Chemistry in the Time of the Pharaohs

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Ancient Egypt *(1)* consisted of a Predynastic period, the time before 3000 B.C.E., and a Dynastic period, when Egypt was ruled by pharaohs (kings), which spanned about 3000 years and ended in the year 30 B.C.E. with the death of Cleopatra, the last reigning monarch of ancient Egypt and a member of the Greek Ptolemaic Dynasty. Famous pharaohs were Ramses II, Tutankhamun, and Thutmosis III and famous queens were Hatshepsut, Nefertiti, and Cleopatra. In the year 30 B.C.E., Egypt became part of the Roman Empire.

The ancient Egyptians were enterprising people: they left many impressive monuments such as pyramids and temples; they were among the first nations to develop metallurgy, out of a need for tools; they were the first to extract copper from its ores and to extract gold by melting; they were experts in jewelry and goldworking as is seen from the world-famous death mask of Tutankhamun; they were experienced in chemical technologies, such as making wine, beer, honey, pottery, and glass; the paintings left behind in their tombs attest to an intricate knowledge of inorganic colored salts used as paint pigments; they were known in the ancient world as expert dyers and were ahead of most nations in the production of cosmetics, perfumes, and pharmaceuticals; and they were the first to apply mummification as an alchemical operation. The earliest chemical manuscripts from Egypt, translated and referred to as the Leyden and Stockholm papyri *(2)*, cover numerous chemical processes, such as making alloys, coloring the surface of metals, writing in gold, dying in purple, and many other techniques.

This article gives an overview of the chemical activities practiced by these ancient Egyptians and proposes that they were among the first practicing chemists. Additional material about these topics can be found in the works of Habashi *(3−7)* and the monumental study edited by Nicholson and Shaw *(8)*.

Natural Resources

Egypt was the gift of the Nile, so said Herodotus, an ancient Greek historian who visited Egypt during the 400s B.C.E. and described many of the customs of the ancient Egyptians in his book *The Histories (9)*. The Nile was the central waterway and used not only for transport but also for many other purposes, such as watering the fields, drinking water, and for various processes. Egypt was known in the ancient world as *Khem*, the Black Land *(10, 11)*, referring to the fertile black silt left behind after the Nile had retreated following its annual inundation; alternatively, it referred to the black cosmetic material used as eye shadow by Egyptian ladies *(3)*. The word Khem may have led to the word chemistry *(3, 10, 11)*, through “chemeia”, a word that referred to the making of gold and silver in ancient Egypt.

In ancient Egypt, the sun and the river were fundamental elements. But the rich natural resources of the country would play a big role in its development and contribute to making it, at the height of its power, the wealthiest land in the ancient world. The land was blessed *(1)* with plenty of gold and copper and mineral deposits such as natron, a hydrated mineral form of the naturally occurring salt of sodium carbonate ($Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$), limestone ($CaCO_3$), and quartzite, a form of silica (SiO_2); in the south of the country there were alabaster quarries and around Aswan there were various types of stone used in the construction of the pyramids such as granite, sandstone, red chalcedony, diorite, and amethyst. Near the Red Sea coast, there were emeralds and galena (PbS).

Metallurgy

As early as 4000 B.C.E., the Egyptians had a good knowledge of copper and of processes to extract the metal *(4, 8, 12)*. At Badari, archeologists unearthed the earliest known copper objects, such as pins, chisels, needles, and so forth, which indicate that they were produced by casting molten metal into moulds *(8)*.

The metals that man first obtained were obviously those found in nature in the metallic form, such as gold, copper, and silver. There were some copper deposits in ancient Egypt, but soon Egyptians learned to extract the metal from its ores, mainly malachite and azurite (both copper carbonates), which have bright colors that would have attracted the attention of prospectors and required only simple smelting procedures to extract the copper *(4, 8)*. The Egyptians were the first to extract copper from its ores by smelting. All they needed to do was to heat the ore in a clay crucible in the presence of carbon, the latter acting as the reducing agent:

$$CuCO_3 \rightarrow CuO \text{ and } CO_2 \quad \text{and}$$
$$2CuO + C \rightarrow 2Cu \text{ and } CO_2 \qquad (1)$$

The melting point of Cu is 1083 °C, so the Egyptians were familiar with methods of achieving high temperatures for melting and casting of copper, such as using blowpipes to force air into the mixture and later foot bellows and small furnaces.

