Substantia
An International Journal of the History of Chemistry

Firenze University Press
www.fupress.com/substantia

Citation: J. Ragai (2018) Snapshots of chemical practices in Ancient Egypt. *Substantia* 2(1): 93-101. doi: 10.13128/substantia-43

Data Availability Statement: All relevant data are within the paper and its Supporting Information files.

Competing Interests: The Author(s) declare(s) no conflict of interest.

Historical Article

Snapshots of chemical practices in Ancient Egypt

Jehane Ragai

Emeritus Professor of Chemistry, The American University in Cairo, 37, Sedley Taylor road, CB28PN, Cambridge, UK
E-mail: jragain@aucegypt.edu

Abstract. This article gives a historical overview of a number of chemical practices carried out by the Ancient Egyptians and shows that beyond being purely empirical, in more than one instance their methods suggest an understanding of the rudiments of modern day chemistry. A close analysis of some of their preparations indicates that Ancient Egyptians were familiar with the principles of oxidation and reduction, could control the pH of a solution and were successful in preparing novel compounds through a controlled technology of chemical synthesis. In the latter endeavor it is shown that these Ancient people embraced the scientific method, preceding Aristotle's rejection in Ancient Greece of a purely deductive approach to scientific enquiry. Egyptian Blue, the only pigment synthesized by the Ancient Egyptians is also discussed, and attention is drawn to its potential future contributions to modern high-tech applications.

Keywords. Ancient egyptians, chemical synthesis, Egyptian Blue, Kohl, scientific method**.**

> "..*It appears that Egyptians have developed a technology of chemical synthesis in solution that allowed preparations of original compounds..*"
> *Phillip Walter* [1]

INTRODUCTION

The embryonic stage of modern chemistry "*Alchemy*" can be traced back to Ancient Egypt, where Hermes Trismegistus[2] said to be a contemporary of Moses, founded the art of *Alchemy* often dubbed the *Hermetic art*[a]. To many the words *Alchemy* and *Chemistry* are linked to "*Khema*" or "*Chemi*"[3] which referred to the ancient name for Egypt meaning the black land.

On the other hand Plutarch attributes the name "*Alchemy*" to the Ancient Egyptian activities, referring to their skills in the extraction of metals, the preparation of alloys, and the working of gold[4-6] all of which contributed to the practical part of Alchemy.

Today an observer reflecting on the achievements of the Ancient Egyptians, would certainly recognize a flurry of activities that could be referred to as '*Chemical'*, which not only served their *Religious beliefs* but also had *utilitarian*, *aesthetic,* and *symbolic* connotations.

It is generally believed that such accomplishments resulted from purely empirical observations. However the question remains: did the Ancient Egyptians at any point grasp the chemical significance of some of these practices?

In what follows snapshots are provided of some of the most impressive '*Chemical*' achievements of the Ancient Egyptians, the origins of which can in many cases be traced back to their religious convictions.

RELIGIOUS BELIEFS AS CATALYSTS FOR CHEMICAL ACTIVITIES

In Ancient Egypt an almost obsessive horror of death and extinction was reconciled with an absolute faith in immortality.

To ensure eternal life, it was essential that the body be preserved in a good condition and that the tomb of the deceased be equipped with implements, stuffed animals, donations, jewelry (*in case of the rich and powerful*)… that would serve the deceased in the afterlife. Corpses as early as the third millennium BC were preserved by a special technique of embalming (*referred to as* **mummification)** where the chemical process of *osmosis* played a crucial role. The main purpose of mummification was the dehydration of the body so as to prevent anaerobic bacteria from living on its tissues, causing their putrefaction and decay.

It is very probable that the Ancient Egyptians did not understand the chemistry behind the phenomenon of osmosis but must have been aware, on a purely *empirical* basis, of the special role of natron (*a mixture of sodium carbonate, bicarbonate with very small amounts of sodium sulfate and sodium chloride*) in this dehydration process. It is of significance that Herodotus and Diodorus used the same word for preserved fish as that for mummy, considering that even in pre-mummification times, salt was used to dry fish.[7]

With bodies placed on a slanting board and covered with dry natron for forty days, fluids flowed readily by osmosis from inside the body through the skin and to the outer high concentration of natron, resulting in total dessication. Bodies were preserved by such a chemical process and satisfied the Ancient Egyptians dreams of immortality as well as their strong belief in the great beyond[8]. The precise methods of mummification varied from period to period, and also within the same period depending on the social status of the dead person.

