Amarna (ca. 1350 BCE); another in Lisht (Smirniou and Rehren 2016: 57–8); and one in Qantir-Pi-Ramses, in the Eastern Delta around 1250 BCE (Rehren 1997; Smirniou and Rehren 2016). In all three workshops, the primary material was obtained using a technique consisting of melting ground quartz pebbles heated to 900°C in the presence of vegetable ash in pottery and then, after removal of the slag, of heating to 1000°C in cylindrical ceramic containers to obtain round ingots of red glass colored with copper oxide, a technique requiring a high degree of control (Rehren 1997; Smirniou and Rehren 2016). Blue glass was obtained, as we have seen, using cobalt oxide, which was exported throughout the Mediterranean Sea basin. This production, which declined in the Twenty-First Dynasty (1096–945 BCE), experienced a final renaissance during the Twenty-Sixth Dynasty (664–525 BCE).

Tanning, currying, and dyeing processes used almost the same techniques (Vartavan 1998). According to archaeological evidence, tanning, which consists in stopping the natural process of degradation of the skin, required the use of urine, animal excrement, or alum for depilation and tannins obtained from acacia seeds (*Acacia nilotica* [L.] Delile 1813). The final touch was the cleaning of the skins with half-moon-shaped flint knives. Red, yellow, and green colors were usually used to dye leather (Lucas 1962: 171–86).

Egyptians wore linen clothing, the whiteness of which was obtained by subjecting it to the action of water, air, and light, followed by an alkaline wash. It was possible to dye the linen, but only with difficulty (Goyon 1996). The study of dyeing in ancient Egypt revealed the knowledge of processes such as using a mordant such as alum from the oases (Lucas 1962: 257–9) and iron acetate (obtained from iron nails dissolved in vinegar). The Egyptians had a long-standing tradition in this field. Egyptian dyeing processes reached such a high reputation that Pliny (*NH* XXXV 42) described as a singular process the mordanting process used by Egyptian dyers. The texts of Dendara referring to liturgical fabrics revealed the use of four substances – red, blue, green, and yellow – associated with the status of the goddess, highlighting the use of the scum resulting from the fermentation of crushed woad leaves (*Isatis tinctorum*). Indeed, the color changes from red to blue and green (Goyon 1980) depending on the level of oxygenation of the bath. Two other reddish tints were used by tanners: one for fatty substances, alkanet (*Alkanna tinctoria*); and the other for blood-red leather, madder (*Rubia tinctorum*), an imported plant (Loret 1930). The dyer's safflower (*Carthamus tinctorius* L., 1753), occasionally used in Egypt before the Roman period, had to be added to obtain a yellow–orange color (Mathieu 2009: 48 and n. 106; Newton et al. 2013: 13).

Cereals were stored in silos to keep them dry. Even in prehistoric times, techniques of watertight construction were sophisticated (Dachy 2014). Silos from the Thirteenth Dynasty (1785–1633 BCE), 5.5–6.5 m in diameter, were discovered in Edfu. For meat products (red meat, poultry, fish), open-air drying was used (e.g. fish were gutted and the heads cut off, sliced, and hung), but they could also be pickled or salted (salt and natron) and stored in jars. This will be discussed in Chapter 8.

Although cereal grains were first eaten as gruel, empirical observations led to the control of several processes discovered serendipitously: dough rose due to fermentation caused by adventitious airborne yeasts, which were also responsible for the alcoholic fermentation of beer (Doyen and Warmenbol 2004). On the names of different kinds breads and cakes, see Salavert and Tengberg (2005) and Schwechler (2017). Beer (*henket*) was made using ground germinated barley (*besha*; *Wb* I: 458, 10) mixed with wheat flour. The Egyptians had observed that using germinated barley turned it into malt and changed the taste. Indeed, we now know that germination triggers biochemical changes in the grain through the release of enzymes, which gives it new flavors. In addition, the observation of the fermentation of natural agents on the surface of the liquid in the beer jar led to the empirical discovery of fermentation. The name given of "brewer's yeast," literally "the one on (it)" (*herut*; *Wb* III: 148, 18), supports this observation. The Egyptians came to the conclusion that cereals were not inert substances, but possessed intrinsic powers that triggered processes such as fermentation (for bread and beer).

As for perfumes, the Egyptians had recourse to several techniques (Castel et al. 2012). The preparation of vegetable perfumes was particularly important. Batches of selected petals, replaced several times during the process, were placed in refined beef dripping to macerate. The oily macerated mixture was then filtered and the perfume obtained – technically a pomade – was packaged in flared cylindrical pots set with a palm leaf ().

FIGURE 2.1 Flared cylindrical perfume pots set with a palm leaf. Old Kingdom. Cairo Museum. © Sydney H. Aufrère.

It is possible that the famous lotus pomade may have been prepared in this way. When rubbed on the skin, hair, and clothes, pomades gave a feeling of freshness (Derchain 1975; Cherpion 1994). Another technique consisted in cold-pressing petals with a delicate fragrance in a cloth sack. This is how the lily perfume was obtained (Bénédite 1921). Many other sophisticated preparations using multiple ingredients and different cooking phases existed. For example, the Egyptian perfume-makers described that the gum resins frankincense and myrrh emitted their odors only when warmed by a charcoal flame.

MESOPOTAMIA

Cale Johnson

As recently as the 1960s, specialists in cuneiform could not agree on the linguistic identification of the five most important metals in Mesopotamian history: it was clear from studies of artifacts and several late examples of words written on the material they denote that the five metals in question were gold, silver, bronze, tin, and lead; however, only three could be securely equated to corresponding Akkadian or Sumerian words: gold (Akk. *hurāṣu* = Sum. ku_3.sig_{17}), silver (Akk. *kaspu* = Sum. ku_3.babbar), and copper (Akk. (*w*)*erû* = Sum. uruda). Benno Landsberger, by far the most important lexicographer in the history of Assyriology, tells the story of Victor Place's discovery in 1854, during his excavations at Khorsabad (ancient Dur-Sharrukin), of "a stone box containing seven inscriptions on tablets of different materials, (i) gold, (ii) silver, (iii) antimony, (iv) copper, (v) lead, (vi) alabaster and (vii) marble. The first four are currently in the Louvre, the other three heavier tablets fell into the Tigris" (Landsberger 1965, summarizing Lenormant 1878 and Delitzsch 1887). As several more recent investigations have shown, only five tablets were actually excavated (made of gold, silver, tin-bronze rather than copper, lead, and magnesite), and only the lead tablet was lost in the Euphrates (Bjorkman 1987; Brinkman 1988).

On nearly all of the tablets, the inscription includes the telltale phrasing "I wrote the spelling of my name on tablets made of gold, silver, copper, tin, lead, lapis lazuli and alabaster and placed it in their [the palaces'] foundation," giving us the final developmental stage of the placement of substances in foundation deposits in order to imbue the building with their properties (see Chapter 1). There is now a widespread consensus that Sum. an.na, read by some as Sum. nagga, corresponds to the Sumerian loanword in Akk. *annaku* "tin," while Sum. a.gar_5 "lead" corresponds to Akk. *abāru*. Due to the fact that tin was difficult to identify in the archaeological record, many objections arose against the identification of Sum. an.na with tin, but Landsberger brings together the relevant evidence for this conclusion, including several inscriptions, ranging from the Gudea Cylinders (ca. 2150 BCE), down to the Neo-Assyrian period (ca. 800 BCE), in which "copper" (Sum. uruda) is combined with "tin" (Sum. an.na) to produce "bronze" (Sum. zabar = Akk. *siparru*). Alloys between copper and

FIGURE 2.2 Three foundation tablets from Khorsabad, Assyrian from the reign of Sargon II (721–705 BCE; gold, silver, and copper). © Bridgeman Images.

lead do exist, but they were never widespread in ancient Mesopotamia or the neighboring region.