More efficient production and the ability to exploit more complex and lower-grade ores required higher temperatures and a procedure termed “fluxing”, the presence or addition of materials to aid the melting and separation of the copper. Iron oxide was the general flux *(8)*. This procedure results in the formation of a mass of mainly iron minerals called “the slag” and the reduced copper. A rise in iron levels of copper artifacts found in Egypt indicates that this procedure was used in the 2nd Dynasty *(8)*. Numerous statues and figures made of copper have been found in Egyptian graves *(3, 12)*.

Bronze, an alloy of copper and tin, became common in Egypt only around 2000 B.C.E. *(4)*, after it had been first developed in the Near East. The tin ore used for this was cassiterite

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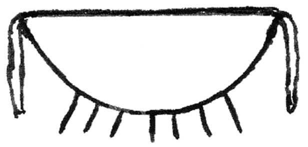

Figure 1. The symbol for gold used by the ancient Egyptians.

(SnO_2), and because this ore was not found in Egypt, the Egyptians had to import it, which would explain the late introduction of bronze in Egypt *(4)*. The ore was powdered and charged into a furnace with alternating layers of charcoal. It was probably smelted together with copper ore or crude copper to make bronze *(4)*. Bronze has superior qualities over copper for making tools and weapons. However, there was still more copper than bronze in the tomb of Tutankhamun, a pharaoh who reigned in the 1320s B.C.E. *(8)*.

By 4000 B.C.E., lead was obtained *(8)* from galena, PbS or cerussite ($PbCO_3$). Lead can be smelted from galena using a simple charcoal or wood fire, involving removal of sulfur by roasting, followed by reduction of the product, PbO *(4)*:

$$2PbS + 3O_2 + C \rightarrow 2Pb + 2SO_2 + CO_2 \qquad (2)$$

Many lead ores also contain silver. Between 3000 and 2500 B.C.E., the cupellation process *(4, 13)* was introduced to obtain pure Ag from Pb/Ag alloys, which resulted from the smelting of such ores. The alloy was melted in a bone-ash crucible, called a cupel, and the Pb was oxidized with a blast of air. The PbO, which was formed, was adsorbed by the crucible, leaving behind a bead of Ag.

Gold was found in mines, associated with quartz. The earliest representation of gold recovery is that in the tomb of Baqt in Beni Hassan, which dates to 1900 B.C.E. *(8)*. After crushing, pulverization, and washing, the fine ore was put onto a sloping table with water running down; the gold-containing particles, because of their density, remained behind, while the matrix was washed out. A refining step was later included where the impure gold was fused with Pb and salt, together with some barley husks, in a cupel, and impurities removed with the PbO *(4)*. The hieroglyphic sign, shown in Figure 1, is the symbol for gold used by the ancient Egyptians *(14)*: the sign consists of the *bowl* in which the metal was washed, the *cloth*, through which it was strained, and the *dropping of the water* all combined in one character, indicating both the process of extraction and the metal. Eyewitness accounts of the gold extraction process in ancient Egypt were written by the Greek geographer Agatharchides of Cnidus in the second century B.C.E. and by the Roman traveler, Diodorus Siculus in 60 B.C.E. *(15)*. In the Nubian dessert are the remains of more than a hundred gold mines, and many of them still contain the remains of the washing tables mentioned by Siculus *(4)*. Modern attempts to duplicate the Egyptian refining process *(16)* have shown that salt alone raised the gold content to over 93%, whereas the addition of charcoal and lead produced a lower percentage.

Ancient Egyptian goldsmiths were highly skilled *(7)*. An outstanding example is the death mask of Tutankhamun, a minor pharaoh, whose tomb was discovered in 1922 by Howard Carter. The mask was beaten from thick gold plate and inlaid with colored glass paste and various stones (lapis lazuli, obsidian, quartz, and feldspar) *(17)*. Numerous other gold artifacts have been discovered. Goldsmiths used silver soldering for gold objects and plated silver onto gold by dipping it into molten electrum (an alloy of gold and silver) *(8)*.