THE TOMB: A PROMISE OF ETERNAL LIFE

With the onset of the Dynastic period (~3300BC) Egyptians built elaborate **tombs** which housed, protected, and equipped their dead for the afterlife. Initially built as a flat-roofed, rectangular structure: the '*Mastaba*', which included a shaft that led to an underground burial chamber, would soon give way to the pyramidal structure of the Giza pyramids (erected around ~2600-2500 BC). A special **mortar** was used as a binder to stabilize the heavy limestone blocks that formed the core and outer layers of these massive constructions.

Alfred Lucas[7] in his pioneering work on Ancient Egyptian mortar, asserted that before Graeco-Roman times, the mortar employed for stone in Ancient Egypt was mainly 'gypsum'.

Some writers on Ancient Egypt have described Ancient Egyptian mortar as burnt lime, however, chemical examination by Lucas[7] has shown that Ancient Egyptians never used lime until the Roman period[b]. Such results were later corroborated by Coppola and co-workers [9] who analysed mortars belonging to the Ramesside era and found that they all had a gypsum based binder.

When heated at temperatures as low as 110°C-160°C gypsum loses water to produce the powder, plaster of Paris ($CaSO_4{\cdot}\frac{1}{2}H_2O$) according to the reaction:

$$2CaSO_4{\cdot}2H_2O \xrightarrow{\text{heat}} 2CaSO_4{\cdot}\tfrac{1}{2}H_2O + 3H_2O$$

and when water is added to the powder of plaster of Paris it rehydrates (absorbs water) and hardens rapidly.

$$2CaSO_4{\cdot}\tfrac{1}{2}H_2O + 3H_2O \rightarrow 2CaSO_4{\cdot}2H_2O$$

According to Coppola, Ancient Egyptian workers seemed to be conscious of the fact that the quality of the raw materials and methods of firing influenced the nature of the final product[9].

There is no doubt that the Ancient Egyptians recognised on *a purely experimental basis* the deceptively simple chemical reactions involved in the preparation of gypsum. They also most likely understood that *lime mortar* entailed the formation of calcium oxide (CaO or quicklime) with the subsequent formation of $Ca(OH)_2$ (slaked lime) to give mortar.

$$CaCO_3 + \text{heat} \rightarrow CaO + CO_2 \text{ and}$$

$$CaO + H_2O \rightarrow Ca(OH)_2$$

Even though lime mortar could have been used in their constructions, they probably realized that the prep-

Figure 1. The Kephren Pyramid in which gypsum mortar was used.

Figure 2. Interior of a tomb.

aration of CaO, requiring a heating temperature close to 900 °C, was not an ideal choice. According to Lucas the scarcity of fuel in Ancient Egypt and the low temperature processing of gypsum undoubtably must have been the reason why Ancient Egyptians preferred gypsum over lime.

It is very probable that the process of preparing a suitable mortar had to be learnt by multiple trials, the results being gauged by the nature of the final product.

Members of the ruling class and nobles were particularly meticulous in preparing their tombs and strived to ensure that all their needs for the afterlife were addressed. Metallic implements, small copper and bronze statuettes representing a variety of deities, colored faience, glass amulets and shawabtis (*small statuettes generally 365, that would serve the deceased every day of the year*), intricate jewelry… all had to be scrupulously prepared and securely buried with the deceased.

The skill for the production of burial implements and accessories, was generally attained through experimental observations, but may have necessitated a certain degree of primitive chemical knowledge.

COPPER AND BRONZE: THE BEGINNING OF A STRONG TRADITION OF METAL WORKING

It is only through heating the copper ore in the presence of carbon (*charcoal*) as reducing agent that, as early as the Old Kingdom (~2600 BC), a successful extraction of copper could be achieved in Ancient Egypt.