Recent surveys of archaeologically attested bronzes suggest that arsenic bronzes arose earlier, perhaps accidentally or through the selection of copper ores that already contained arsenic such as the arsenic-rich copper ores from the Amarak-Talmessi mines on the central Iranian plateau, while tin bronze, which must be a consciously formulated alloy, only begins to dominate in the middle of the third millennium BCE (Moorey 1994: 252–4; De Ryck et al. 2005; Potts 2007: 127; see, however, the discussion in Chapter 5). In the Late Uruk list of metal objects, three identifiable finished products predominate: "knives" (GIR_2), "drill bits" (NAGAR), and perhaps "scrapers" (NU). And as Englund and Nissen argued in their pathbreaking edition of the lexical lists, the primary metal used for these objects was almost certainly copper (Englund and Nissen 1993: 34; Englund 2006: 12). Within the list, however, ordinary objects in copper like GIR_2, NAGAR, and NU are contrasted with the same signs followed by the cuneiform sign AN, which may be related to the later orthography for tin (Sum. an.na): these entries probably refer to arsenical bronzes produced, if intentionally, through the selection of arsenic-bearing ores rather than the alloying of tin and copper (Englund 2006: 12, citing Waetzoldt 1981 against Vaiman 1982).

Until the discovery of the Ebla archive in 1974–5, relatively little progress had been made in making sense of tin bronzes in Mesopotamia. The earliest known cuneiform document to distinguish between copper and bronze (UET 2, 373) dates to 2900–2800 BCE or so, but the Ebla archive (dating to 2380–2333 BCE) presents us with the crucial evidence for tin bronze alloys (Archi 2017). The Ebla texts distinguish between two qualities of copper: "unrefined copper" (Sum. urudu) and "refined copper" (Sum. a.gar$_5$.gar$_5$, a neologism derived, through reduplication, from the standard Sumerian term for "lead," Sum. a.gar$_5$), whereas in contemporary southern Mesopotamia refined copper was termed "washed copper" (Sum. urudu luh.ha; see Waetzoldt and Bachmann 1984). Refined copper and tin appear in Ebla administrative documents in the 6:1 ratio that we might expect in a proper tin bronze (Archi 1993: 618, referencing the tablet TM.75.G.1310). The clearest evidence, however, for the alloying process used in the creation of tin bronze is found in an Ur III (ca. 2112–2004 BCE) problem text known as UIOM 892: it begins with the desired finished product, one mina (= 60 shekels or 500 g) of bronze (Sum. zabar), and then, line by line, sets out the ingredients and material losses that took place during the smelting and alloying of the materials (Jones 1961: 114; Waetzoldt 1981; Waetzoldt and Bachman 1984). The inputs are 56 shekels of refined copper (= 466 g) and 8 shekels of tin (= 67 g), giving a ratio of 7:1, but it also states the amount of material lost during the alloying process: 4 shekels (= 33 g, hence 56 + 8 – 4 = 60 shekels of bronze). The fact that the text begins with a single unit (Sum. 1 ma.na "mina" = 60 gin$_2$ "shekels") and goes on to separate out the individual elements shows its affinity with contemporary mathematical procedure texts, but we already have this type of schematic ratio in an Early Dynastic III administrative document from Girsu (RTC 23), where 80 shekels of refined copper are combined with 13 1/3 shekels of tin, yielding a slightly lower 6:1 ratio, designated as a "seven part mixture" (Sum. 7(diš*tenû*) la$_2$).

If "copper" (Sum. urudu) served as the prototypical base metal, the Sumerian word ku$_3$ "shining (metal)" was used to refer to precious metals, with the distinction between gold and silver made in terms of color: "shining yellow (metal)" (Sum. ku$_3$ sig$_{17}$ = Akk. *hurāṣu*) designated gold, while "shining white (metal)" (Sum. ku$_3$.babbar = Akk. *kaspu*) was used for silver. Ostensible gold objects from the Royal Graves at Ur, dating to the Early Dynastic IIIa period (ca. 2600–2500 BCE) have recently been shown to consist of varying percentages of gold and silver, almost certainly due to the co-occurrence of these two elements in nature; similar objects that required greater strength or durability also show substantial amounts of copper (Hauptmann et al. 2018). But soon after this, again in the Syrian city of Ebla (ca. 2350 BCE), we find careful grading and labeling of different qualities of gold, based on its relative value in comparison with silver (Waetzoldt 1985; Paoletti 2016a). Likewise in the Ur III period (ca. 2112–2004 BCE), gold was classified into three grades on the basis of its purity: "yellow brilliant gold" (Sum. ku_3.sig_{17} huš.a, valued at 15–21 shekels of silver for each shekel of gold, and often translated as "red gold"), "mixed gold" (Sum. ku_3.sig_{17} HI.da, valued at 10–15 shekels of silver), and "normal gold" (Sum. ku_3.sig_{17} si.sa_2, valued at 6.5–10 shekels of silver; Waetzoldt 1985; Paoletti 2016b: Hauptmann et al. 2018; Kleber 2019). The first decisive evidence for cementation (using vapors from salt or alum to convert silver into silver chloride and thereby remove it from molten mixtures of gold and silver) comes from an Old Babylonian period letter from Mari (ca. 1750 BCE), which reads, in part, as follows:

> Speak to my lord, thus [says] Mukannišum: "The four minas of gold [ca. 2 kg] for the two sun-disks that my lord has sent to me have been powdered. I have taken four shekels [ca. 33.3 g] for each of the four ingots[?], and I purified it in order to determine the fineness. Half a shekel and 10 grains of gold [= ca. 4.63 g] were lost from the four shekels of gold, that [means] 25 grains per shekel [= 13.9 percent] were lost. The goldsmith said "It [viz. the gold] is not red [*ul sām*]!"
>
> (Kleber 2019: 22; cf. Paoletti 2016a)

Here, a fire assay shows that the gold in question – once it is refined – will not be sufficient to make the sun-disks that the goldsmith has been asked to produce. The goldsmith describes the gold as "not red" (Akk. *ul sām*), demonstrating the continued use of "red" as a description of the highest-quality gold. Only much later, in the Neo-Babylonian period, do we see new terminologies arise for the testing of the quality of gold using a touchstone (Akk. *pidānu*), a loanword from Arabic or another language from the Arabian peninsula that enters the Akkadian alongside a distinctive term for Arabian gold (Akk. *nalṭar*; see Kleber 2016; Kleber 2019).

Few textiles other than linen and wool were regularly used throughout Mesopotamian history, and linen could only be dyed in a limited and rather specific way (Gittinger 1982; Dalley 1991: 120); therefore, much of the Mesopotamian textile tradition is based on an ever-growing interdependence between the production of textiles in wool and the dyeing of wool textiles with a wide variety of materials. Contemporary with the development of metal industries at the beginning of the third millennium BCE, we also see in Mesopotamia a so-called "fiber revolution," in which woolen textiles were produced on an industrial scale (McCorriston 1997). It was in the context of this revolution that methods of finishing and dyeing woolen textiles became a central area of technological development in Mesopotamia. Thanks to the unprecedented level of administrative detail preserved in the Ur III textual record, the production of woolen textiles in Mesopotamia is one of the best-documented economic sectors in all of antiquity. Texts like ITT 5, 9996 describe the processing of the materials for large 7 × 7 cubit textiles through several different stages of cleaning (Sum. za.ri$_2$.in) the wool, plucking it apart, airing it out and sorting it (Sum. peš$_5$), combing (Sum. $^{\text{giš}}$ga.rig$_2$ ak), spinning (Sum. U.NU), warping (Sum. dun.dun), and weaving (Sum. tag or tuku$_5$; Waetzoldt 1972). Once the weaving was complete, a distinct group of workers finished the textiles using a number of substances that are occasionally recorded in administrative documents such as ITT 2, 902+:

