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Gemstone manufacturing in the Arab scientific heritage from the Umayyad Era to the end of the Mamlūk Era (41-923 AH/ 662-1517AD): A cultural historical study

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Abstract

This research investigates the advanced experimental methodologies developed by Arabic chemists (8th-14th Calendar centuries) for the synthesis and imitation of gemstones, with a primary focus on the corpora of Jābir ibn Ḥayyān [1]. Diverging from traditional historiography that often relegates these works to the realm of allegorical alchemy, this study provides evidence of early "materials engineering" based on a sophisticated understanding of the optical and mechanical properties of inorganic substances. By analyzing historical recipes through the lens of modern solid-state chemistry, the paper reveals Arabic pioneering in four technical domains: First, refractive index tuning is done through the strategic incorporation of lead oxides into silicate glass matrices in order to enhance optical dispersion. Second, the management of redox potentials to precisely control the chromatic spectra of transition metal ions such as copper, iron, and manganese. Third, crystal growth via chemical vapor transport is evidenced by protocols involving the sublimation and condensation of arsenic sulfides to produce high-purity crystalline solids. Finally, colloidal and substrate engineering is utilized in order to plaster calcium-based carriers and organic binders to stabilize organometallic pigments. The findings demonstrate that these protocols functioned as "Standard Operating Procedures" (SOPs) aimed at engineering synthetic alternatives that replicate the specific gravity, hardness, and refractive indices of natural rubies, emeralds, and lapis lazuli. By achieving these objectives, the study contributes to a significant re-evaluation of the history of materials science, positioning medieval Arabic chemistry as a direct precursor to modern glass technology and solid-state physics.

Keywords: Chemical vapor transport, Lead-Silicate glass crystal growth, Materials science, Medieval Arabic chemistry, Precipitation on substrates, Refractive index, Synthetic gemstones, Tuning redox potentials.

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1. Introduction

This research addresses a significant gap within a crucial field of the history of science, specifically regarding the scientific heritage of a particular era focusing on the subject of gemstone synthesis and imitation. It demonstrates that synthesized gemstones differ fundamentally from imitated ones in terms of their material composition, whereas imitated stones are crafted from glass, plastic, or other inexpensive and readily available materials which are then dyed to match the color of the desired gem. For this reason they remain distinct from both natural and truly synthesized stones. In the modern era, the industry of synthesizing and imitating gemstones has reached such a degree of precision and sophistication that even an expert cannot distinguish them without the aid of specialized gemstone-detection equipment [2].

Furthermore, the research reveals that attempts to synthesize and imitate gemstones, including diamond, are not new. Ibn al-Wardi [3] noted that, during the very year Tāriq Ibn Ziyād conquered Spain, he "discovered a manuscript containing instructions for the preparation of dyes for rubies and other gemstones," which he subsequently presented to the Umayyad Caliph, Al-Walīd Ibn Abdul Malik [3].

The study also indicates that efforts to imitate gemstones date back to the era of the Ancient Egyptians. Among the papyri discovered in the 19th Calendar century, recipes were found for the preparation of copper acetate (verdigris) a green-colored substance utilized in the creation of artificial emeralds which specifically stipulated that the copper used in the process must be of Cypriot origin. The author of this recipe wrote:

"Clean a well-crafted sheet of Cypriot copper using pumice stone and water; dry it, then lightly coat it with a small amount of oil. Spread the coating evenly, then wrap a rope around the sheet. Afterward, suspend it inside a wooden barrel containing strong vinegar, ensuring that the copper does not come into direct contact with the liquid. Then, seal the barrel tightly to prevent evaporation. If you place the copper inside the barrel in the morning, you may carefully scrape off the verdigris by evening. Then suspend it once again until it is completely consumed and the vinegar becomes spent and unfit for further use [4].



Figure 1.
These synthetic diamonds are produced by chemical vapor deposition (CVD).
Source: <https://www.gia.edu/gem-synthetic>

From both a theoretical and practical standpoint, the scholar Jābir ibn Ḥayyān [1] was among the pioneering scientists who formulated a theory affirming the possibility of creating or "generating" any substance; a process he termed al-Tawlid (Generation). He provided us with a comprehensive array of methods for the synthesis and imitation of gemstones, particularly in his treatise *Al-Durrah al-Maknūnah fī A'mal al-Aḥjār al-Masūnah* (The Hidden Pearl: On the Crafting of Precious Stones) [5].

In contrast, the practice of synthesizing and imitating gemstones did not emerge in Europe until the 19th Calendar century. It was not until 1877 that the French chemist Edmond Frémy succeeded in producing the first crystal of a substantial size; one that met the standards required to be classified as a gemstone [2]. Consequently, this research aims to serve as a beacon for scholars, encouraging them to undertake further in-depth academic and scientific investigations whether through Master's theses and Doctoral dissertations or through the authorship of specialized monographs by research groups dedicated to this significant field.

1.1. Research Significance

The significance of this study emanates from the fact that it is the first scientific study – as far as the researcher knows – that discusses the knowledge of Arab and Muslim scholars about the manufacturing of gemstones during the period from the dawn of Islam until the end of the Mamlūk era.

1.2. Research Objectives

The main goal of this research is to shed light on the most important scientific achievements of the Arab and Muslim scholars in terms of the manner in which they determined gemstone manufacturing.

1.3. Research Questions

The research will answer a major question, which is: What are the novel scientific and practical additions that Arab and Muslim scholars have added to the science of the manufacturing of gemstones during the period from the dawn of Islam until the end of the Mamlūk era? Three questions branch out from this major question, which are:

1. Have there been any previous studies about the Muslims knowledge of gemstone manufacturing, and what is particularly important about such knowledge?
2. What is the value of the gemstone manufacturing and its applications compared to other fields of science during the period subject matter of this study?
3. What are the methods of gemstone manufacturing as identified by Muslim authors?

1.4. Research Methodology

This research adopted the historical, analytical, critical and descriptive research method in which scientific material is collected from the most reliable sources and then arranged, classified and presented in the form of a descriptive, analytical and critical study, by comparing it with the scientific material contained in the contemporary sources.

2. Furnaces Used in the Manufacture of Gemstones

Further corroborating the Arabs' knowledge regarding the synthesis and imitation of gemstones is the fact that they provided detailed descriptions of the specific types of furnaces required for these processes. This is precisely what we find in Jābir's book, *Al-Durrah al-Maknūnah*, a work upon which al-Ḥimyarī al-Marrākushī (d. 1253 AD) later wrote a commentary.

Al-Durrah al-Maknūnah is considered one of the foundational texts in the field of industrial chemistry, as Jābir focused therein on the practical application of gemstones rather than merely their natural description. The book covers: methods for coloring, and in the technical chemical sense counterfeiting gemstones, i.e. the production of artificial pearls and the formulation of the dyes and chemical substances necessary to transform inexpensive stones into stones resembling precious gems. In this book he showed ways how to synthesize many gemstones including diamond.



Figure 2.
CVD- and HPHT-grown synthetic diamonds occur in a variety of colors.
Source: <https://www.gia.edu/gems-gemology/summer-2018-features-of-synthetic-diamonds>

An illustration of a furnace used for the manufacture of gemstones, as depicted by Jābir in his book *Al-Durrah al-Maknūnah*. This indicates that the actual processes of manufacturing or simulating gemstones were indeed being carried out [1].