The ore basically in the form of malachite (basic copper carbonate) was crushed into small pieces and heated, in the presence of charcoal, to temperatures beyond 1000^0C (*reached at by means of blow pipes or foot bellows*) changing at first to copper oxide and then to molten copper.

$$CuCO_3 \cdot Cu(OH)_2 \rightarrow 2\ CuO + CO_2 + H_2O$$

$$C + CuO \rightarrow Cu + CO$$

It would take a thousand years after that discovery for bronze (*an alloy of copper and tin*) to enter into extensive use in Ancient Egypt. A wide spectrum of statues, implements, weapons made out of this alloy were all buried in the tombs. As there are no tin ores in Egypt, it has been suggested that the tin was probably imported from Persia and possibly brought in by Phoenician traders[10].

The Egyptians would soon realize in their preparation of bronze, that the melting point of copper could be lowered by alloying it with tin, an observation which would prove handy in many instances.

Both the extraction of copper and the preparation of bronze seem to have been achieved through trial and

Figure 3. Extraction of Copper (malachite mixed with charcoal heated with blowpipes and then pouring of the molten copper as shown on the left).

Figure 4. Bronze statue of the Goddess Bastet.

Figure 5. Gold Pectoral (parts soldered by colloidal hard soldering).

error with the results embodied in empirical observations which were methodically recorded and strictly followed.

GOLD: FROM *RELIGIOUS STATUARY* TO LEGENDARY *JEWELRY*

Identified with the sun god Ra and with the dazzling solar light, gold occupied a very special place amongst Ancient Egyptian metals. Its shine and glitter also made it quite attractive for use in ornaments and jewelry.

The successful preparation of bronze would pave the way for the progress Egyptians would attain in working gold, namely in relation to the successful soldering of intricate pieces of gold jewelry.

As judiciously pointed out by Cyril Aldred:

> *There seems little doubt that ancients soldered their goldwork by the process known as colloidal hard soldering. In colloidal hard soldering, ground copper carbonate, probably in ancient Egypt in the form of powdered malachite so commonly used as an eye-cosmetic, is mixed with gum or glue and this adhesive is employed to stick the grains or wire into place, or to coat the adjacent edges of the parts to be joined…*[11]

After heating and gradually increasing the temperature from 100˚C to 880 ˚C,

> *… at about 880˚C … the gold in contact with the copper melts to form a welded joint, whereas both gold and copper melt at nearly the same temperature well above this point, viz. 1083˚C and 1063˚C respectively.* [11]

This lowering of the melting point of both Copper and Gold was, as mentioned earlier, certainly inspired by bronze making. There is no recorded evidence, however, that the Egyptians had grasped the underlying chemical principle that governs such a phenomenon (*lowering of the chemical potential etc…..)* as we understand it today.

EGYPTIAN BLUE: A REMINDER OF SUBLIME JUSTICE AND PERFECTION.

Tomb walls were generally adorned with colored representations, mostly associated with deities, and symbolizing the sacred over the profane. Many of these depictions were painted in blue as to the Ancient Egyptians the blue color had a special significance. Worn on the breast plates of Egyptian priests, it was regarded as the color of *Divine Truth*. The blue colored *war* crown became very popular during the New Kingdom (~1500 BC) and was believed to confer upon its wearers, special protection from mysterious hostile forces.[7]

Lapis lazuli (most important component is *lazulite* of formula $Na,Ca)_8(AlSiO_4)_6(S,SO_4,Cl)_{1\text{-}2}$.) and the naturally occurring blue pigment Azurite ($(Cu_3(CO_3)_2(OH)_2$ *a basic copper carbonate*) were both known to the Ancient Egyptians. However, the rare occurrence of lapis lazuli and the pale blue color of the azurite pigment, encouraged the Egyptians to produce their first synthetic pigment, the well known 'Egyptian blue'[b]

The earliest recorded use of Egyptian Blue is in the Old Kingdom (~ 2600-2100 BC) and its preparation continued into the Greco-Roman Period (330BC-400AD)[10] [c]

Figure 6. Preparation of Bronze (heating by means of foot bellows).

The secret of its manufacture was lost in the fourth century AD, and rediscovered only in the nineteenth.