> (Five garments): the work-days required for them (equals) 195 work-days. The oil needed for it: 1 liter. The alkali: 5 1/2 liters. The string: 10 shekels.
> (Waetzoldt 1972: 158)

Based on Waetzoldt's work, Potts has described the work of the fullers as follows:

> It is estimated that 7.7 work days were required by the fullers to treat each kilogram of finished cloth. Depending on the type of cloth being treated, greater or lesser amounts of oil and alkali were needed, varying somewhat in ratio between 1:5.5 to 1:4 [i.e. oil:alkali] per kilogram of cloth.
> (Waetzoldt 1972: 159; Potts 1997: 95)

Different oils and fats, both vegetable and animal, two types of alkali (Sum. naga and Sum. naga.si.e$_3$), and substances such as "white earth" (Sum. im.babbar$_2$), "probably fuller's earth" according to Potts, also played important roles in the work of the fullers (Potts 1997: 106; Wasserman 2013: 266). What is usually termed "alkali" is actually ash from an alkali-bearing plant, such as *Salsola kali* or *Salicornia*, which was mixed with oils or fats to make soap, while "white earth" was presumably burned and crushed gypsum that was rubbed on cloth as the last stage in the fuller's work (Forbes 1965: 85; Firth 2011). Other materials, such as barley for the brewing of a kind of beer for soaking garments (Akk. *mihhu*) and a type of alum called Akk. *allaharu*, appear in the texts as well, but there is no trace, in Mesopotamia, of using sulfur fumes as a bleaching agent.

Unlike the work of the fuller, the production of linen from flax does not seem to have involved any major chemical processes in Mesopotamia, but leather was a different story: many of the same materials that were used for finishing cloth or dyeing linen are also found in the tanning of hides and the finishing of leather. Stol's entry for "Leder (Industrie)" (1983) in the *Reallexikon der Assyriologie* outlines two methods of depilation and tanning: "a 'primitive' method involves using salt, sour milk or flour to remove the hair, and pomegranate skins or plant roots to perform the actual tanning. The 'industrial' method uses calcium [i.e. lime] to take off the hair, and gall nuts, oak bark, sumac, or alum for tanning" (Pott 1997: 96). Both of these techniques are attested, to a limited degree, in cuneiform sources, but in the two recipes we have for tanning leather (one for making a leather poultice, for medical purposes, out of goatskin and the other for making a drumhead out of steer hide), only the later method, involving "madder" (Sum. giš/u$_2$.hab = Akk. *hūratu*) and, as its mordant, "alum" (Sum. im.sahar.na$_4$.kur.ra = Akk. *gabû*) is used. The hair was removed using a milky liquid made with fermented flour known as Sum. a.gar, and a depilated hide was spoken of as "leather eaten by a.gar" (Sum. kuš a.gar gu$_7$.a). It is difficult to separate out tanning, staining, and dyeing, but, as Van De Mieroop notes, there were distinct processes and ingredients for producing white, black, red, and green leathers (1987: 30). The alum known as Akk. *allaharu* seems to have been used to produce white leather, while the ingredients for black leather included, alongside strained oil and pomegranates, a substance named Sum. im.ku$_3$.GI = Akk. *šarserru* (i.e. "golden" or perhaps "shining earth"), which we might expect to be green vitriol (ferrous sulfate) based on Talmudic and Greco-Roman parallels, but is, in fact, described as a red earth or paste in the lexical tradition. Campbell Thompson (1936: 19) took it to be ferric oxide, but does not recognize that it is used for dyeing leather black; green ferric sulfate becomes red ferric oxide when heated, so the lexical tradition may have been misled by traditional associations between gold (Sum. ku$_3$.GI = ku$_3$.sig$_{17}$) and the color red in the languages of Mesopotamia. Madder (Sum. u$_2$.hab$_2$ = Akk. *hūratu*) is often enough found in combination with *allaharu*-alum (Sum. al.la.ha.ru = Akk. *allaharu*) in the Ur III and early Old Babylonian periods, sometimes alongside im.ku$_3$.GI, and the resulting red leather was known as "madder leather" (Sum. kuš u$_2$.hab$_2$; lexical lists make a strict distinction between Sum. giš.hab$_2$ = Akk. *hūratu* and Sum. u$_2$.hab$_2$ = Akk. *būšānu*, but only u$_2$.hab$_2$ is found in combination with mordants in the Ur III period). Green leather was known as "*dušu* leather" (Sum. kuš du$_8$.ši.a), after the stone of the same name, and it was pigmented using copper acetate or verdigris: in BIN 9, 455, for example, we learn that slightly more than 8 shekels of copper (ca. 70 g) was used in the coloring of one skin (Van De Mieroop 1987: 31). As Van De Mieroop puts it: "Three materials were used for coloring: im-KÙ.GI for black, copper for green, and madder for red" (1987: 32).

The earliest reference to dyed fabric or textiles, predominantly wool in Mesopotamia, is from an Early Dynastic list of terms related to lapis lazuli (Biggs 1966), and for much of the early history of dyeing textiles, which must be kept separate from both finishing textiles and dyeing leather, it was the resulting colors rather than the material of the dye that served as the basis for categorization. Besides Forbes' survey (1965), the most important point of orientation for colors in Mesopotamia is Landsberger (1967), while the

FIGURE 2.3 Vials of kermes and *Rubia tinctorum*. Photograph © Nicole Reifarth.

best recent survey of textile dyeing is Thavapalan's new monograph on color terminology and meaning (2020), which offers a comprehensive picture of the different methods for dying fabrics in Mesopotamia but appeared too late to be incorporated here in a substantial way. In line with van Soldt's 1990 overview, it is best to look at dyes in three or four groups: insect-based dyes, plant-based dyes, and copper/verdigris dyes (murex-based dyes were probably not sourced in Mesopotamia, although there may have been some possibilities in the vicinity of Bahrain; see van Soldt 1990: 345–6; Eden 1999). Insects found in the kermes oak were known by the same name: "kermes and cochineal, dyes extracted from the bodies of female insects belonging to the family Coccidae" (Forbes 1965: 100), and they were used to produce a reddish dye known in Akkadian as *huruhurātu* (not to be confused with Akk. *hūratu*, "madder"). The most important of the pharmaceutical lists, Uruanna III 237, references a "red worm" (Akk. *tūltu sāmtu*) in connection with "the red dye extracted from the kermes worm" (CAD T 467a; see already Forbes 1965: 104, n. 19; for Nuzi and Middle Assyrian evidence, see Donbaz 1988 and Soldt 1990: 347). The most important plant-based dye was, as noted above, madder or dyer's madder (*Rubia tinctorum* = Akk. *hūratu* = Ugr. *puwatu* = Arab. *fuwwatu*; see Hoffner 1967: 301; Soldt 1990), but there were other plants involved, namely Akk. *tiyatu* and Akk. *nuhurtu*, and like madder, both *tiyatu* and *nuhurtu* are also found fairly often as ingredients in medical recipes. Other terms, including Akk. *uqnâtu* for woad or Akk. *azupirānu* for saffron, are used to refer to both a material in dyeing processes and, separately, a plant, so we can be fairly confident that these were also plant-based dyes (Soldt 1990: 347–9). The most important mineral dyes were, as noted above, made from copper for leather goods, in particular verdigris and copper acetate (Akk. *šuhtu*).

Much of the Akkadian terminology for dyed fabrics, however, refers to several shades and varieties of colored garments, without specifically describing their color or the dye that was used to produce them: color terms are often used to translate Akkadian words like *hašmanu* "red-purple (garment)," *tabarru* "red (garment)," *takiltu* "blue (garment)," among others, but this can be rather misleading: these are not color terms, but rather words that designate types of garment (or textile) that have a distinctive color. Campbell Thompson raised the possibility that the rare Akkadian term *hazallūnu*, on the basis of a supposed Syriac parallel in *halāzūnā*, might be the term for murex in Akkadian, but this has not been substantiated (Campbell Thompson 1934: 781; Levey 1959: 108). Purple garments dyed with murex must occasionally have been imported

FIGURE 2.4 Archaeological remains of dye in Qatna. Photograph © Nicole Reifarth.

into southern Mesopotamia, and we have solid evidence for their production and distribution in and around Ugarit on the Syrian coast, including surviving traces of purple-dyed garments from a royal tomb in Qatna (James et al. 2011).