3. The Manufacture of Emeralds

Jābir Ibn Hayyān outlines three technical methods for producing glass facets that visually simulate the appearance of emeralds:

3.1. The First Method

This requires "one part clear glass and one part high-quality verdigris. If you wish to produce the red variety, add two parts of red lead; if you desire a green emerald, substitute the red lead with two parts of Roman lapis lazuli. Grind all the ingredients together after sifting them through a silk cloth and place the mixture into a clay crucible that has been sealed

with a luting mixture of clay and hair. Apply heat beneath it until it melts. The sign of complete liquefaction is when you insert an iron rod into the mixture and it penetrates fully. Thereafter, you may fashion from the material whatever you desire whether facets or other forms [1].

The scientific process described by Jābir begins with the preparation of the primary silica base (clear glass), followed by its integration in equal proportions with copper oxide (verdigris). The latter will act as a structural coloring agent which will impart a green pigmentation to the mass. To fine-tune the optical properties, lead (II) oxide (red lead) is added; this functions as a "flux," serving to lower the melting point and increase the refractive index, thereby enhancing the material's luster. Additionally, powdered lapis lazuli is incorporated to precisely adjust the color's wavelength. The ingredients are thoroughly ground and sifted to ensure granular homogeneity, and are then placed into a clay crucible that has been thermally insulated with a layer of luting mortar reinforced with fibrous material. The melting process is conducted at elevated temperatures until a state of "viscous fluidity" is attained, which can be verified through a simple physical test ultimately yielding a lead glass that visually mimics the appearance of an emerald.

3.2. *The Second Method*

"Take two dirhams of Iron oxides and one dirham of green zinc oxide; crush them and roast them over heat. Then, add one daniq each of Natron and Qali [sodium carbonate salts] to the mixture. Next, take one hundred dirhams of high-quality 'Pharaonic' or 'Kufic' glass as noted by Al-Marrākushi or Al-Halabi. Crush the mixture into a powder as fine as dust. Then, take an amount of starch equal in weight to the glass; pour water over it and stir vigorously until it forms a homogeneous mixture. Allow it to settle until the liquid clarifies; then, use this liquid to moisten the glass powder. Finally, add the prepared chemical agents to the glass and smelt the mixture; the result will be a fine emerald. Comprehend this instruction well and execute it precisely, and by the grace of God Almighty you shall achieve a masterful result [1].

This recipe relies on the preparation of a complex chemical intermediate consisting of oxidized copper ores and zinc oxide. These components are thermally activated in the presence of sodium carbonate salts (natron and alkali), which serve as a chemical "flux."

The glass silicate material, either "Pharaonic" or "Kufic" in origin, is crushed into micron-sized particles and then immersed in a colloidal starch suspension. This suspension acts as a binding agent, ensuring the uniform distribution of the coloring elements throughout the glass granules. Upon final smelting, a homogeneous glass matrix with a stable chemical composition is formed within this matrix, copper and zinc ions modify the spectral properties of the glass to produce an emerald-like appearance that mimics natural gemstones with remarkable fidelity.

3.3. *The Third Method*

"Take one hundred dirhams of Jawhar al-Rasm, two hundred dirhams of clear crystal, ten dirhams of Dahanj, and twenty dirhams of magnesia. Heat each of these substances separately; then place them all together in a cauldron over a fire. Kindle the flame beneath it, and stir the mixture with an iron rod until it is thoroughly roasted or turns red. Immediately pour the entire contents while still hot into cold water. Wash the mixture in this water until the water runs clear; then add a quantity of crushed salt to it and grind the mixture together with the salt. Once you have eliminated its turbidity and salinity through washing, place the substance into a clay-sealed pot. Submerge it in vinegar filling the pot to a level four fingers' breadth above the mixture and add one hundred dirhams of alkali salt and fifty dirhams of powdered natron. Ensure that the lid and seams of the pot are securely sealed; then place it in a furnace and fire it for two days and one night, maintaining a steady, uniform heat until the mineral substances have completely dissolved. Once it has cooled, remove it from the furnace. Add litharge containing perforations; then take the molten mass, crush it, and grind it into a fine powder. Grind into this powder ten dirhams of verdigris, one dirham of Iron oxides, three dirhams of red lead, and two dirhams of magnesia.

Grind and mix all these ingredients thoroughly; then return the mixture to the clay-sealed pot. Place the pot upon the furnace hearth and apply a blast of air using charcoal and firewood until the mixture melts. Stir it continuously, and observe its consistency by sampling a small amount on the tip of a metal rod. Continue this process until the mixture cools and reaches its optimal state of completion. The definitive test for its readiness is to cast a small drop onto a smooth, flat surface; if it appears as a clear green substance, it has reached its proper state of maturity; otherwise, continue applying the blast until it attains the correct consistency. Finally, pour the finished product into any vessel or container of your choice [6].

This recipe relies on a "dual chemical treatment" process to prepare a host matrix composed of pure silica. It begins with surface activation achieved through the thermal shock of quartz crystals combined with copper and magnesia which creates a microscopic porosity that facilitates ion incorporation. The first phase is "alkaline purification," wherein the mixture is immersed in a medium of vinegar and sodium carbonate salts (natron and alkali) within a kiln for 60 hours, which yields a vitreous melt that has been purified of extraneous oxides (impurities). In the second phase, the melt undergoes optical tuning where copper oxide (verdigris) is added as the primary coloring agent; iron oxide (rust) is introduced at a precise concentration to fine-tune the color hue; and lead oxide (red lead) is added to enhance the refractive index. Continuous blowing with charcoal creates an oxidative environment that ensures the copper ions remain in the Cu^{2+} state, which is the specific oxidation state responsible for the pure emerald-green color. The result is a lead-silicate glass material that convincingly mimics natural emerald in its hardness, luster, and chromatic depth.

Later, Abdul Rahman Ibn Umar al-Jawbari (died after 663 AH / 1265 AD) described a method for creating emeralds, as follows: "One such technique involves crafting a very fine green ruby gemstone. To achieve this, take a desired quantity of natural crystal quartz and melt it in a clean iron crucible. Once melted, add in equal parts of verdigris, high-quality

indigo, *al-habba al-khadra* (green grains), and henna leaves. Then grind all these ingredients together and cast the mixture into the molten crystal. The result is a green ruby unparalleled in beauty. Indeed, nothing surpasses it in loveliness, and no one would doubt even for a moment that it is anything other than pure emerald or ruby [7].

This recipe relies on the technique of "doped fused silica," wherein natural crystal (silicon dioxide) is melted in an iron vessel to serve as a high-purity base material. Add to the melted crystal a mixture consisting of copper oxide (verdigris) and organic indigo compounds, alongside carbon-rich plant extracts (green grains and henna), which act as chemical reducing agents. This reaction facilitates the incorporation of copper ions into the silica's crystal lattice, thereby altering its light-absorption properties and producing a deep green hue. The result is a glass-ceramic material that in terms of both hardness and refractive index closely mimics natural green rubies or emeralds, rendering it exceedingly difficult to distinguish visually from genuine gemstones.

Another method is described as follows: "Should you wish to achieve it, take fine, clear crystal and place it in a Barrām stone pot. Then pour over it a quantity of oleander juice sufficient to submerge the crystal to a depth of four fingers and add to the mixture one carat of Syrian verdigris. Then cook it over a moderate fire until it takes a vivid green color; the result is a stone that emerges as the finest possible imitation of an emerald [6].