The nature of this pigment has been extensively investigated[12-15] and was found to be a calcium-copper tetrasilicate with the formula $CaCuSi_4O_{10}$ or ($CaO.CuO.4SiO_2$) with a definite composition and crystal structure. Building on previous work and through their own attempts at preparing Egyptian Blue, Wiedemann and Bayer[13] concluded that the raw materials had to be close to the stoichiometric composition 1 CaO, 1 CuO, $4SiO_2$ and that small amounts of fluxes (borax, salt) were needed to catalyse the reaction and to yield a better crystalline structure. It was also observed that in order to achieve a bright blue color the synthesis had to be carried out in an oxidizing atmosphere and at a temperature lower than 1000^0C.

Even though it may never have been explicitly indicated, these results suggest that the Egyptians must have also been familiar with the rudiments of oxidation and reduction.

Today *Egyptian Blue* is another important and fascinating legacy spawn by this Ancient Egyptian civilization with the recent observation that when irradiated with visible light, it fluoresces with exceptional strength in the near infrared region of the electromagnetic spectrum [16-17]. Such a property appears to have an important future in modern high-tech applications, ranging from special fibre optical systems for telecommunications[18] , state-of-the-art high resolution biomedical imaging [19-22] luminescent fingerprinting dusting powder [23]and security ink technology[24].

COLORED AMULETS: BESTOWING PROTECTION, HEALTH AND GOOD LUCK

To match their magico-religeous beliefs the Ancient Egyptians fashioned small and beautifully colored objects (*notably scarabs, amulets, ushabtis*) made of a ware far better adapted that the rough clay, the so-called *Egyptian Faience*. Such a ware composed of a body(core) coated with an alkali-based glaze, gave the Ancient Egyptians the opportunity to produce a wide spectrum of colors.

Until the XVIIIth dynasty (1550 – 1295 BC), blue faience was produced from the thermal decomposition of malachite or azurite during the manufacture of the glaze (the color was mainly due to copper *Cu* in the

Figure 7. Hippo Goddess (Taweret, goddess of childbirth) in blue faience.

form of copper oxide CuO). Ancient Egyptians would soon become aware that a prolonged exposure to high temperature would favor the green color over the blue.[25] Caution therefore had to be exercised in the heating of the glaze and it was only during the Middle Kingdom (2055–1650 BC) that blue became common in faience.

During the XVIIIth dynasty(c. 1550-c. 1292 BC), cobalt in the form of cobalt oxide (CoO) was the principal colorant for blue faience and was generally accompanied by a significant amount of copper. An intense blue color was obtained with concentrations of CoO as low as 0.05 per cent which turned to violet or indigo when concentration was increased to 0.2 percent.

In the coloring of the glaze, the Egyptians realised, again probably on a purely empirical basis, that the colors exhibited by metal oxides in minerals could not always be transferred to the vitreous state. In view of the ligand field and crystal field effects, rarely does a transition metal in glass have the same chemical environment as in a mineral.

Amulets in the form of the Ankh sign (*the key of life*), the Eye of Horus, or the scarab, were often depicted in blue and were worn by the Egyptians and also buried with their mummies providing protection and prosperity.

Here to the symbolism of color (blue) was added the symbolism of form (amulet).

EYE MAKEUP: A VEHICLE TO GOOD HEALTH AND IMMORTALITY

*Makeu*p occupied a primary position at all levels of Ancient Egyptian society and played an important role in funerary rites for the purification of the body[26]. Beauty symbolised holiness – a key to the attainment of eternal life – and eye makeup in particular had an important standing in the Ancient Egyptians' collection of cosmetic elements.