It is telling that the one collection of recipes for dyeing fabric that we have from Mesopotamia, a Neo-Babylonian compilation that likely reiterates recipes known from the mid-second millennium BCE, includes various combinations of different dyeing elements and mordants for a variety of colors, but only describes the red-purple known in Akkadian as *argamannu* as "imitation" (Leichty 1979; Finkel et al. 1998). This was the term used in the Eastern Mediterranean for murex-based purple dyes, a term originally borrowed from Hittite, where it referred to "tribute" delivered to one's suzerain, but it is little wonder that this prototypical form of tribute eventually morphed into a designation of the royal dyestuff itself (Soldt 1990: 344, n. 164). In administrative documents from both Nuzi and Assur in the second half of the second millennium BCE down to Neo-Babylonian temple records, we find clear descriptions of the same materials mentioned in the Neo-Babylonian recipe collection, including specifications of Akk. *huruharātu* dye used for Akk. *tabarru* "red" garments in Middle Assyrian sources (Donbaz 1988) and, in contrast, in the Neo-Babylonian period, Akk. *tabarru ša inzahurētu* "red (wool) dyed with *inzahurētu*-dye" (Payne 2007: 137). As Oppenheim already suggested in his brief description of the mid-second-millennium BCE chemical trade in 1967, the terminology for non-murex dyes seems to include Hurrian elements, such as the Hurrian term loaned into Akkadian as *inzahurētu*, and it is likely that both the terminology and the recipes for non-murex red-purple dyes arose in inland Syria, in the state of Mitanni in the middle of the second millennium BCE, likely in competition with the famous murex dye trade in the Eastern Mediterranean (Oppenheim 1967: 242–3).

Glass is the most important and dramatic of the artificial materials invented by humankind in antiquity: it was probably invented in Mesopotamia, and it plays a special role in the early history of chemistry in the ancient Near East. As Henderson puts it, "glass was the first man-made translucent solid," but unlike its immediate precursors, such as glazed steatite and faience, the production process involves careful management of the pyrotechnic environment in which it is produced and of the forming of objects in a molten state (2012: 1). Two archaeologically well-stratified examples, from Tell Brak and Eridu, date to ca. 2300 BCE, suggesting that glass technologies were already in development in the late third millennium BCE in Mesopotamia. This is symbolized by the highpoint of a Sumerian epic known as *Enmerkara and the Lord of Aratta*, in which Enmerkara, the ruler of Uruk, is engaged in a technological competition with his nemesis, the ruler of faraway Aratta. Challenged to produce a scepter of no known material, not made of wood, metal, or stone, Enmerkara comes up with an unfortunately broken and poorly understood recipe for producing a "reed of splendor" (Sum. gi su.lim.ma, lines 426 and 430), which is "poured like oil"

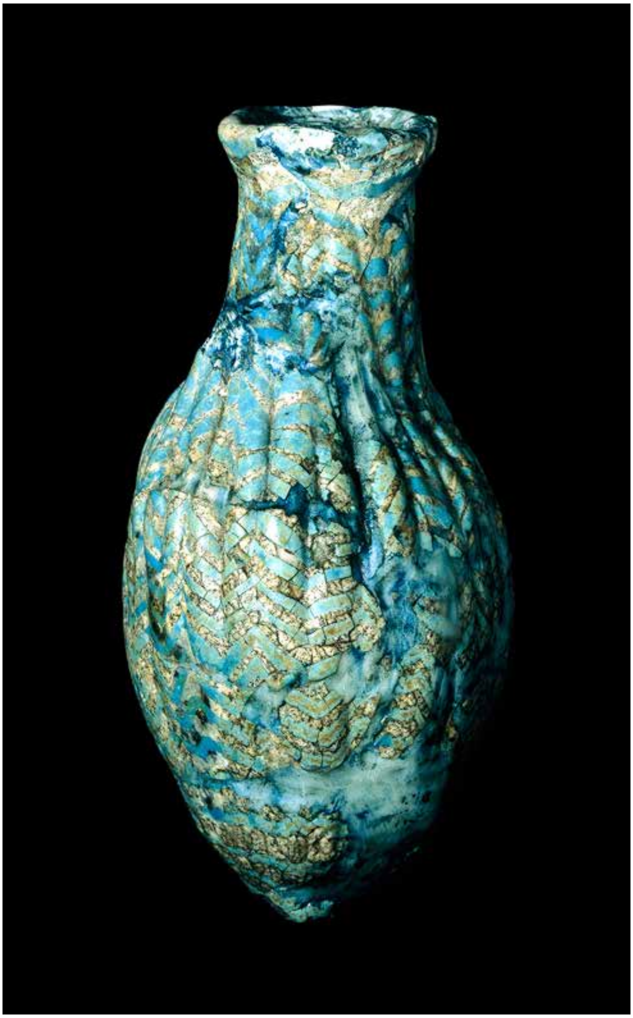


FIGURE 2.5 Fluted glass bottle. © The Trustees of the British Museum.

(Sum. i_3.gin_7 mu.ni.in.de_2, in line 426). The resulting material is characterized by a two-line proverb: "From the sunlight it emerged into the shade, and from the shade it emerged into the sunlight" (transl. after Vanstiphout 2003: 80–1), likely a description of the translucent nature of glass. This crowning achievement in the competition between the technological centers in Uruk and Aratta, namely the creation of a translucent solid, is portrayed as taking place in the Early Dynastic period – Enmerkara is one of the rulers of Uruk preceding Gilgamesh – but was certainly first composed in the Ur III period (ca. 2100–2000 BCE), well within the experimental period leading up to the origins of the glass vessel industry in 1600–1500 BCE. Contemporary Ur III administrative documents use the Sumerian term an.zah (= Akk. *anzahhu*), in all likelihood to refer to faience or the partially processed material known as frit, while the term used in reference to glass in *Enmerkara and the Lord of Aratta* (Sum. su.lim) may be related to the term for "amber" (Sum. $su_3.ra_2.ag_2$ = Akk. *elmešu*) in the lexical tradition (see Cassin 1968 for a survey of the terminology of "splendor" and its links to royal display).

Core-formed glass *vessels* first appear, as part of a regular and well-contextualized archaeological industry, in the middle of the second millennium BCE, largely in cities under the control of the Hurrian state of Mitanni such as Tell Brak, Chagar Bazar, Alalakh, Assur, and Nuzi (Henderson 2012: 129–38). Besides the Kassite glass ax-heads, which derive from a late Seleucid-period hoard, glass mosaics are known from Kassite-period Dur-kurigalzu and, as Henderson emphasizes, "the largest amount of Bronze Age glass of any Middle Eastern site" was excavated in Ugarit, so glassmaking was not a Hurrian monopoly (Saldern 1970: 207, 213–15; Henderson 2012: 136). Flinders W.M. Petrie (1924–5) was the first to suggest that the Egyptian glassmaking industry may have been based on Hurrian artisans and technologies that were extracted from Syria in the course of Thutmose III's campaigns there, an idea that was reiterated by Oppenheim (1973). As Nicholson (2012: 17–19) emphasizes, this would nicely explain why copper and cobalt blue glasses were known as "Menkheperre [i.e. Thutmose III's throne name] lapis-lazuli and turquoise" in contemporary inscriptions. In the Amarna Letters, as Oppenheim first pointed out, two terms are used for glass, supposedly Hurrian *ehlipakku* and another term, perhaps West Semitic, *mekku*; *ehlipakku* is actually glossed with the term *mekku* in RS 17.144 (PRU 6, no. 8), a letter to the ruler of Ugarit about high-value goods, including horses, textiles, and glass, so we can be certain of the equation (Nougayrol 1970: 7–9; Richter 2012: 76 rejects Oppenheim's contention, following the suggestion in Landsberger and Reiner 1970: 26 [= MSL 10] that *ehlipakku* is actually an Akkadianized Sumerian expression, viz. hi.li.ba, subsequently loaned into Hurrian). In spite of the terminological discrepancies, it is clear that a wide variety of glass objects were included in the gifts of Mitanni kings to the Egyptian Pharaoh, reinforcing the general perception that inland Syria was the center of innovation in glassmaking in the second half of the second millennium BCE.