Here, we observe a shift from "total melting" to a technique resembling "hydrothermal surface treatment" conducted at moderate temperatures. This technique relies on the principle of "thermally induced ionic diffusion," wherein crystalline quartz (the crystal) is immersed in a liquid medium specifically, a plant extract (oleander juice) that serves as a transport medium to which copper oxide (verdigris) is added as a source of coloring ions. The heating process takes place within a Barrām vessel (made of soapstone), a material distinguished by its exceptional capacity to retain heat and distribute it uniformly.

The application of a "moderate fire" causes the pores on the crystal's surface to dilate, thereby allowing copper ions to penetrate the crystal's outer layer through diffusion. The result is a stone that retains the natural hardness of quartz while acquiring a green coloration that convincingly mimics the visual allure of an emerald.

4. The Manufacture of Lapis Lazuli

The Egyptians previously utilized a type of artificial lapis lazuli to color the engravings on mummy masks, as well as on certain pieces of furniture discovered in the tomb of Tutankhamun. Furthermore, there exist Assyrian texts that date back to the 7th century BC containing recipes for creating gemstone pastes including blue lapis lazuli and ruby. In the 12th Calendar century, during the era of China's Tang Dynasty, a variety of artificial lapis lazuli emerged; the Chinese referred to it as Si-Si Schafer [8].

Shihāb al-Dīn Aḥmad ibn Yūsuf al-Tifāshī [9] described his own process for manufacturing lapis lazuli using the following method: "Take one part of red arsenic, an equal part of yellow arsenic, one-quarter part Kermani vitriol, and an equal part of pure glass free of dust and impurities. Each ingredient is to be ground separately, sifted, and then mixed together; subsequently, the mixture is moistened with high-quality vinegar.

Next, take a clay vessel sealed with a sturdy clay mixture containing hair and clean, high-quality dung and set it aside until it dries and hardens. Then, place the prepared ingredients into the vessel while they still retain the moisture of the vinegar, filling it to a consistency resembling roasted grain flour. Seal the mouth of the vessel with a ceramic shard and lute its rim with clay. Subsequently, heat a kiln using firewood and dung until the layer of burning dung inside reaches a thickness equivalent to the width of a forearm. Place the vessel inside the kiln, bury it beneath the dung, and seal the kiln's opening with clay, luting it from the bottom up. Leave it overnight. Once the process is complete, remove the vessel from the kiln and extract its contents; you will discover within it red crystals resembling rubies: some round like small beads, and others elongated like arrowheads. This serves as a carrier, a base upon which you may subsequently grow or form any type of lapis lazuli you desire, whether mineral-based or artificial [10].

This technique aims to produce a "sulfide-based glass base" intended to serve as a substrate for the manufacture of synthetic lapis lazuli. The reaction between arsenic sulfides and iron sulfates (vitriol) conducted within a reducing environment rich in carbon and carbonaceous residue, yields a dark vitreous melt. When viewed in dense, solid masses, this material appears a deep red hue, which is a visual effect resulting from the high sulfur concentrations. This substance functions as the "carrier" or chemical vehicle onto which the lapis lazuli pigment is subsequently "loaded", whether mineral-derived or synthetically produced.

The methodology employed here falls under the category of "carrier material engineering." It involves preparing a base material endowed with specific physical properties and density, designed to effectively receive and anchor the deep blue coloration characteristic of lapis lazuli, thereby imparting a visual depth that convincingly mimics that of the natural gemstone.

Al-Jawbarī [7] also described a method for creating lapis lazuli, as follows: "take eggshells, subject them to calcination, and then apply to them the *dyers' herb*, a plant known to the people of Fez as *al-wasma*, or *al-ghubayra*. Subsequently, they add to this mixture a quantity of Indian indigo extract; the result is a high-quality lapis lazuli."

"Regarding this specific method, I am personally aware of forty-eight distinct variations. If I to enumerate every technique I know, no single book could possibly contain them all. I have, therefore, chosen to present only a selection, from which the nature of the whole may be readily inferred [7].

Here, he outlines a technique for organometallic pigment synthesis aimed at producing synthetic lapis lazuli using a calcium-based substrate. This technique relies on the thermal transformation of calcium carbonate (derived from eggshells) into calcium oxide through a process known as *calcination*, thereby creating a highly porous and absorbent substrate material. This base is combined with plant extracts containing "indigo" molecules derived true indigo, which function as

organic blue pigments.

The chemical reaction between the alkaline calcareous medium and the pigment results in color fixation and the formation of a stable color complex that mimics the chemistry of *Maya Blue* or *Synthetic Lapis*. The methodology employed is "Precipitation on a Mineral Carrier," wherein lime serves as a physical substrate, endowing the organic pigment with the density and structure characteristic of gemstones.

Natural lapis lazuli is currently imitated by materials known as "German Lapis" or "Swiss Lapis." These consist of a type of jasper dyed blue through a process involving iron, potassium cyanide, and ferrous sulfate; a reaction that yields "Prussian Blue" (also known as "Berlin Blue"). Both German Lapis and Swiss Lapis differ from natural lapis lazuli in that they possess greater hardness and distinct color characteristics, beside the ability to synthesize them chemically [11].

5. The Manufacture of Ruby

Ruby held a position of high esteem within Arab and Islamic civilization. A significant stride taken by Arab and Muslim scholars was their shift toward the synthesis of ruby, rather than relying solely on what nature spontaneously provided. This endeavor was undertaken by Jābir ibn Ḥayyān [1] and subsequently by Shihāb al-Dīn Aḥmad ibn Yūsuf al-Tifāshī [9] in a treatise written in Persian titled *On the Synthesis of Ruby*. A treatise preserved in collection No. 6539/5 [12].

Jābir ibn Ḥayyān [1] presented the methods of synthesis of red ruby as follows Jābir ibn Ḥayyān [1]. "Take one hundred dirhams of agate, two hundred dirhams of rock crystal, and twenty-five dirhams of magnesia. Heat each of these substances individually, and then quench them in sour vinegar three times. Afterward, crush the moisture and boil it in sour wine vinegar in which alkali has been steeped. Strain the mixture into a clay-lined pot. Cook it thoroughly for half a day until it dries out and becomes plastered. Then, quench it in cold water and wash it with water and salt until the liquid runs clear and the mineral essence is purified. Next, place it in a clay-lined pot along with one hundred dirhams of natron, fifty dirhams of alkali salt, forty dirhams of Armenian borax, and ten dirhams of coarse salt. Fire it in a furnace for two days and two nights or for one day and one night.



Figure 3.

These beautiful synthetic rubies may easily be mistaken by many as natural.

Source: <https://www.etsy.com/in-en/listing/775070689/oval-faceted-lab-created-ruby-red>

Once it has melted and cooled, remove it and discard the slag. Take the molten mass and grind it together with sixty dirhams of red lead, five dirhams of cinnabar, two dirhams of red arsenic (ground with vinegar), five dirhams of magnesia, five dirhams of rusukhn, and ten dirhams of hematite, all of which must be finely ground. Mix the ingredients, place the mixture in a clay-lined a crucible, and apply a continuous blast of air to it until it melts and subsequently cools. The sign of its successful completion is to cast a small sample of the material onto a smooth surface and allow it to cool; if it takes the form of a red substance possessing a high degree of translucency and a luster characteristic of ruby, then the process is complete. However, if any turbidity remains, continue to apply the blast of air until the desired perfection is achieved."