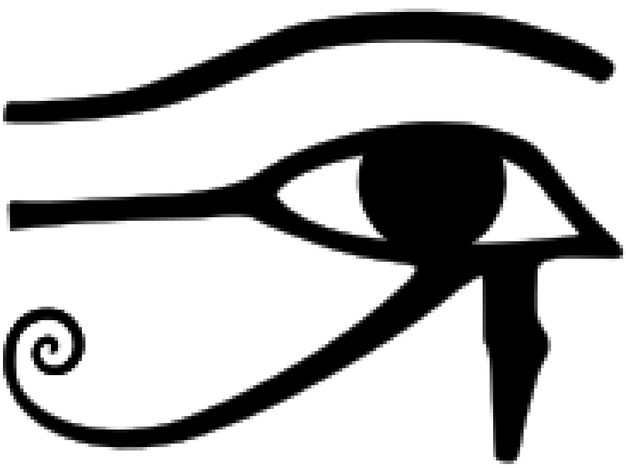

Figure 8. The eye of Horus.

A close connection was perceived between the *madeup eye*, the lunar cyclical renewal and the clash between the gods Horus and Set[26]. According to one myth, Set gouged out Horus's eye in a battle, an event perceived by the Egyptians as an interruption of the usual lunar cycle and a threat to the return of the new moon[27]. For the reestablishment of the cosmic order the eye had to be reconstituted and cured – a task successfully achieved by *Thot* the God of writing.

Philip Walter referring to the rehabilitation of Horus's eye points out that..

> *...The eye of the God should... be completed, reconstituted with makeup and unguents to ensure by the beneficial power of cosmetics the integrity and the health of the Divine eyes, and the victory of the Light.* [28]

The *Eye of Horus adorned with makeup* came to symbolise the moon with all its powerful and protective connotations. Ancient Egyptian religious texts attest to its primary symbolic role and importance:

> *Take two eyes of Horus, the black and the white, take them to your forehead that they may illuminate your face...*[29]

Such beliefs led the Egyptians to regularly use eye makeup during their lifetime. They also ensured that upon their death and as a vehicle to good health and immortality, containers holding cosmetic powders would be included in their burial surroundings .

KOHL AND THE PRACTICE OF WET CHEMISTRY

The 1798 Napoleonic expedition to Egypt brought back a large number of these powders preserved in alabaster, ceramic, wood or reed jars dating from 2000 B.C., the latter have been kept in the storage rooms of Louvre's laboratories.[26,30] Amongst these were two forms of eye makeup used since predynastic times: the green eye paint prepared from the mineral malachite which was usually applied to the lower eyelids and the black makeup, known as *Kohl*, generally used for the upper lids.

In 1995, a group of French scientists led by chemist Philip Walter started researching these Ancient Egyptian cosmetics through a collaborative partnership between the CNRS (National Center for Scientific Research), the Louvre Department of Egyptian Antiquities and the Scientific laboratories of l'Oreal. The collaboration lasted close to seventeen years and part of the work entailed the analysis of black ***Kohl***[26].

Using scanning electron microscopy in conjunction with X-ray diffraction for structural characterisation and phase identification, Walter and co-workers identified two ores of lead namely galena and cerussite (PbS and $PbCO_3$), but to their great surprise the analyses also revealed the presence of copious amounts of laurionite (Pb(OH)Cl) and phosgenite ($Pb_2Cl_2CO_3$)[31].

In view of their very rare presence in nature and their copious amounts in the cosmetic vials, it was concluded that these minerals must have been artificially produced. The excellent state of preservation of the containers ruled out any possibility of weathering or alteration effects.

For comparative purposes Walter and co-workers prepared these lead compounds by stirring lead oxide (PbO litharge) with rock salt (NaCl) in carbonated free water to give *laurionite* (Pb(OH)Cl) and by adding to the mixture natron (mainly Na_2CO_3 and $NaHCO_3$) to obtain *phosgenite* ($Pb_2Cl_2CO_3$). In both cases the prepared minerals were very close in composition and texture to the archaeological compounds[32].

To avoid the undesirable formation of hydroxides the reactions taking place (equations 1 and 2), seemingly quite simple, had to be closely monitored as a neutral pH needed to be maintained.

$$PbO + H_2O + NaCl \rightarrow Pb(OH)Cl + NaOH \quad [1]$$

$$PbO + H_2O + NaCl + 1/2Na_2CO_3 \rightarrow 1/2\ Pb_2Cl_2CO_3 + 2\ NaOH \quad [2]$$

Such a preparation therefore entailed the repeated addition of fresh water and sodium chloride and the continuous removal of the supernatant liquid. The process required several weeks to reach completion[31].