The Egyptians called iron "the metal of heaven" or "ba en pet" *(10)*, indicating that its origins must have been meteoric. Few iron objects have been discovered from early ancient Egypt. This is associated with the problems of extracting the metal from its ore. Egypt never played a major part in the early history of iron *(4)*. Steel was being produced in parts of the ancient Near East by the closing centuries of the second millennium B.C.E. A process termed "carburization" adds carbon to the iron thereby producing steel that can be quench-hardened and tempered to considerable hardness *(4, 8)*. By the middle of the first millennium, the production of iron had increased dramatically *(8)*, but not in Egypt. Indeed, the supremacy of iron weapons over the copper alloy ones has been seen as a major factor in the Persian conquest of Egypt in about 600 B.C.E. *(8)*. After this time, iron smelting began in Egypt *(4)*.

From the 4th Dynasty onward (2500 B.C.E.), the pharaoh had the monopoly of metals and the management of mines and quarries was entrusted to high officials. Because of the close association of the royal families and the priests, practical chemistry probably was first practiced in laboratories associated with Egyptian temples *(18)*.

Tools for Stone Working

The ancient Egyptians used copper chisels, saws, and bow-driven drills with copper and sand as an abrasive to cut the sandstone and granite blocks required for the construction of the pyramids *(19, 20)*. Recent metallurgical testing *(21)* showed that cold-hammered copper could easily cut into the Tura limestone; however, tools made of flint, a form of quartz, were used to cut into granite, as tests showed that only flint tools were able to make the deep incisions into the hardest stones used in ancient Egypt. Vast quantities of flint nodules were available for shaping into chisels and punches.

Wine and Beer Industries

Wine was produced *(14)* by trampling the grapes in a large basin. The juice ran out of a spout on the side of the container. The must was then forced through a sack. The first "still" fermentation took place in the trampling vat; the second "turbulent" fermentation in the wine amphorae. The vessels were closed with a mud stopper and several small holes in the stopper allowed the CO_2 to escape. The Egyptians had several different types of wine, some of which were recommended by ancient authors for their excellent qualities, for example, the sweet wine "Mareotis" *(22)*. Vines needed particular care and were planted in hollows filled with Nile mud. Some wines were imported, mainly from Syria *(17)*.

Breweries *(17)* were always constructed close to bakeries, because they used the round loafs for making beer. Dates were used to produce the necessary yeast cultures. So, chopped bread, water, and dates were mashed to a porridge in a large vat and left to ferment. The liquid was then pressed through a woven cloth. Barley and other herbs were added to give flavor. One particular excellent beer, called "zythus", was highly praised by early travelers *(22)*.

Bee Keeping and Honey

The oldest bee-keeping record dates to the 5th Dynasty (2500−2350 B.C.E.) and was found at the Aba Ghorab Sun Temple at Neuserre and is now at the Egyptian Museum in

Berlin *(23)*. It shows the honeycomb being removed from the hives, jars being filled with the honey, filtering the wax that floats to the top through a cloth, and finally the honey being sealed in containers. Later records of this type of activity, for example, in the tomb of *Rekhmire (23)*, show the comb collector using a censor for producing smoke to drive the bees away. In ancient Egypt, there was no sugar produced, so honey was used to add sweetness to food.

Pottery

There was a need for cooking vessels and early man must have noticed that heat hardened the clay around a fire *(24)*. Early potters selected suitable clays, moistened them so as to work them to a suitable consistency, formed them into suitable vessels, and then fired them. Early firings on open fires reached 450−750 °C, a temperature range that just dried out the clay. The invention of the kiln allowed temperatures up to 1000 °C, causing chemical changes in the clay, making the pottery stronger and less porous *(24)*. The earliest kilns date to about 3000 B.C.E. Several murals in Egyptian tombs depict pottery scenes *(14, 25)*.

Glass Making

Ancient Egyptian glass is among the finest from the ancient world *(26)*. The discovery that a mixture of soda (Na_2CO_3), sand (SiO_2), and lime (CaO), made by heating $CaCO_3$, can be fused into a vitreous fluid, which on cooling results in glass, is very old *(11, 14, 24)*. Glazed stone beads were produced in Egypt around 4000 B.C.E. *(27)*. Addition of certain minerals, such as cobalt salts, to the fusion mixture produced colored glasses, used to glaze pottery and make imitation gemstones. It is believed *(26)* that glass was introduced into Egypt and then independently manufactured, once the industry had been established. The words the Egyptians used when referring to glass are of foreign origin and it is suggested that the first glassmakers and workers may have been brought to Egypt following the campaigns of Thutmose III *(26)*. The oldest dated glass object *(18)* is a large ball bead bearing the cartouche of the pharaoh Amenhotep I (1546−1526 B.C.E.), whereas the earliest glass portrait is of the head of the pharaoh Amenhotep II who reigned from 1450−1425 B.C.E. *(28)*.