This recipe relies on the engineering of high-density lead crystal glass through a series of multi-stage chemical reactions. The process begins with the thermal and mechanical activation of pure silica (agate and rock crystal), wherein thermal shocks applied within an acidic medium (vinegar) are employed to induce microscopic fissures that facilitate subsequent pulverization and chemical bonding. The initial phase involves "chemical purification," utilizing magnesia as a decolorizing agent and alkaline salts (natron and borax) as fluxes to reduce the melt's viscosity and expel mineral impurities.

In the second phase, advanced ionic doping is performed; lead oxide is added in high proportions to elevate the refractive index and enhance light dispersion properties that endow the stone with its characteristic luster and ruby-like brilliance. The deep crimson hue is achieved through a blend of mercury sulfide and iron and manganese oxides (hematite and magnesia), with arsenic serving as a stabilizing and clarifying agent. Continuous blowing with a bellows ensures a stable oxidative environment for the integration of these heavy metal oxides into the glass matrix, yielding a material that closely mimics natural ruby in both its specific gravity and chromatic depth.

Jābir then described how rubies could be imparted with other colors by treating them according to the following

methods: "If you want it (the ruby) to be a clear green, then after removing it from the furnace grind sixty dirhams of verdigris with it, along with five dirhams of iron oxides, five dirhams of magnesia, two dirhams of red lead, and five dirhams of dahinj.

If you want it to be violet, then grind it with twenty-five dirhams of verdigris, five dirhams of sādinj, ten dirhams of red lead, ten dirhams of yellow arsenic (ground with egg yolk), five dirhams of iron oxides, and five dirhams of magnesia; this yields a violet ruby.

If you want a yellow ruby, then grind it with thirty dirhams of yellow arsenic (ground with egg yolk and vinegar), ten dirhams of red lead, three dirhams of iron oxides, three dirhams of magnesia, two dirhams of mirdāsanj dates, and five dirhams of lapis lazuli; this yields a yellow ruby."

Furthermore, Al-Rāzi, et al. [13] presented several methods in his book, *Sirr al-Asrār*, for the purely chemical synthesis of rubies methods that employ a scientific approach closely resembling that of Verneuil (flame fusion).

5.1. The First Method

"In the following I am describing a formula for a substance resembling the Bahramānī ruby; one which I have personally crafted with my own hands on numerous occasions." Take two pounds of laminated yellow arsenic resembling sheets of gold and grind them thoroughly and set them aside. Next, take two ounces of walnut-yellow sulfur and two dirhams of crystalline sal ammoniac; grind them well, sift them, and mix them with the arsenic. Then, take an amount of unused white glass equal to half the total weight of the mixture. Crush the glass by first heating a piece of it intensely, then quenching it in a solution of alkali and salt water; it will then shatter, allowing you to grind it into a fine powder. Mix this glass powder with the aforementioned ingredients namely, the sulfur, arsenic, and sal ammoniac.

Place the entire mixture into a green, clay-sealed jar, filling it to no more than one-quarter of its capacity. Place a layer of crushed salt beneath the mixture inside the jar. Mount a well-fitted cup atop the jar, inverting the cup so that the jar's mouth fits snugly inside it; seal the joint with clay, smoothing and refining the seal. Set the jar surmounted by the cup upon a circular furnace structure, embedding the jar halfway into the masonry. Ensure the jar is fitted with a collar or flange that rests upon the rim of the furnace opening. Maintain a steady, moderate fire beneath the jar for two days and two nights. Finally, allow the apparatus to cool completely before opening it gently. You will find the interior of the cup filled with suspended deposits resembling clusters of grapes of a deep red, exquisite substance. It closely resembles red spinel ruby indeed, it is even finer, more brilliant, and purer. From it, fashion as many gemstones and decorative inserts as you desire; furthermore, it can be turned on a lathe to create chess pieces, dice, and anything else you wish, should you choose to do so [13].

Here, Al-Rāzi, et al. [13] transitions from the subject of "glass coloring" to the process of "sublimation and synthesis of metal sulfides" to produce a solid, crystalline material that mimics deep vivid red Bahramani ruby. This recipe relies on the technique of "Physical Vapor Deposition" (PVD) conducted within a closed system. The process begins with the preparation of "chemical precursors, specifically arsenic trisulfide (yellow arsenic) and elemental sulfur to which ammonium chloride is added to serve as a chemical vapor transport agent. This mixture is then combined with silica powder (white glass) that has undergone "thermal shock" treatment in an alkaline medium to enhance its surface area.

Upon continuous and moderate heating for 48 hours, the sulfides undergo sublimation and react within the gas phase; they subsequently condense in the cooler upper section (the trimmed crucible), to form synthetic crystals of arsenic disulfide or complex sulfur compounds. The result is a solid crystalline material resembling clusters of gemstones characterized by a deep ruby-red hue and a crystal structure that permits mechanical turning and shaping. This endows the material with physical properties superior to those of traditional glass, closely approximating the appearance of natural ruby.

5.2. The Second Method

"The Preparation of Noble Gemstone: I acquired this procedure from Ahmad Ibn al-Mulqi, and it is a method he verified as authentic. The process is as follows: Take one hundred dirhams' weight of Garnet comprising stones, gems, and fragments along with one hundred dirhams of lapis lazuli, one hundred dirhams of pure crystal, sixty dirhams of Pharaonic glass, and fifty dirhams of magnesia. Pulverize all these ingredients; then, after heating them thoroughly, boil them once in a mixture of vinegar and alkali. Thereafter, remove the mixture, wash it thoroughly, dry it, and grind it into a very fine powder. To this mixture add and mix one hundred dirhams of natron, fifty dirhams of alkali, and twenty dirhams of yellow arsenic.

Next, place the mixture into a clay-lined pot; seal the pot with the lid and its joints securely. Place the pot inside a furnace and fire it continuously for three days and three nights. After it has cooled, remove it, break it open, and discard the dross. Retrieve the molten gemstone material, grind it, and pulverize it. To this pulverized powder add and grind together: eighty dirhams of red lead, ten dirhams of cinnabar, fifty dirhams of yellow arsenic (previously ground with egg yolk and vinegar), twenty dirhams of magnesia, fifty dirhams of iron oxides, and twenty dirhams of golden marcasite. Pulverize and blend all these ingredients together; then, place the mixture into a crucible or pot and set it atop a furnace. Maintain a constant, intense fire beneath it using a large quantity of charcoal until the mixture melts and reaches its proper state of maturity. The sign of its maturity is that, when a metal rod is dipped into it, the tip of the rod emerges coated with the molten material; when this material is cast onto a stone surface and allowed to cool, if you observe it to be a pure red with a shimmering yellow tint within it then it has reached maturity. If it does not appear this way, continue firing it until the process is complete and the desired state is attained. Finally, pour the molten material and fashion from it whatever you desire such as cups, bowls, and other vessels for the result will be a pure red material with a radiant yellow luster shining

from within." so dazzling to the eye in its beauty that the value of a single mithqal of it will be one hundred and twenty dinars [13].