As pointed out by Patricia Pineau, director of research communication for the cosmetics giant L'Oreal:

> *Without knowing much chemistry, how did they have the foresight to know that a chemical reaction started on one day would produce such and such a result after several weeks?*[30]

This discovery led to the astonishing revelation that the Ancient Egyptians were in fact quite versed in the rudiments of ***wet chemistry***, a practice which enabled them to synthesise original compounds in solution. The question remained: why did the Ancient Egyptian add these preparations to their eye makeup?

Old manuscripts indicated that eye cosmetics "… *were essential remedies for treating eye illness and skin ailments…*"[32] and the Ancient Egyptian Ebers medical papyrus mentioned Kohl for the treatment of a plethora of eye diseases[33].

Intrigued by this situation, the French scientists Amatore, Walter and co-workers embarked on a project to find out if lead compounds had indeed any therapeutic effects. Using ultramicroelectrodes they showed that submicromolar concentrations of Pb^{+2} generated by the partial solubility of *laurionite* (Pb(OH)Cl) and added to human skin cells led to the production of NO, a molecule which played a role in the body's immune response.[32] Commenting on such findings Martin Oliver from McGill university suggested that the released nitric oxide could either stimulate the immune cells present in the eye or alternatively kill the disease-forming bacteria close to the eye[34] .

It is therefore possible that the Ancient Egyptians realised on a purely empirical basis, that whenever a white paste (identified today as laurionite or phosgenite) was present in the eye makeup preparation, it would have a therapeutic effect on its bearers and would give them greater immunity. This observation may have been the driving force behind this specific synthesis[32] .

According to Bernstein such an activity "….*remains the first known example of a large scale chemical process*" in Ancient Egypt[35] !

SOME REFLECTIVE COMMENTS

Having dwelt at length upon some of the fascinating '*Chemical*' accomplishments of the ancient Egyptians, it is now perhaps prudent to examine more closely the role of *empirical probing* as opposed to *rational thinking* and *quantitative speculation* in the chemical endeavors of these remarkable people.

Almost a century ago, L.E. Warren referring to the Ancient Egyptians chemical practices expressed the following opinion:

> *It should be understood that the Egyptians in general did not possess an inquiring mind and that ordinarily they would not conduct experiments merely for the purpose of satisfying curiosity or gaining knowledge…* [36]

More recently Wledemann and Berke[14], with regard to Egyptian Blue and other Ancient Egyptian chemical activities, suggested that:

> *…Man-made blue pigments required sophisticated chemical and technological developments… Ancient chemical achievements could not be based on atomic or molecular grounds. Therefore any progress was established by long and tedious processes of empirical probing*[14]

There is no doubt that many of the Egyptians accomplishments, some of which are described in this text, must have come as a result of long and laborious experimental scrutiny and elaborate processes of empirical trials.

However when one considers Egyptian blue, the rigorous stoichiometric requirements *and* the specific conditions for its preparation (*oxidizing atmosphere, addition of a small amount of catalytic flux, temperature control*)[13], must have no doubt involved some degree of *quantitative speculation* and *rational thinking*. Furthermore, the *idea* in itself of preparing one of the first known synthesized pigments, suggests the Ancient Egyptians' ability to *innovate* and *think creative*ly.

The same is true with regard to the synthesis of the new compounds *laurionite* and *phosgenite* using "*wet chemistry*" in which the acidity had to be controlled over several weeks, and the alkaline supernatant liquid continuously removed with the attendant addition of salted water. This certainly entailed quite an elaborate empirical process but also reflects an activity which is implicitly intermingled with sound knowledge *and* which is not totally devoid of any *rational speculation*.