Within a few centuries of the development of the glassmaking industries in Syria and Egypt, at the midpoint of the second millennium BCE, the first recipes for making both imitation semiprecious stones and colored, translucent glass were recorded in cuneiform writing. Unlike the archaeological finds from the Eastern Mediterranean, Syria, and northern Mesopotamia, the glassmaking recipes point to Mesopotamia proper (present-day Iraq and eastern Syria) as the central region for innovations in glassmaking in the ancient world. The cuneiform glassmaking recipes are all written in Akkadian and stem from both northern Mesopotamian Assyrian sources and southern Mesopotamian Babylonian traditions in the fourteenth to twelfth centuries BCE. The three most important blocks of text are (a) the Alpha Group from the Neo-Assyrian period compilation from Assurbanipal's Library in Nineveh, (b) Paragraph U in the Beta Group from the same compilation, and (c) the Middle Babylonian Glass-Making Tablet (BM 120960), published by Gadd and Campbell Thompson in 1936 (Oppenheim 1970). Each of these groups of recipes differs in orthography, vocabulary, and textual format; moreover, the Neo-Assyrian compilation from Nineveh actually includes a widely divergent array of different text types and formats. The procedural texts, such as paragraphs 1–3, 4–6, and 13–15 in the Alpha Group, have garnered the most attention from present-day scholars, largely because they describe a multistage process – with each stage demarcated by a horizontal ruling in the text and named intermediate products such as Akk. *zukû* or Akk. *tersītu* – and distinctive final products: paragraphs 1–3 and 4–6 produce *zagindurû*, a "deeply saturated lapis lazuli blue," while paragraphs 13–15 produce "fast bronze" (Akk. *siparru arhu*; see Thavapalan et al. 2016, especially 201–3, for these translations and the research history). The third paragraph in each of these sequences focuses on opacifying translucent glass, since the goal of all these recipes is to produce imitation stones, which are necessarily opaque. In contrast to the use of the *kūru* furnace and tests for the viscosity of molten glass in the procedural texts, the texts in paragraphs 7–12 of the Alpha Group adopt a simpler formulation – nearly identical in places to the well-known style of medical prescriptions – and exhibit an older technological profile: an Akk. *atūnu* "kiln" is used (instead of the Akk. *kūru* "furnace"), the repeatedly ground materials are placed in "molds" for a week at a time, and if not sufficiently vitrified, they are simply returned to the oven for another week. The Beta Group from Nineveh and the Middle Babylonian text focus largely on the production of different types of red glass, with individual recipes attributed to different regions (Assyrian, Babylonian, and Elamite, in present-day Iran, but no mention of Syria) and even, in two cases, named ancient authorities, although both names are unfortunately broken.

Perfume-making was also an essential part of the technical practice carried out in the palace in order to promote the well-being of the crown and those around him. Already in the Early Dynastic and Ur III periods, in the second half of the third millennium BCE, we find administrative records that quantify more than a dozen different aromatics that were used in the production of perfume (Brunke and Sallaberger 2010). Most of these ingredients reappear in receipts and perfume-making recipes in the second millennium BCE and also form the basis for numerous medical recipes that were presumably first recorded in the Old Babylonian period but only survive in the first-millennium BCE Library of Assurbanipal. The main ingredients throughout this lengthy period of time were the oil that served as the carrier, almost certainly sesame oil (Sum. i_3.giš =

Akk. *šamnum*), from at least the Old Babylonian period on, and oils or resins derived from evergreens such as "cedar" (Sum. erin = Akk. *erēnu*), "juniper" (Sum. za.ba.lum = Akk. *supālu*), "cypress" (Sum. šu.ur$_2$.me = Akk. *šurmēnu*), and "myrtle" (Sum. ad$_2$ = Akk. *asu*). In addition, approximately a dozen other ingredients, nearly all classified as "aromatics" in cuneiform through the use of the cuneiform determinative šim (= Akk. *riqqu*), occur in different periods in much smaller quantities. It is fairly clear from the Middle Assyrian step-by-step perfume-making recipes, published by Ebeling in 1948–50, that warm maceration was the primary way of producing perfumes for the crown, including numerous repetitions and quite complex movements of the macerating material from one vessel to another throughout the process. The complexity of these procedures, in combination with his own preconceived notions, led Levey (1959: 36–8) to see in these practices a primitive form of distillation, but there is a solid consensus, at present, that distillation was not known in second- or first-millennium BCE Mesopotamia (Jursa 2005: 335). The fact that these "perfumes" played a central role in religious practices and that the same aromatic ingredients reappear in many medical recipes shows that these substances were not only or even primarily aesthetic in function. Except for Jursa's recent entry under "Parfüm (rezepte)" in the *Reallexikon der Assyriologie* (2005), there has not been much effort to identify broader continuities between the different historical periods, although there have been a number of important studies of individual historical phases in recent years (Jursa 2009; Brunke and Sallaberger 2010; Cousin 2013; Middeke-Conlin 2014; Escobar 2017).

GRECO-ROMAN WORLD

Matteo Martelli

Despite its Greek etymology, the term "chemistry," or at least its earliest cognate, entered the Greek vocabulary only at the edges of the chronological period under consideration in this volume. Indeed, the Greek term *chymeia* (with its various Byzantine spellings, such as *chēmeia*, *chymia*, or *chēmia*) made its first known appearance in the writings of the Greco-Egyptian alchemist Zosimos of Panopolis at the end of the third century CE. Zosimos interestingly introduced *chymeia* – usually translated as "alchemy" – in the framework of a wider discussion on the boundaries of this art (*technē*): an alchemical book, he claims, must not only explain how silver can be dyed gold, but it must also include a wider spectrum of practices that could produce a variety of chromatic transformations in all kinds of metals (Martelli 2014a: 9–15). The same definition of alchemy and the practices it should encompass seems to be under debate here.

This debate did not take place in a vacuum, but was firmly rooted in a rich technical and artisanal tradition, which alchemy inherited and reshaped when it took its first steps in Greco-Roman Egypt. Already in classical antiquity, a wide range of artisanal practices exploited properties of the natural world that we would call chemical nowadays. One can retrospectively detect a variety of chemically relevant passages, so to speak, which are scattered in many Greco-Roman texts dealing with different technologies, from metallurgy to pharmacy, from dyeing techniques to cosmetics. The variety of the described procedures is so wide and scattered in texts belonging to such different genres that it would be risky and anachronistic to reconstruct some supposed classical view of chemistry as a unified and well-defined field of inquiry in the Greco-Roman world (Healy 1999: 115–16). However, against this fragmented picture, one must observe that some practices started to be grouped together and recognized as a consistent set of technologies by the authors of the earliest alchemical writings. As clearly emerges from the extant works of this literature, in the first centuries CE, alchemical authors constructed their own writings around specific areas of expertise. The four books of Pseudo-Democritus dealt with four main "chemical" subjects: (a) the making of gold, namely a set of techniques to dye metals yellow; (b) the making of silver, that is, how to whiten metals; (c) the making of artificial gemstones; and (d) purple dyeing (Martelli 2013). Likewise, a similar range of techniques is described in the Leiden and Stockholm papyri, two chemical recipe books dating to the third to fourth centuries CE (Halleux 1981; English transl. in Caley 1926 and 1927).