This recipe is grounded in the methodology of "Mineral Matrix Enrichment." The text begins by utilizing the fragments and raw materials of natural stones of Garnet, Lapis Lazuli, and Quartz. These components undergo a process of "surface activation" involving thermal shock and chemical treatment with acids (vinegar) and bases (alkalis) to destabilize their crystalline structure and facilitate their integration into the liquid phase.

The first stage is the "Formation of the Base Glass Frit," wherein silicate materials are melted together with natron, arsenic, and magnesia (acting as a decolorizing and purifying agent) within a furnace for 72 hours. This extended duration aims to ensure "complete chemical homogeneity" and to expel gases and impurities, thereby yielding a highly pure glass mass. The second stage involves "Engineering Optical and Colorimetric Properties," during which the resulting material is melted with the addition of high concentrations of lead oxide to increase the material's density and refractive index.

This process imparts the aforementioned "brilliance" to the material. The specific color described as a "pure red with a yellowish tint" is achieved through a complex chemical reaction combining mercury sulfide, arsenic sulfide, and iron oxides, along with the addition of golden marcasite (Pyrite or iron sulfide). Here, marcasite acts as an agent imparting a microscopic "metallic luster" known as the Schiller effect or as an internal pigment that lends the red hue a golden sheen. The result is a heavy flint glass that, in both its luster and hardness, emulates rare gemstones, which explains its high estimated value.

Al-Jawbarī [7] also described several methods for creating ruby: "Take your desired quantity of agate free of impurities and melt it in an iron crucible. Once it has melted, take a portion of Brazil wood, a portion of cinnabar, and a portion of alkanet. Grind all these ingredients finely and cast them onto the molten agate. The mixture is thereby transformed into a red ruby. Finally, place it upon a smooth slab and cut it into pieces of whatever size large or small they desire [7].

This technique is referred to as "Organic-Metallic Doping of Molten Silica," which is employed to produce a visual simulation of red ruby using agate as the base material. The recipe relies on the principle of "modifying the oxidation state of silica" through the incorporation of heavy metal oxides combined with carbon-based pigments. The process begins with melting natural agate (crystalline silica) in an iron crucible, which is a procedure that requires extremely high temperatures to transform the material into a viscous liquid state. The molten mass is then doped with cinnabar (mercury sulfide), which serves as the primary source of the red coloration, alongside the addition of extracts of wood Brazil wood which contains the organic *hematin* and the alkanet plant.

These organic substances function as chemical reducing agents and carbon sources, for they effectively prevent the oxidation of the mercury, thereby ensuring the stability of the red pigment within the vitreous matrix. Once the molten mixture is poured onto the "smooth slab," it undergoes a rapid cooling process (quenching), which renders it suitable for subsequent mechanical cutting and shaping. The result is a glass-ceramic material of high optical density that mimics the luster and hardness of natural sapphire after having integrated plant-based and mineral components into a fused silica structure.

He then presented a second method, stating that: "Among the techniques is the creation of a very fine yellow sapphire gemstone. To achieve this, take crystalline quartz and crush it in a clean iron mortar. Once it has melted, take a tiny portion (one part in a thousand) of saffron; dissolve it, add it to the molten quartz, and pour the mixture onto a slab. It then transforms into a yellow sapphire of unparalleled beauty. Finally, cut it to the desired dimensions and sell it as genuine sapphire at the highest market prices [7].

This recipe relies on a technique involving the "coloring of high-purity silica" using infinitesimal concentrations. Crystalline quartz is melted in an iron mortar until it reaches a liquid phase; a saffron pigment is then added in a ratio of one part per thousand (1:1000). In the context of modern materials chemistry, this process is interpreted as the carbonization of organic matter (the saffron), yielding carbon particles or trace metal oxides that become dispersed throughout the silica matrix.

This extremely low concentration, which is equivalent to the impurity levels found in natural gemstones, results in the absorption of short-wavelength light (blue and violet), while allowing the yellow spectrum to pass through with exceptional clarity. This is followed by a process of "rapid crystallization" involving casting onto a slab. In this way the technique traps the coloring ions within a silica glass matrix, yielding a material characterized by high hardness and a refractive index that closely mimics that of yellow sapphire, while exhibiting exceptional transparency as a result of the precise proportions employed.

He then presented a third method, stating that: "To dye sapphire to a celestial hue, take a yellow sapphire, place it in a crucible, and then place ammonium chloride both beneath and above it. The vessel is then sealed with clay of wisdom (heat-resistant luting clay) and subjected to a blast of heat until the stone glows red. Once cooled and removed, the yellow coloration is found to have sloughed away, leaving behind a colorless, white stone. This stone may then be dyed in any color desired, and the result will manifest exactly as intended [7].

This technique is known as "Thermal Decolorization", which involves modifying the crystal lattice structure of natural gemstones. The process relies on the principle of "modifying color centers" within the crystals, specifically, yellow sapphire which typically derives its coloration from iron impurities or from lattice defects when exposed to elevated temperatures within an environment rich in ammonium chloride.

During the sublimation process, ammonium chloride acts as a "reducing" or "chlorinating" chemical medium, facilitating the extraction or neutralization of the iron ions responsible for the yellow coloration. Thermal treatment conducted in a "Clay of Wisdom" (a sealed, insulating system) induces an electron rearrangement within the crystal lattice, which then results in the shedding of the yellow hue and the transformation of the stone into colorless corundum (Leuco-

sapphire). The resulting white stone is characterized by newly induced microscopic porosity or vacant ionic receptor sites rendering it primed for a capillary diffusion process. This process allows the stone to be imbued with artificial colors (such as sky-blue) by infusing new metal oxides into its physical structure, which is the technique that represents the pinnacle of medieval gemstone engineering.

He then presented a fourth method, stating that: "To reveal the secret of transforming Maha into ruby, take as much silicon dioxide as you desire and fashion it into cabochons. Then steep these stones in the soap solution known as *Ra's* water for three days. Next grind laurel dust using urine as a medium into which you cast the stones for another three days. Subsequently, boil fuller's earth until it turns yellow; then grind clarified saltwort ash using vinegar and apply this mixture to the stones. The result is a ruby of the utmost beauty [6].

This technique relies on the principle of "chemical etching", followed by "surface ionic doping." The process begins by steeping the silicon dioxide in a strong alkaline medium (soap solution) to enhance surface porosity and disrupt the external molecular bonds. Orpiment (arsenic trisulfide) is dissolved in an acidic uric medium (urine) and utilized as a source of coloring ions; meanwhile, clarified potassium/sodium carbonate combined with acetic acid (vinegar) acts as a localized fluxing agent upon heating.

Thermal treatment in this "washing solution" stimulates the diffusion of arsenic ions and associated minerals into the microscopic fissures of the crystal surface. The result is a "hybrid stone" that retains its original quartz core while acquiring a chemically integrated surface layer that mimics the color and optical depth of ruby, which is the process known in modern terminology as "thermal diffusion treatment."