With regard to the synthesis of phosgenite, Philip Walter suggested :

> *We might presume that the observation of natural phenomena may have enabled them to develop and invent such a science. Due to the regular flooding of the Nile and the presence of the desert, Egypt is a country that offers opportunities to observe a large number of mineral formations of exceptional character, especially around the salt lakes of the Wadi Natrun which supplied the natron so necessary to mummification. These carbonates of sodium are produced by chemical reactions between the salt water of the lake and the limestone substrate of the lake bottom, following very similar mechanisms to those involved in the making of the synthetic constituents of cosmetics…*[28]

It can be therefore be surmised that the Ancient Egyptians in their synthesis of *phosgenite* applied a version of our modern day scientific method. Assuming that they *observed* as suggested by Walter the natural formation of this compound, this would then have led them to *hypothesise,* as an informed guess, the needed conditions for a successful preparation, followed by *testing* through carefully controlled and replicable experiments (*control of the acidity through continuous washing…)* and ultimately *verifying* the validity of their hypothesis and *checking* whether or not it needed modification (*obtaining a white compound with immunological effects*..).

This should not come as a surprise to us since according to the Edwin Smith papyrus there are indeed indications that the Ancient Egyptians had a rational approach to medicine in which they applied the present day *scientific method*[37,38].

The chemical practices of the Egyptians stand in partial contrast to Plato's deductive mode of thinking where pure reasoning was the only route to knowledge at the total exclusion of experimental verification. There is no doubt that the Egyptians' manufacture of these artificial lead–based compounds reflects an inductive approach very much in keeping with our modern scientific mode of inquiry!

NOTES

a) "Hermeticism, also called Hermetism is a religious, philosophical, and esoteric tradition based primarily upon writings attributed to Hermes Trismegistus[39]. According to the 'Hermetic view' man can share in divinity and is therefore at least potentially in constant communication with God. The notion of a mystical ascent to the good acts as a unifying theme in 'Hermetism'.

b) Other pigments used in Ancient Egypt were mostly natural minerals. When working in 1980 as a chemical consultant to' The Sphinx Project' at the American Research Center in Egypt (ARCE), I analysed by X-ray Diffraction some blue pigments which were extracted from a cache in the front paws of the Sphinx. These were identified as Egyptian blue (Jehane Ragai: Special report to ARCE, 1982).

c) My own analysis of a series of Ancient Egyptian mortars extracted from the Great Giza pyramid, the second Giza pyramid and the Sphinx revealed the predominant presence of a Gypsum based binder.

REFERENCES

1. P. H. Walter, *Cosmetic and Therapeutic Chemicals* **2003**, 1.
2. Herodotus, *Euterpe,* Vol. 1, LXXXII. 381,Earle, Philadelphia, p. 1814.
3. *The Alchemy Reader: From Hermes Trismegistus to Isaac Newton*, (Ed.: S. J. Linden), Cambridge, **2014**, p. 5.
4. L. E. Warren, *J. Chem. Educ.*, DOI 10.1021/ed011p146.
5. *A History of metallurgy*, (Ed.: F. Habashi), Quebec, **1994**, pp. 11-42.
6. J. Ogden in *Ancient Egyptian Materials and Technologies*, (Eds.: P. T. Nicholson, I. Shaw), Cambridge, **2000**, pp. 148-173.