The addition of an alkali to SiO_2 lowers the melting point to below 1000 °C *(26)*. Lucas *(29)* suggested that the source of the alkali in Egyptian glass was natron, because he observed that Egyptian glass consists of 15−20% Na_2O.

The making of raw glass proceeded as follows *(26)*: the first step in the process was to grind together all the ingredients; the second step was to heat the mixture in a process called "fritting", which is a solid-state reaction; finally, the third step was to cool, grind, and melt the mixture to form the final product; this last step may have been repeated several times to improve the quality of the glass.

Papyrus

The writing material used in ancient Egypt was made *(14, 25)* from the papyrus plant that grew along the Nile: the stems of the plant were slit and cut into thin strips that were placed side-by-side. This layer was then covered by another layer at right angles. The strips were then sprinkled with water and pressed together to release the starches, which then, with the water, served to bond the strips together *(14, 25)*. The sheets, which measured 15−50 cm wide, were then laid out to dry.

Table 1. Chemical Verification of Ancient Egyptian Paint Pigments

Pigment Color	Chemical Substance
Red	Iron oxide, anhydrous hematite Red ochre: hydrated oxides of Fe
Yellow	Clay mixed with iron or yellow ochre Orpiment, As_2S_3, a naturally occurring sulfide of arsenic As_2S_3
Blue	Egyptian blue
Pale blue	Copper carbonate is azurite
Black	Charcoal from burnt plant or bone
Green	Malachite ($CuCO_3$), green frit, Mixing yellow and blue
Gray	Mixing limestone and charcoal
White	Calcium carbonate

Paint Pigments

The beautiful mural paintings in the tombs of ancient Egyptian pharaohs and high officials are often still as fresh as when painted in ancient times. The reason for this is that ancient Egyptians used mainly inorganic colored salts as paint pigments *(30)*. Chemical analysis *(18)* of the various colored paint pigments found in the tomb of Perneb, dating to 2650 B.C.E., and other sources *(30)* gave results as shown in Table 1.

The Egyptians were excellent at using naturally occurring colored minerals for the various colors required. However, if needed, they could also synthesize a chemical substance required for its color. An example is Egyptian blue *(30)*, which is the first synthetic pigment, made as early as 3000 B.C.E. Its chemical composition is $CaCuSi_4O_{10}$, or $CaO \cdot CuO \cdot 4SiO_2$, and it is a calcium copper silicate. It was produced by heating together quartz sand, a copper compound, $CaCO_3$, and a small quantity of alkali (plant ash or natron) to 800−1000 °C for several hours, during which time the following reaction took place:

$$Cu_2CO_3(OH)_2 + 8SiO_2 + 2CaCO_3 \rightarrow 2CaCuSi_4O_{10} + 3CO_2 + H_2O \quad (3)$$

Depending how this glaze was ground, it produced a range of blue colors: the finest powder gave a light sky blue color and coarser grains gave deeper blue colors.

Dyes

The ancient Egyptians were known in the ancient world as excellent dyers *(14)*. They knew about mordants to bind the dye to the cloth and that alums provide excellent mordants *(14)*. Often the aluminum potassium sulfate salt contained traces of iron, which would introduce an unwanted color in the dying process. It seems likely *(24)* that in ancient times the alum was purified by recrystallization.

Besides the mineral ochre, the Egyptians used vegetable dyes: madder, safflower, and alkanet for red; woad for blue; and the bark of the pomegranate tree for yellow *(17)*. The red extract from the madder plant contains alizarin, which has been detected on red fabrics found in Tutankhamun's tomb *(31)*. Indigo or blue came from either the indigo plant or from woad *(11, 24)*. The plant was mashed in water and the mixture allowed to ferment, after which a blue precipitate of indigotin was formed. This was dried and used in this form. The indigotin was then reduced to a soluble colorless compound by chemical treatment, for example, honey or lime, and the fabric was then immersed in the solution and allowed to dry. The blue color developed as a result of aerial oxidation during the drying process *(24)*.