He then proceeded to describe the method for imitating gemstones through coloration: "Know that these craftsmen fashion gemstones from amber, marcasite, lapis lazuli, emery, agate, glass, crystal, and indeed from any material to which the designation 'gemstone' may apply. As for those fashioned from glass, they are dyed using two distinct methods. The first involves preparing a paste from barley bran much in the same manner that dyestuffs are prepared; and taking a slab of red clay that has been tempered with this barley bran. They then fashion square or circular molds or any shape they desire and press them into the clay slab, thereby creating hollow recesses within the slab where the gemstones are to be seated. These recesses resemble the settings found in jewelry mounts, capable of accommodating five or six stones. They then take the colored glass dyed to whatever hue they wish and, using tongs, they insert it into a furnace fueled by the aforementioned barley bran. They then apply a blast of air until the glass melts and flows into the molds; they then withdraw the piece and allow it to cool. Subsequently, they grind and polish the stones using water and a polishing stone, and finally, they give them a finishing boil using walnut wood. The result is a product that rivals the finest quality rubies. As for the second method for crafting these gem-stones, a detailed explanation would be quite lengthy; however, the information provided thus far should suffice for any intelligent and discerning individual [7].

Here, Al-Jawbarī [7] transitions from the realm of "transformative alchemy" to that of "mechanical molding engineering and surface thermal treatment." This particular recipe relies upon the technique of "open-mold casting," combined with advanced physical and chemical surface treatments. The process commences with the creation of "ceramic" molds fashioned from red clay reinforced with barley bran; in this context, the plant fibers (the bran) serve as a structural strengthening agent, preventing the mold from cracking under thermal shock while simultaneously facilitating the venting of gases. Colored silica (glass) is melted in "bran furnaces", which provide a uniformly distributed thermal environment. The critical stage is "mechanical polishing," utilizing a carbon- or stone-based abrasive to remove oxidized layers, followed by a process of "hot oil treatment" or "walnut wood boiling." In this stage, the phenolic compounds and volatile oils present in the walnut wood act as "chemical polishing" agents, penetrating the microscopic surface pores of the glass, which enhances its light-reflecting properties and imparts to the facets an "acrylic-like" luster that mimics natural ruby in both its color depth and visual brilliance.

Subsequently, Mīr Sayyid Sharīf 'Alī ibn Muḥammad al-Jurjānī [14] authored a specialized treatise in Persian detailing the methods for manufacturing rubies [12].

6. The Manufacture of Agate

Al-Jawbari noted that the Arabs were familiar with the dyeing of agate long before the Europeans. He stated that: "To reveal the secrets of dyeing agate and etching it, the results are such that anyone who beholds the stone would harbor no doubt that its appearance is entirely natural. I have observed a group of practitioners in the arts of astrology and talisman art crafting various items using these methods, in which they deceive people to whatever extent they desire. When they wish to undertake this process, they tamarisk leaves and mix them with a double quantity of alkaline ash, then saturate the mixture with water until it acquires the consistency of an ointment. They then take a gemstone or stone specimen and etch it with whatever designs, images, or figures they desire, ensuring that the engraving is executed with precision. They proceed to fill the engraved recesses with the aforementioned chemical paste, allow it to dry, and then wrap the stone in a cloth. This bundle is placed inside a pot and subjected to gentle heat over a fire. After a period, they retrieve the stone; if they observe that the inscribed areas have turned a distinct, bright white, they deem the process complete. If not, they leave it for another hour until the desired effect is achieved. Finally, they remove the stone and wash it, whereupon they observe that every area beneath the applied paste has turned white, while the remaining surface retains its original red hue [7].



Figure 4.
This green synthetic affordable agate may be preferred to natural ones.
Source: <https://www.gemsnegems.com/product/lab-created-green-agate/>

This "superficial chemical process" diverges from total fusion and shifts toward the "localized chemical modification" of hard stone surfaces, specifically agate, through techniques involving "thermo-alkaline bleaching." This technique relies on the principle of the "photochemical and thermal decomposition of iron impurities" embedded within the crystalline structure of agate (Chalcedony). Red agate known as Carnelian consists of crystallized silica containing impurities of iron oxide (Hematite).

Upon the application of the "remedy" composed of tamarisk ash (rich in potassium) and sodium carbonate, a highly concentrated alkaline medium (a caustic paste) forms in the incised grooves. Through gentle heating (using a soft flame), a chemical reaction ensues that converts the colored iron oxides into colorless or white sodium and potassium compounds, or effectively leaches these ions out of the surface's crystal lattice. This process results in "localized decolorization," wherein the incised area takes a brilliant white as a result of light reflecting off the pure silica, now stripped of its impurities while the remainder of the stone retains its original red hue. This methodology bears a striking resemblance to modern "dry etching" techniques currently employed to modify the surface properties of semiconductor materials.

In 1902, the French scientist Auguste Verneuil successfully synthesized agate, a process that allowed him to dye the material to any desired color. The resulting synthetic agate so closely mimicked the color and appearance of natural agate that distinguishing between the two became exceedingly difficult [2].

7. The Manufacture of Pearls

Contemporary methods for imitating pearls typically involve crafting hollow glass spheres, the interiors of which are then coated with a fish-based glue containing powdered scales from the Aplet a small species of fish. The nacreous substance surrounding the base of this fish's scales known historically as the *Fat of the Easterners* is utilized to endow the imitation pearls with the luster and appearance of natural pearls, which is subsequently preserved in a solution of ammonium hydroxide [2].

The art of manufacturing and imitating pearls has been known since the era of Jābir ibn Ḥayyān [1] who himself documented and presented several distinct methods for achieving this craft. He summarized his notes as follows: "To create pearls, carve as many as you desire of spherical olive-shaped beads from marine shells. Such beads can be readily obtained in their carved form from bead-makers, so you can procure the quantity you require. Thread them onto a string, wash them, and immerse them without touching with your bare hands in a thin solution of cheese glue. Once you withdraw them from the glue, allow them to drip until the coating is uniform, ensuring no single spot is thicker than another.

Next, coat the bead with a layer of talc (powdered mica) suspended in liquid, and suspend it in the sun until it dries. Inspect the bead; if you observe any uneven spots or depressions, file them down until the surface is perfectly smooth, then polish it using a jeweler's polisher. If the talc coating appears complete and flawless, proceed to the next step; otherwise, return the bead to the cheese glue and talc bath repeating the initial process and allow it to dry again. The coating may be perfected in a single attempt, or it may require two or three repetitions. Once the surface is smooth and even, polish it using an iron polisher. Finally, wipe the bead with a very light application of mastic oil (specifically, the prepared variety). Suspend the bead on a string between two bowls and leave it in the sun for two or three days or longer to prevent dust or

debris from settling upon it. Conclude the process by rubbing the bead with a linen cloth to give it a final polish. Should you desire to enhance its luster further, repeat the application of mastic oil and the subsequent drying process to intensify its brilliance [1].



Figure 5.
These natural cultured pearls have been extracted from one single oyster.
Source: <https://syperlas.com/en/pages/tahitian-cultured-pearls?srsId>

This recipe represents a transition from "chemical synthesis" to "Thin-Film Engineering" for the production of high-quality artificial pearls. This technique relies on mimicking natural "nacre" (mother-of-pearl) by constructing interconnected Nano-scale layers. The process begins by utilizing calcium carbonate (marine shell) as a structural substrate, which is then coated with cheese casein (cheese glue), which acts as a natural polymer to serve as a flexible, adhesive binding agent. Finely ground talc (magnesium silicate) is applied over this colloidal medium, where the micron-sized talc platelets serve to scatter light and induce "optical interference," imparting a pearlescent luster (iridescence) to the bead.