These sources describe procedures that in many cases can be located in other ancient technical writings as well. The Leiden and Stockholm papyri include recipes on ink-making along with various techniques to test artificial products, thus continuing a rich tradition well attested in earlier authors such as Pliny the Elder and Dioscorides (Halleux 1981: 42–3; Greenaway 1986). Pliny (*NH* XXXIV 112) explains that verdigris was adulterated with *atramentum*, a green vitriol (i.e. ferrous sulfate). A papyrus soaked in an infusion of gallnuts could reveal the composition of the drug to be tested: the papyrus, in fact, turns black in the presence of ferrous sulfate (Healy 1999: 136), and ferrous sulfate was indeed an essential component of iron gall black inks. In his *Compendium on Mechanics* (IV 77, in Diels-Schramm 1920: 79), the third-century BCE writer Philo of Byzantium mentions a special ink made of gallnuts dissolved in water, which allowed letters to be written that became invisible as the mixture dried; however, the letters became legible again after being washed with a sponge soaked in a solution of vitriol (Forbes 1965: 236–9; Christiansen 2017: 188–9).

Between the fifth and fourth centuries BCE, technical writings were composed on a variety of arts (Cambiano 1991: 29). Plato refers to cookbooks (*Grg.* 518b), Aristotle mentions books on agriculture (*Pol.* I 11, 1259a), and many medical treatises were grouped around the figure of Hippocrates. The author of *On Ancient Medicine* (§§ 3–9 = I 574–91 Littré) links the origins of medicine to the development of cooking techniques, such as the making of wheat bread and barley cakes. Leavened wheat bread became widespread in the Roman Empire, when different sources of leavening were exploited: next to dough left to sour naturally, Pliny mentions millet or wheat bran fermented in grape must (*NH* XVIII 102) and the yeast produced by the Gauls and Iberians (*NH* XVIII 68), who, when making beer, used the foam that formed on the surface during the process as leavening (Forbes 1965: 97–8; Monteix 2015: 214). Beer, indeed, is often mentioned in Greco-Roman sources: in Hellenistic Egypt, brewing was a royal privilege, and an anonymous alchemical text (*CAAG* II 372) describes the making of barley beer (Forbes 1965: 130–4; Rasmussen 2014: 29–48). Mead and palm and date wine are also mentioned by Roman authors, but grape wine was certainly the most popular alcoholic beverage in the Greco-Roman world: it was often flavored with pitch and resins, which could also prevent the conversion of alcohol into vinegar, thus preserving the wine (Rasmussen 2014: 18–25, 66–7). Vinegar, on the other hand, was the main acid substance known in the Greco-Roman world. As well as being used to treat metals (e.g. iron or gold; see Halleux 1987), it was employed in medicine. Various recipes for the preparation of vinegar are given by ancient authors, such as Columella and Julius Africanus. In a fragment of his *Cesti* (F12 § 19 in Wallraff et al. 2012: 94–7), Africanus lists various kinds of vinegar, produced with the addition of soda (*nitron*), pepper, and burned barley (see also Columella, *On Agriculture*, XII 17).

A wide range of chemicals were used by ancient artisans, such as metalworkers, shoemakers, tanners, goldsmiths, and pharmacists. Even though mainly based on plants, the Hippocratic medical recipes include mineral compounds as well: along with metals (especially copper), one can find litharge (*lithargyros*), verdigris (*ios*), white lead (*psimythion*), and different kinds of vitriol, to name but a few (Goltz 1972: 107; indexes in Totelin 2009; Laskaris 2016: 156–7). Many of these substances were used as pigments as well. Section 8 of Theophrastus' treatise *On Stones* is specifically devoted to mineral colors: both natural and artificial materials are described, according to a useful division that was still used to classify *colores* in the eighth book of Vitruvius' *On Architecture* (Romano 1998). Art imitates nature, Theophrastus claims (*Lap.* VIII 60): technological treatments seem to follow those natural processes that produce minerals under the ground, such as filtering, roasting, or cementing; therefore, if the treatment is correct, what is artificially produced departs minimally from its natural "model."

Some artificial products were discovered by accident. The Athenian painter Cydias (fourth century BCE), for instance, realized that roasted yellow ochre could be used as a purple dyestuff after a fire burned a shop (*Lap.* VIII 53). In some cases, similar treatments were applied to different metals. Pieces of lead or copper were exposed to the vapors of vinegar in order to produce a white or a green pigment, respectively. Theophrastus describes the making of the white pigment (*psimythion* in Greek and *cerussa* in Latin), namely a basic lead carbonate later called "white lead," as follows (*Lap.* VIII 56):

> A piece of lead as big as a brick is placed above some vinegar in a cask. When after about ten days, the lead has acquired thickness, the cask is opened and a kind of mildew scraped from the lead, which is repeatedly placed in this way until it is used up. The scrapings are pounded in a mortar and continually strained away; and the white lead is the matter finally left deposited.
>
> (Eichholz 1965: 79; see also Vitruvius, *On Architecture*, VII 12.1)

Modern replications have shown that the treatment produces a thick layer of white crust around the lead, which can be easily scraped off. The jar certainly contained air, an essential source of atmospheric carbon dioxide, which allows the conversion of lead acetate into lead carbonate (Principe 2018: 163–5). According to Dioscorides (V 88.1–3), a net of reeds was put in the jar over the vinegar: it collected the fragments of the white crust that dropped down during the process, thus preventing them from dissolving in the vinegar. We must observe that in his work *On the Capacities of Simple Drugs* (IX 3.39 = XII 253 Kühn), Galen suggests administering *psimythion* after diluting it in strong vinegar. Moreover, white lead often received a second treatment: roasted on hot coals, it was turned into a red substance suitable both as a pigment and as a medicine (called *sandyx*). Pliny prescribed adding red ochre to white lead before roasting (*NH* XXXV 40). Dioscorides (V 88.5) provides a different description of the process, where a new clay container containing ground white lead was placed on hot coals (see also Plin. *NH* XXXIV 176).

Lead oxide or litharge (*lithargyros* in Greek and *spuma argenti*, "foam of silver" in Latin) was produced by treating argentiferous lead ores. The ores were first smelted to obtain metallic lead with different percentages of silver. In order to separate silver, this lead was remelted in open furnaces (a cupellation process): it quickly oxidized and turned into liquid lead monoxide, which overflowed onto a second crucible (Plin. *NH* XXXIII 106–10). According to the cooling time, two allotropic forms of litharge were produced, namely a yellow and a red litharge, which only differ in their crystalline structure. Their possible identification with the three types of litharge mentioned by ancient sources – *chrysitis* ("gold-like"), *argyritis* ("silver-like"), and *scalauthritis* or *molybditis* ("lead-like") – is still debated (Bailey 1929–32: vol. 1, 215; Halleux 1975; Healy 1999: 320–6). These kinds of litharge were further manipulated in order to make medicines of different colors. Broken into pieces and boiled in water with wheat and barley wrapped in linen cloths, *argyritis* turned into a shiny white drug (Plin. *NH* XXXIII 108; Diosc. V 87). Ground in mortars and treated with salt and soda, it could possibly produce white lead chlorides, as suggested by Healy (1999: 325; see Diosc. V 87.11; Plin. *NH* XXXIII 109). Bailey (1929–32: vol. 1, 216) compared this product with "Pattinson's white lead," produced in 1841 by the English chemist Hugh Lee Pattinson, who patented a new process to produce lead oxychloride, commercialized as white lead pigment. The polychromy of mineral products captured the attention of Greco-Egyptian alchemists as well. In a recipe from his book *On the Making of Silver* (§ 5), Pseudo-Democritus explains how to make litharge whiter than *psimythion* by means of different ingredients (sulfur, orpiment, cadmia), but a strong heat – he explains – would turn the product yellow, since "the nature of lead quickly undergoes many transformations" (Martelli 2013: 110–11).