The most prized dye of antiquity was Tyrian purple. This dye is dibromoindigotin. The ancients obtained an almost colorless precursor, a few drops at the time, from the glands of a shellfish that they harvested from the Mediterranean Sea *(24)*. The purple developed when the treated cloth was dried in the sun. An Egyptian papyrus dating to 236 B.C.E. mentions dyers as "stinking of fish, with tired eyes and hands working unceasingly" *(32)*.

Mummification

This process, used to preserve the body for the afterlife, relied on desiccation of the tissues to resist putrefaction *(33)*. It developed from a simple beginning to an elaborate process. Herodotus *(9)* says that the body, after removal of the brain and certain internal organs, was covered with natron for 70 days to desiccate the tissues. Lucas *(29)* investigated the use of natron as a dehydrating agent and concluded that it was used in the dry state and not as a fluid. Further work *(33)* has confirmed this and the optimum period for desiccation was found to be 30−40 days. The use of plants and plant products in mummification was also investigated by Lucas. Molten resin was also used as an embalming agent. Technical improvements during the 19th Dynasty enabled the natural skin color to be retained as is seen on the mummy of Ramses II *(33)*.

Cosmetics and Pharmaceuticals

Ancient Egyptian women used black eye makeup known as kohl *(14)*, made from galena (PbS) and antimony sulfide (Sb_2S_3). They also introduced a liquid suspension of this makeup directly in the eye, so as to enlarge the eye pupil and act as an early form of sunglasses *(34)*.

At parties, the ladies often wore on their heads a flower-scented cone of ointment *(14, 25)*, which was essentially animal fat that had been impregnated by perfumes from plants and flowers. To give an agreeable odor to the body, the Egyptians used many kinds of perfumes, consisting of myrrh, frankincense, and several other ingredients. These substances were pounded and then mixed together. When a certain quantity was put on the fire, "the smell in the house and on the clothes was pleasant" *(25)*. Honey was also added and pills were manufactured, which when chewed by women "made the breath of their mouth sweet" *(25)*.

Several medical papyri have survived that give the impression that the level of medicine in ancient Egypt was of an exceptional high standard. The Edwin Smith papyrus, and especially the Ebers papyrus, gives hundreds of recipes for all kinds of diseases *(35, 36)*. Many plants were used as medicines *(37)* and recent research by Jackie Campbell at Manchester University *(38)* showed that the Egyptians knew when to concentrate a drug by boiling, when to dilute it, and that grinding released more of the active ingredient. They were experts in extracting drugs from plants and steeping them either in water or alcohol, depending on the solubility of the active compound.

The Leyden and Stockholm Papyri

In the year 290 C.E., the Roman emperor Diocletian decreed that all books and manuscripts dealing with metals or the making of gold were to be destroyed *(36)*. This led to the destruction of a mass of information. Two papyri, containing details of chemical processes from ancient Egypt, have survived by chance: the Leyden papyrus and the Stockholm papyrus *(2)*. Both of these seem to be by the same hand and written about 300 C.E., but copied from earlier documents *(11, 36)*. It is possible that the work represents the notebook of a fraudulent goldsmith *(11)*.

The Leyden papyrus *(36)* has 75 recipes pertaining to the making of alloys, soldering metals, coloring of metal surfaces, testing of the quality or purity of metals, or for imitating precious metals. It also gives 15 recipes for writing in gold or silver or imitating this. It has 11 recipes for dyeing in purple and other colors. The metal sections deal with the formation of gold, silver, or electrum from cheaper materials or with giving a superficial color of gold or silver to cheaper metals.

The Stockholm papyrus *(36)* has 150 recipes in total: 9 deal with metals and alloys, over 60 relate to dyeing, about 70 relate to the production of artificial gems, and 10 deal with the whitening of off-color pearls or the making of artificial pearls.

Conclusion

The ancient Egyptians were masters in metallurgy and were known throughout the ancient world as expert goldsmiths. They were doing extremely complex things with dyes, pigments, precious stones, and the manufacture of glass. They manufactured the first synthetic pigment, called Egyptian blue. The Egyptians were ahead of most nations in the research and production of cosmetics, perfumes, and pharmaceuticals.

The Egyptians obviously did not understand the chemistry as we know it, but they were keen observers and experimenters and knew how to apply certain processes to end up with the required substance. They were indeed among the first practicing chemists and it is appropriate that chemistry derives its name from ancient Egypt, where much of the early development of chemistry took place.

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