This is followed by a mechanical polishing process to smooth the surface and eliminate imperfections, after which the layers are coated with mastic resin. This resin acts as a "protective varnish" and enhances the surface's refractive index. Repeated application of this process results in the accumulation of "multi-layered thin films," deepening the optical luster and thereby creating a comprehensive physical and chemical simulation of natural pearls through coating and layer-deposition techniques.

There is another method for creating pearls, described as follows: "Take small pearls, crush them, and wash them with water and salt. Then, pour over them some distilled sorrel juice in a clean vessel; keep the vessel in a warm place and shield it from dust. As the liquid level diminishes, replenish it until the mixture acquires a dough-like consistency. Next, take white seashells and plaster them by roasting them in a kiln until they turn into a substance resembling gypsum. Then, take the quantity you desire from washed mercury that has been sublimated three times using vitriol and salt, and subsequently sublimated once more using salt alone (by heating it between two inverted cups) until it appears as white as snow. Take one part of each of these ingredients and knead them together in a cup. Before doing so, wrap your finger in a clean, thick binding preferably silk that is impermeable to water. Use only a minimal amount of the distilled sorrel juice for kneading, should you find it necessary. Then, wash your hands thoroughly and place a piece of pure white silk upon your palm. Take a portion of the prepared paste selecting a quantity appropriate for the size of the pearl you wish to create, and place it in the center of a thick piece of cloth. Roll and shape the paste to your desired size upon a silk rag placed inside a bowl or dish, and cover it with another rag. Once it has dried, prepare a second, drier paste using pure white henbane seeds, and place a small lump (about the size of a hazelnut) of this dry paste inside the pearl core. Take a larger portion (roughly the size of a small loaf) of the original paste and embed the henbane filling in its center, and seal it by covering it with another layer of the paste. Place the formed pearl on a baking tile inside a kiln or oven, and cover it. Once you determine that it has fully set, remove it. If the result meets your expectations, it is complete; otherwise, if it has failed, there are two possible courses of action: .

- The first method involves encasing it within a loaf of bread or a flatbread.
- The second method is to embed it in dough; feed it to a chicken, keep the chicken confined for two or three days, then slaughter it and retrieve the object from its gizzard.
- A third variation involves placing it inside a fish and roasting it; this method is considered superior to using the chicken's gizzard [1].

This recipe relies on the reconstruction of calcium carbonate aragonite in a "chemical mortar" matrix. It begins by breaking down the structural bonds of small pearls using a "distilled acid" (a weak organic acid) to create a paste from plastered shell powder (calcium oxide). The addition of sublimated mercury (mercuric chloride) acts as both a "bleaching" agent and a chemical binder, imparting an internal metallic sheen that mimics the natural "luster" of nacre. The formed spheres then undergo a process of "hydrothermal/biogenic annealing"; heating them inside the "loaf of bread" provides

uniform, moist heat that prevents cracking and facilitates the hardening of the mortar.

As for the "biogenic integration" technique (inside the chicken or fish), it represents a remarkable approach that utilizes digestive enzymes and a warm, acidic internal environment to polish the external surface and modify its luster through subtle biochemical reactions. This process yields a composite pearl characterized by regularly aligned calcareous layers that in terms of their luster and light translucency closely resemble natural pearls.



Figure 6.

It will not be easy to distinguish between synthetic (left) and natural (right) pearls.

Source: <https://syperlax.com/en/pages/tahitian-cultured-pearls?srltid>

A third method for creating pearls involves taking pure shell, clear crystal, and pearls of equal quality. The mixture is thoroughly pounded and ground together with zinc oxide, sal ammoniac, and distilled vinegar, and if the sal ammoniac itself is distilled, the result will be even more potent. Place this mixture into a sealed, clay-lined vessel and subject it to heat for two days and two nights in a furnace featuring a graduated temperature profile. Upon removing it, you will find it transformed into crystalline fragments gems more exquisite than pearls. Should you wish to shape it, you may proceed to do so. If this process is applied to actual pearls which must first be pierced, they are then subjected to this specific calcination method while embedded in a protective medium, such as dough or a similar substance capable of withstanding the heat of the fire. Beyond its proven efficacy and relative simplicity, this technique offers a singular advantage: if the resulting material is fashioned into elegant vessels such as a cup, a goblet, or a delicate tray and is subsequently encased in dough (or a similar medium), covered with a matching layer, and placed between two vessels over a fire, it will emerge as a vessel of pure "pearl-substance." Such a vessel is priceless; its luster possesses the very iridescence of pearls, for it is derived from pearls, mother-of-pearl, or should you choose to incorporate it crystal.

The proper method of preparation involves grinding the ingredients to an extremely fine consistency. Indeed, the quality of the final product depends entirely upon the thoroughness of the grinding, the kneading, and the shaping executed with the utmost craftsmanship as well as the subsequent calcination process that induces its solidification, in accordance with the principles we have outlined elsewhere in this book. Be aware that, of all the challenges encountered by practitioners, none is more difficult than the process of solidification; indeed, no substance will successfully solidify except through the specific methods I have prescribed for all such alchemical operations.

Furthermore, understand that if you take the material while it is still moist and in a kneaded state, and expose it directly to the dry heat of a fire, it will yield absolutely nothing of value. This principle necessitates a specific protective strategy, which falls into three categories: the first involves encasing the material in a protective layer possessing a "hot and moist" temperament. This ensures that the intense heat of the furnace is transmitted to the material in a controlled manner sufficient to effect the transformation without causing the material to crack, crumble, or otherwise be ruined. Examples of such protective mediums include the entrails of a chicken, dough, fish, and similar substances.

The second method involves drying it and subjecting it to fire. The third method entails utilizing the initial preparatory process, specifically, the incorporation of specific admixtures to impart a temperament that is either "hot and moist" or "hot and dry." Our discussion here relies on analogy and metaphorical description; for even if the substance itself does not inherently possess a "hot and moist" or "hot and dry" nature, such properties are introduced through the aqueous media employed during the preparatory stages such as solutions of ammonium chloride, various salts, and other chemical agents. As for the washing process, it is performed in two ways representing the most complete and refined methods available: either using distilled, dissolved mercury water (a technique considered the ultimate standard of purity), or using "hot waters," such as solutions of salts and other dissolving agents [6].

The subject addressed in this text closely resembles the technique of "Bioceramic Synthesis" for the production of "Bulk Synthetic Pearl"; a material capable of mechanical shaping. This specific formula relies on the principle of "Carbonate Recrystallization" in a glassy matrix in which "seashells and pearls" serve as the source of calcium aragonite (CaCO_3) characterized by its layered biogenic structure, while "rock crystal" serves as the source of silica (SiO_2). The process commences with the mechanical and chemical activation of the surface through "Nanomilling" (ultra-fine grinding) in the presence of ammonium chloride and zinc oxide, in an acidic medium (vinegar). In this context, distilled ammonium

chloride functions as a "Chemical Transport Agent", that facilitates the dissociation of the raw materials' ionic bonds and their subsequent rearrangement.