As in the making of white lead, vapors of vinegar were used to treat copper leaves as well, in order to produce verdigris (*ios* in Greek and *aerugo* in Latin). Theophrastus (*Lap.* VIII 57) prescribed the use of wine lees rather than vinegar, which appears, in turn, in the recipe given by Vitruvius (VII 12.1). According to Dioscorides (V 79.1), a jar containing vinegar was simply covered with an inverted copper vessel, whose internal surface reacted with the vapors of vinegar. Sometimes a lump of copper was stashed among old pressed grapes, or copper blades were simply sprinkled with vinegar (Diosc. V 79.2; Plin. *NH* XXXIV 110–11). The production of verdigris is accurately described in the chemical Stockholm papyrus (§ 74): a sheet of Cyprian copper is first cleaned by means of pumice stone and water, then smeared with oil; a cord is tied around it in order to suspend it in a vessel containing strong vinegar.

Along with verdigris, the ancients produced other kinds of rust. Iron rust, for instance, was used in medicine (Diosc. V 80), while Greco-Egyptian papyri mention "gold rust" (*PGM* XII 193–201; Halleux 1981: 163–6; Betz 1986: 160–1). Gold, in fact, was treated with specific cements, namely mixtures of minerals (salts, sulfur, alum, vitriols), which reacted with its impurities (especially copper), thus producing a "rust" to be scraped off (Halleux 1982: 197–8; Halleux 1985: 45–8). In some cases, vinegar was used to "wash" these impurities away, as one can infer from the mention of "vinegar from the purification of gold" in the chemical Leiden papyrus (§ 14; Halleux 1981: 87; Halleux 1985: 55–7).

Cementation processes were frequently used in ancient metallurgy, when metals were heated in contact with different ores or mineral products. In the *Sophistical Refutations*, Aristotle mentions various metals that imitate gold and silver (§ 1, 164b23–4): "silver-like metals produced with lead oxide (*lithargyrina*) or tin (*kattiterina argyrâ*), and gold-like metals dyed with bile (*cholobaphina chrysâ*)." The use of bile (*cholē*) to tinge metals – replicated by Bailey with some success (1929–32: vol. 2, 164) – is recorded in various inscriptions, as well as by Pliny the Elder (Halleux 1981: 41). Lead oxide (*lithargyros*) is added to tin or lead in order to whiten the metals in the papyrus of Leiden (§ 11). As for tin, a chapter of Pseudo-Aristotle's *On Marvellous Things Heard* reads (§ 62, 835a): "They say that Mossynecian copper is very shiny and white, not because there is tin mixed with it, but because some earth is combined and molten with it" (Hett 1936: 263).

The identification of the earth mentioned in the pseudo-aristotelian text is a matter of debate among scholars: it could refer either to arsenic ores, which would have produced a white arsenic-copper alloy, or to zinc ores (Halleux 1982: 194). Indeed, zinc-rich minerals too were added to copper in a crucible to produce brass. An early reference to this process seems to be detectable in *On Stones*, where Theophrastus mentions an earth that, when mixed with melted copper, improves the beauty of its color (*Lap.* VIII 49). The fourth-century BCE historian Theopompus describes a stone from the city of Andeira in Troad, which produces *oreichalkos* when mixed with copper (fr. 112 Jacoby; see also Strabo, *Geography*, XIII 1.56). Even though the meaning of *oreichalkos* is uncertain in ancient sources (Halleux 1982: 195), Theopompus seems to be referring to a zinc-copper alloy produced by treating copper with zinc ores. More certain is the identification of the Latin *aurichalcum* with brass, since Roman writers often stressed the yellow color of this alloy. Pliny specifies that copper *Marianus* (mined in Cordova) "most readily absorbs *cadmea* and reproduces the excellence of the *aurichalcum*" (*NH* XXXIV 4). The term *cadmea* (*kadmia* in Greek) referred either to natural zinc ores (such as calamine) or to zinc oxide artificially produced by heating zinc-rich ores and collecting the vapors that condense in contact with the walls of the furnaces (Plin. *NH* XXXIV 100–3; Diosc. V 74).

The ability of ancient sculptors and metalworkers to produce metallic alloys clearly emerges from Pliny the Elder's description of ancient statuary in book 34 of his *Natural History*. He mentions the Egyptian black *niello*, a black alloy manufactured by using sulfur to darken a silver-copper alloy (*NH* XXXIII 131; see also the Leiden papyrus, § 35 in Halleux 1981: 93). Corinthian bronze was also very precious – a dark blue bronze made by treating the surface of a copper-silver-gold alloy (Plin. *NH* XXXIV 8). Similar techniques for producing black bronzes are described in the alchemical books by Zosimos of Panopolis (*CMA* II 222–32), who explains the preparation of many dyeing *pharmaka* (Giumlia-Mair 2002; Hunter 2002). These could be watery substances as well, such as "sulfur water" or "divine water," a red liquid made of sulfur and lime diluted in vinegar or urine. Ancient alchemists used to play with the term *theion*, which could mean both "divine" and "sulfur" (Martelli 2009). The earliest recipe for the making of this "water" is recorded in the chemical Leiden papyrus (§ 87; Halleux 1981: 104). Lime and sulfur are ground and mixed in vinegar or urine. After being boiled, the liquid becomes a red "water," which is used after being filtered. Modern replications have shown that if a piece of silver is dipped into this "water," the metal quickly changes its color, becoming very similar to gold. As Principe explains, the process leads to the "the formation of extremely thin layers of sulfides on the metal surface" (Principe 2013: 10–11).

Mercury is often mentioned in processes for dyeing metals superficially, such as mercury gilding, in which a gold–mercury amalgam was smeared on copper (Halleux 1981: 97–8; Healy 1999: 290–3). A method for extracting the liquid metal is already attested in Theophrastus' *On Stones* (VIII 60): cinnabar (a mercury sulfide) was ground with vinegar in a copper mortar with a copper pestle. A mechanochemical reaction is here described, in which copper reacts with sulfur, thus liberating metallic mercury (Takacs 2000). Pliny (*NH* XXXIII 123) and Dioscorides (V 95) also explain a second technique, namely a hot extraction, in which cinnabar was placed in an iron spoon and heated in a double vessel (see Chapter 3): drops of sublimated mercury precipitated on the upper vessel, from which they were collected. These two methods were inherited by the earliest alchemists. Maria the Jewess and Zosimos ground cinnabar by using mortars of different metals, such as lead and tin (*CAAG* II 172,12–19; *CMA* II 47). Pseudo-Democritus used to grind cinnabar in oil of soda and then distil the mixture (*CAAG* II 123,3–7). Moreover, ancient alchemists tried to make mercury solid again (thus producing artificial cinnabar). Pseudo-Democritus mentions that mercury is made solid by means of various minerals, such as stibnite, roasted lime, and sulfur, while Zosimos specifies that vapors of sulfur can solidify mercury and make it yellow/red again (see Mertens 1995: 11; Colinet 2010: lxxxiii–xci; Martelli 2013: 86–7).

These procedures may have fostered the idea that mercury could be extracted from various minerals. Pseudo-Democritus, in particular, mentions mercury from cinnabar as well as from other ores, especially orpiment and realgar. We cannot exclude the possibility that ancient alchemists tried to process different minerals with the same methods that were used to extract mercury from cinnabar. This seems to be most evident for arsenic ores. While in Pliny the Elder (*NH* XXXIV 177–8) and Dioscorides (V 104–5) orpiment or realgar is simply boiled in water – a process that might have produced white arsenic oxide (Bailey 1929–32: vol. 2, 207) – an alchemical treatise ascribed to the goddess Isis (first to second centuries CE) describes a different process: orpiment and realgar were ground in a mortar with an ear of corn and a little oil, then sublimated in a double vessel (*CAAG* II 32–3; Mertens 1984: 138). The collected vapor that condensed on the upper vessel (perhaps metallic arsenic) was probably equated with a kind of mercury.