7. A. Lucas, J. Harris, *Ancient Egyptian Materials and Industries*, Dover Publications, **1999**, p. 283.
8. J. Ragai, G. De Young in *Encyclopedia of the History of Science, Technology and Medicine in Non-Western Cultures*, (Ed.: H. Seline), Springer publications, **2008**, pp. 749-750.
9. M. Coppola, M. G. Taccia, C. Tedeschi, *Proceedings of Conference Built Heritage 2013, Monitoring Conservation and Management* **2013**, 1382.
10. H. A. Ead, **2011**, http://www.touregypt.net/science.htm
11. C. Aldred, *Jewels of the Pharaohs: Egyptian Jewelry of the dynastic Period*, Thames and Hudson Ltd, **1971**, p. 99.
12. W. T. Chase, *Science and archaeology*, Cambridge, Mass, **1971**, pp. 80-90.
13. H. G. Wiedemann, G. Bayer, *Anal. Chem.* **1982**, 54(4), 619.
14. H. G. Wiedemann, H. Berke, *Proceedings of the conference : The polychromy of Antique Sculpture and the Terracota Army of the first Chinese Emperor: Studies on Materials and Techniques conservation* **2001**, 158.
15. M. S. Tite, M. Bimson, M. R. Cowell in *Archaeological Chemistry III*, (Ed.: J. B. Lambert), Washington, DC, **1984**, pp. 215-242.
16. G. Accorsi, G. Verri, M. Bolognesi, N. Armaroli, C. Clementi, C. Miliani, A. Romani, *Chem. Commun.* **2009**, 23, 3392-4.
17. R. Brazil, *Chemistry World* **2017**, 14(6), 19.
18. D. Johnson-McDaniel, C. A. Barrett, A. Sharafi, T. T. Salguero, *J. Am. Chem. Soc.*, DOI 10.1021/ja310587c.
19. G. Pozza, D. Ajò, G. Chiari, F. De Zuane, M. Favaro, *J. Cult. Heritage* **2000**, 1(4): 393.
20. G. M. Davies, R. J. Aarons, G. R. Motson, J. C. Jeffery, H. Adams, S. Faulkner, M. D. Ward, *Dalton Trans.*, DOI 10.1039/B400992D.
21. N. M. Shavaleev, L. P. Moorcraft, S. J. A. Pope, Z. R. Bell, S. Faulkner, M. D. Ward, *Chem. Eur. J.* **2003**, 9, 5283.
22. M. H. V. Werts, R. H. Woudenberg, P. G. Emmerink, R. van Gassel, J. W. Hofstraatand, J. W. Verhoeven, *Angew. Chem.* **2000**, 39, 4542.
23. B. Errington, G. Lawson, S. W. Lewis, G. D. Smith, *Dyes and Pigments* **2016**, 132, 310.
24. C. Q. Choi, *Scientific American* **2013**.
25. A. Kaczmarczy, R. E. M. Hedges, *Ancient Egyptian Faience*, Aris and Phillips Ltd., London, **1983**.
26. P. H.Walter, F. Cardinali, *L'art-chimie: enquête dans le laboratoire des artistes*, Michel de Maule, **2013**.
27. G. Pinch, *Egyptian Mythology: A Guide to the Gods, Goddesses, and Traditions of Ancient Egypt*, Oxford University Press, **2004**, pp. 131-132.
28. P. H. Walter, *Molecular and Structural Archaeology: Cosmetic and Therapeutic Chemicals* **2003**, 1.
29. R. O. Faulkner, *The Ancient Egyptian Pyramid Texts*, Clarendon Press, Oxford, **1969**.
30. B. Thorson, *The Independent*, **1999**, http://www.independent.co.uk/arts-entertainment/science-the-art-of-ancient-egypt-1110924.html
31. *P.* Walter, P. Martinetto, G. Tsoucaris, R. Brniaux, M. A. Lefebvre, G. Richard, J. Talabot, E. Dooryhée, *Nature* **1999**, 397(6719), 483.
32. *I.* Tapsoba, S. Arbault, P. Walter, C. Amatore, *Anal. Chem.*, DOI 10.1021/ac902348g.
33. R. Kreston, *Discover magazine*, **2012**, http://blogs.discovermagazine.com/bodyhorrors/2012/04/20/ophthalmology-of-the-pharaohs/#.WbqO_8Zx3IU
34. W. R. Corliss, *Science Frontiers Online*, **1999**, http://www.science-frontiers.com/sf123/sf123p01.htm.
35. M. Bernstein, M. Woods, *ACS*, **2010**, https://www.acs.org/content/acs/en/pressroom/newsreleases/2010/january/ancient-egyptian-cosmetics.html.
36. L. E. Warren, *J. Chem. Educ.*, **1934**, 11(3), 146.
37. D. K. Mak, A. T. Mak, A. B. Mak, *Solving everyday problems with the scientific method: thinking like a scientist*, World Scientific, **2016.**
38. M. Stiefel, A. Shaner, S. D. Schaefer, *The Laryngoscope*, **2006**, 116(2), 182.
39. R. Audi, *The Cambridge Dictionary of Philosophy (2nd ed.),* Cambridge University Press, **1999**.

PICTURE CREDITS

All pictures are from the public domain except for Figures 2, 3 and 4 were drawn by Fadia Badrawi.