The thermal phase that is conducted in a furnace featuring a graduated temperature profile over a period of 48 hours aims to transform the prepared paste into a composite material. The text demonstrates a profound understanding of "Heat Transfer Mechanisms"; specifically, the utilization of a "paste" or "lining of the chicken" method is not a mere whim; rather, it is an application of the concept of "indirect heating within a moist medium" creating a hydrothermal-like environment designed to prevent the thermal stresses that lead to cracking. This technique ensures that heat penetrates slowly and uniformly, thereby facilitating gradual solidification without the loss of "optical water" (the pearlescent luster).

As for the "solidification" a feat that had eluded others, Jābir explains it scientifically in terms of phase equilibrium between the wet state (the paste) and the solid state (the ceramic body). The use of "dissolved mercury water" or "salts" during the final washing stage aims to achieve chemical-mechanical polishing (CMP), for these solutions work to remove microscopic protrusions and seal surface pores, thereby enhancing the optical interference necessary for the emergence of the "pearly luster" on the finished pearl vessels. The result is a "nacre-like glass-ceramic" material that combines the hardness of silica with the luster of biogenic carbonates [1].

Furthermore, Abdul Rahman Ibn Umar al-Jawbari revealed methods through which we can manufacture imitation pearls of such high quality that no one could distinguish them from genuine pearls. To accomplish this process, take small pearls and choice mother-of-pearl, and cleanse them of all external black impurities. Next, grind them into an extremely fine powder, which you then saturate with the juice of citron sorrel by dissolving the powder therein. Once it has dissolved and attained a dough-like consistency, incorporate snail mucilage into the mixture; some practitioners, however, prefer to add purified glue instead [15]. Then fashion a small silver spoon to scoop out the preparation in the desired quantity, specifically, an amount equivalent in size to a pearl. This portion is placed inside an eggshell and rubbed vigorously until it becomes warm.

Once the mixture has attained the desired consistency, set it aside to dry in the shade; taking great care to protect it from dust. When it has dried slightly, take a boar bristle and use it to pierce the bead, and leave it to dry completely before proceeding to the final stage: the "setting" process. The method for this setting varies: some practitioners encase the bead in a lump of dough and feed it to a black pigeon, which they then slaughter the following day.

Others feed it to a goose, taking care to ensure the bird consumes nothing else throughout that day. On the second day, the bird will excrete the bead, whereupon you retrieve it, rub it clean, and sell it. Still others embed the bead in chicken fat and wrap it in a scrap of red satin cloth. In this case, procure a fresh fish, which has just been caught from the water; clean it, and slit open its belly, removing everything from its interior save for the swim bladder (which they refer to as the "floater"). Then slit open the swim bladder, insert the bead into it, and tuck the bladder back inside the fish's cavity. Finally, stitch the fish's belly closed, place it in a baking pan, and cook it in an oven until the fish is thoroughly done. Upon removing it, find that the bead has transformed into a fine, exquisite pearl. Some practitioners, incidentally, substitute dissolved talc for the snail mucilage. Be aware that I am acquainted with forty-seven distinct variations of this technique, each differing in its specific procedure. Each procedure offers a high quality pearl [7].

This recipe relies on a technique known as "Biogenic Calcium Carbonate Restructuring." In this technique, aragonite is extracted from powdered pearls and seashells, and then treated with citric acid to transform it into a pliable, easily moldable paste. Snail mucilage or animal glue is employed as a polymeric binder, serving to mimic "conchiolin" the natural substance that binds the layers of a pearl together.

The critical stage is "biochemical processing," which takes place either within the digestive tracts of birds or through "enzymatic digestion" inside a fish's swim bladder. These biological environments provide a source of constant heat, digestive enzymes (such as pepsin), and gastric acids that perform a microscopic chemical polishing of the pearl's surface while simultaneously hardening the protein binder. Such a bio-thermal reaction endows the manufactured pearl with a characteristic "nacreous" luster known as *orient* resulting from the interference of light within its newly restructured protein and calcium layers. Consequently, the final product closely mimics natural pearls in both density and optical brilliance.

8. Conclusion

In this research, light was shed on all the scientific methods provided to us by Arab and Muslim scientists for how to manufacture and imitate gemstones, by virtue of which we have reached the following results:

1. Methodological leadership in applied chemistry: Arabic manuscripts (especially the works of Jābir Ibn Hayyān and Abu Bakr al-Rāzi) presented the first integrated and systematic research program for the synthesis of gemstones. This program was not limited to random recipes, but rather included a deep understanding of unified chemical-physical processes, such as controlling the ratios of reacting materials (Stoichiometry), controlling the temperatures of melting and sintering, using fluxes such as natron and borax, and separating the reaction stages (initial purification, melting, color grafting, and subsequent heat treatment), which reveals an advanced scientific and experimental mind.
2. Controlling materials and optical properties through advanced technologies: Scientific analysis of recipes showed that Arab and Muslim scientists used advanced technologies, centuries before their European counterparts, including:
 - High-Lead Crystal Glass engineering which aims to imitate the sparkle of precious stones (rubies and emeralds) by adding lead oxide in calculated concentrations.
 - Ion doping to modify color spectra in order to produce a wide range of colors (red, green, violet and yellow) by adding fine metal oxides (copper, iron, chromium, manganese) to the silica matrix, with an implicit understanding of redox reactions.

- Colloidal synthesis of noble metals: Al-Rāzi presented a recipe for producing “red rubies” by melting gold and copper filings into glass, which is an early and amazing documentation of the “Gold Ruby Glass” technology that relies on the dispersion of gold nanoparticles (Surface Plasmon Resonance), a technology that was not physically understood and produced commercially in Europe until the seventeenth century.
- 3. The texts document advanced methods for improving natural stones or changing their colors through “chemical etching” and “thermal shock,” creating surface porosity, followed by soaking in organic and mineral solutions with controlled heating. This method represents an early form of the “diffusion coloring” technique, used recently in the treatment of rubies and sapphires.
- 4. Biogenic-Inspired Processing: The research revealed a fundamental and unprecedented innovation in the texts of Jābir Ibn Hayyān and Al-Jawbari, including the processing of artificial pearl pellets inside animal organs (chicken gizzard or fish intestines) after cooking them. This process is not a ritual, but rather represents a deep understanding of harnessing “Biogenic Annealing” using digestive enzymes and a warm, regular humid environment. The objective is to polish the surface chemically, harden the binding proteins, and precisely mimic the layered structure of natural mother-of-pearl.
- 5. Establishing a quality testing system (Quality Control): The texts included clear physical and chemical indicators to determine the successful completion of the reaction, such as a viscosity test using a metal rod, an examination of color and transparency, and a hardness test. These tests form the early nucleus of quality control systems in industrial laboratories.
- 6. Filling a major chronological gap in the history of science and technology: By chronicling and scientifically analyzing these practices, the research corrects the Eurocentric narrative of the development of modern chemistry and materials science. It proves that the techniques for creating rubies, emeralds, lapis lazuli, and pearls did not appear suddenly in the nineteenth century with Verneuil and Chatham, but rather are the result of a long-term accumulation of knowledge, at the heart of which was the Arab-Islamic civilization, which was seven to ten centuries ahead of Europe.
- 7. Redefining the concept of “imitation stones” in the ancient scientific context: The research proves that Arabic texts were not just an optical illusion, but rather sought to imitate nature (mimesis) by constructing a material similar to the original material in its composition and basic properties (hardness, luster, density). This elevates the concept of “counterfeiting” from a mere commercial fraud to an authentic scientific research enterprise aimed at understanding and reproducing the material.

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