Glass too was included by ancient authors among metallic (or, more generally, mineral) substances (Beretta 2004: 4–16; Beretta 2009: 1–55). In his *On Stones*, Theophrastus both mentions vitreous sand as an important component of glass (*Lap.* VIII 49) and lists the Egyptian *kyanos* among artificial blue pigments (*Lap.* VIII 55). The term *kyanos*, already attested in Mycenaean tablets (Halleux 1969; Delamare 2007: 29–30), refers to different blue substances that, when finely ground, could be used as pigments: natural blue ores, in particular azurite, a deep blue copper mineral (Diosc. V 91; Plin. *NH* XXXVII 119); perhaps lapis lazuli, a semiprecious stone usually called *sappheiros* in Greek (Theophr. *Lap.* IV 23; Diosc. V 139); and an artificially produced pigment, the so-called Egyptian blue, actually a vitreous product containing silica, copper, and calcium. This pigment had been manufactured in Egypt since the third millennium BCE by heating together quartz sand (as a silica source), lime, a source of copper (natural ores such as malachite or copper filings), and soda (*nitron* as the alkali flux; Nicholson and Shaw 2000: 108–10). If archaeological evidence points to the production and use of this pigment in pharaonic Egypt, no Egyptian texts record its recipe. Many centuries later, Vitruvius describes how to make a synthetic blue pigment, called *caeruleum*, which was produced in Pozzuoli according to an Alexandrian method (Vitr. *De Arch.* VII 11.1): sand and soda were finely ground and mixed with copper filings to produce small balls that, put in an earthen jar, were heated in a furnace. However, quantities are not specified, and, more importantly, no source of calcium seems to be mentioned among the listed ingredients (Delamare 2003; Delamare 2007: 40–3).

Pliny deals with glassmaking at the end of book 36 (§§ 190–6). Here, he also skeptically reports the discovery of a "flexible glass" (*vitrum flexile*) during the reign of Tiberius, who ordered the workshop responsible for the invention to be destroyed, since it would have resulted in the devaluation of metals; according to Petronius, its inventor was executed by the emperor (*Sat.* 51). Flexible glass is usually regarded as a technological myth. However, it is worth mentioning a recipe for unbreakable glass (*vitrum quod non frangitur*) that is included in the *Mappae Clavicula*, a Latin early medieval recipe book probably based on a lost Greek model (third to fourth centuries CE): finely ground glass was mixed with lead, white lead (*cerussa*), quartz, and resins, then melted in an iron crucible. The process is described in recipe 162 according to Baroni's edition of the *Mappae Clavicula* (Baroni et al. 2013: 174; see Halleux and Meyvaert 1987: 56 and Tolaini 2004: 203). This text, by contrast, is not included in the English translation by Smith-Hawthorne (1974), where we do find another recipe (§ 69 on p. 37) that describes how to produce a glass stronger than metals (see Baroni et al. 2013: 188).

On the other hand, in the same section, Pliny records the use of glass to imitate obsidian and other colored stones. The topic is fully developed in book 37, specifically devoted to gemstones: in fact, Pliny claims, many precious stones were imitated by coloring glass, such as opals, "carbunculi," and jaspers (*NH* XXXVII 83, 98, 117). Pliny also mentions treatises on the counterfeiting of gemstones (Plin. *NH* XXXVII 197), and Seneca reports that Democritus was credited with the discovery of how "a boiled pebble could be turned into an emerald" (*Ep.* XC 32). As already seen, the third alchemical book of Pseudo-Democritus was devoted to the making of precious stones. The book is unfortunately lost, and the practices described there are difficult to reconstruct on the basis of later sources (quotations in Byzantine recipe books and Syriac translations). While the *Mappae Clavicula* includes recipes on the making of colored glasses for imitating gemstones (Tolaini 2004), the Leiden and Stockholm papyri provide evidence for a different technology. Rock crystal (*crystallos*) or tabashir (*tabasios*) were dipped in dyeing baths (made of mineral, vegetal, or animal dyes) after undergoing a preliminary treatment called *stypsis*. In fact, rock crystals were processed with mordants (astringent substances such as burned copper, alum, or iron oxides), which made them more receptive to the dye. This technique seems to imitate the methods used to dye textiles. Pliny, in particular, credits Egyptian dyers with the invention of mordants: they used to smear fabrics not with dyes (*colores*), but with chemicals (*medicamenta*, lit. "medicines, drugs") that caused them to absorb the colorants (*NH* XXXV 150). In his *On Odors* (§§ 7–8), Theophrastus interestingly compared these techniques for fixing dyes with the making of perfumes. In fact, in order to produce perfumes, the ancients used a variety of aromatics (mainly vegetal substances) that were boiled in oils; fixatives (especially myrrh) were added to the mixture in order to make the perfumes more stable (Forbes 1965: 30–40).

Purple dyeing was particularly valued in antiquity. Aristotle already provided a description of the sea snails (belonging to the Muricidae family) that secrete the dye known as Tyrian purple (*Hist. An.* V 15, 547a; Longo 1998). However, many substitutes for this expensive dyestuff were used; dyeing algae, cochineals, woad, alkanet, and madder are often mentioned. Many of these dyeing substances are described by Pliny and Dioscorides, such as madder (Diosc. III 143; Plin. *NH* XIX 47), kermes (Diosc. IV 48; Plin. *NH* XVI 32), or woad (Diosc. II 184; Plin. *NH* XX 59). Sections on purple dyeing are included in Pseudo-Democritus' alchemical books (Martelli 2013: 78–81) and in the Leiden (§§ 89–99) and Stockholm (§§ 89–159) papyri (Pfister 1935; Halleux 1981: 43–6). Alkanet – also used to dye perfumes (Theophr. *On Odors*, 31) – produced a dyestuff that the ancients had trouble fixing on fabrics, since it requires a specific treatment with iron salts; the complex method for processing madder, on the other hand, is fully described in the chemical Stockholm papyrus (§§ 109–11).

CONCLUSIONS

Marco Beretta

The degree of specialization achieved in the chemical arts in ancient Egypt is evident when you look at both the complex classification of minerals and metals expressed in the hieroglyphics and the vast repertoire of archaeological remains. The Egyptian classification embodied the principles of an approach to experimental practice that was shared by all three ancient civilizations addressed in the present volume. The analogy established between native metals and minerals and those products of the chemical arts that imitated them enhanced the role of artisanal knowledge. Within this framework, it was therefore consequent that metals were sometimes evoked in the hieroglyphic sign of a crucible, alluding to the operation of melting. Chemical operations, therefore, helped to define natural products.

The growing importance of the chemical arts in Egypt and Mesopotamia encouraged the creation of large-scale sites of experimentation. Metals, minerals, and precious stones played important roles in Mesopotamia's economy. Glass, the "first man-made translucent solid" (Henderson 2012: 1), became one of the most valuable commodities, and it was within this art that the most important innovations prior to glassblowing were introduced and exported. The remarkable property of glass of imitating precious stones and minerals demonstrated the idea that chemical crafts could replicate natural products. The fluctuating hierarchy between *physis* and *techne* in the Greco-Roman world was the effect of both the progress made in the chemical arts and the interest they raised among natural philosophers. It is in this context that we see the first attempt to group together the different techniques entailed in metallurgy, pharmacy, dyeing, and cosmetics into a consistent view on the properties of matter. The works of the alchemist Pseudo-Democritus and the surviving Leiden and Stockholm papyri listing chemical recipes offer crucial evidence of the efforts to treat the manipulation of matter within a comprehensive philosophy of matter.