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Tekhelet: Setting the Ancient Record Straight

The past two decades have seen a seeming explosion of both scholarly and popular examinations of *tekhelet*, the biblical dye, and its revival in practical halakhic practice. However, one of the main problems related to this field is that most of those who have written or lectured on this subject have never themselves dyed with the purplish pigment extracted from certain sea snails with the same materials and methods that were utilized by the ancient dyer. In performing dyeings with the natural materials available in antiquity—and not with the synthetic materials used today—one gains certain insights into the ancient dyeing process and what was possible to accomplish.[1] Because the production of wool-dyed *tekhelet* is a chemical process, it is obviously vital that those ruling on its halakhic validity be aware of the full scientific aspects associated with this craft as practiced in antiquity. Unfortunately, in this case, rabbinical authorities rarely possess a full grasp of this knowledge because nearly all writers and lecturers have presented only a partial picture while ignoring certain talmudic, historical, and scientific problems related to their deliberations. This results in serious consequences regarding two main points related to the production of *tekhelet*: the identity of the specific sea-snail (*hilazon*) and the final color of the woolen dyeing.

This article aims to set the biblical-talmudic, archaeological, and scientific record straight through a critical examination of the processing of *tekhelet* as it would have been performed in ancient times. I will also attempt to correct various erroneous statements presented in some

[1] Zvi C. Koren, "New Chemical Insights into the Ancient Molluskan Purple Dyeing Process" in *Archaeological Chemistry VIII*, ed. Ruth Ann Armitage and James H. Burton, ACS Symposium Series 1147 (American Chemical Society, 2013), 43–67.

DOI: 10.54469/LPJ6OAYG6

TRADITION 54:1 / © 2022
Rabbinical Council of America

written and oral discussions of *tekhelet*. Additionally, the source and color of its non-identical twin, *argaman*, will be identified.

The results discussed here are based on my three decades of experimenting with natural dyestuffs, including the first successful reconstruction in Israel of the all-natural Murex-snail dyeing as practiced by the ancient purple dyer.[2] Further, instrumental chemical analyses that I performed on archaeological textiles from Israel and beyond have also resulted in a deeper understanding of the dyeing process. What is clear is that the modern practiced method for the production of blue-colored *tzitzit* is definitely not the way that *tekhelet* was produced in antiquity. A solution out of this dilemma is presented in my concluding remarks.

The Modern Color of Ancient Tekhelet

Ask any Israeli youngster today what is the color *tekhelet* and the child will point to the clear blue daytime sky above. However, we cannot extrapolate back in time and automatically state that the color of biblical *tekhelet* was identical to daylight sky-blue as would be indicated by modern Hebrew. According to tradition, its hue is blue—or better "bluish"—however, interpreters of the Bible are radically diverse in their view as to how "bluish" was *tekhelet*'s color. These divergent renditions range from green, turquoise, blue (light and dark), to dark blue-purple (or violet).

It is clear that the Talmud's understanding of the meaning of *tekhelet*, as given by Rabbi Yishmael, is that it is the color of the wool-dyeing, "*tekhelet amra hu*," i.e., not the color of the raw pigment extracted from the sea snail.[3] However, before delving two millennia back, we will make a stop in the medieval period in order to understand the speculations regarding *tekhelet*'s color from Rashi and Rambam. Regrettably, their actual statements have been misunderstood by some commentators.

Rashi's Color Conundrum

Some modern interpreters commit two errors—one of omission and the other of commission—regarding Rashi's position on the color of *tekhelet*. Some omit the fact that Rashi consistently referred to the color of *tekhelet* as green (*yarok*). Conversely, some state that Rashi's judgement was that *tekhelet* was the color of the dark skies at night.

[2] Zvi C. Koren, "The First Optimal All-Murex All-Natural Purple Dyeing in the Eastern Mediterranean in a Millennium and a Half," *Dyes in History and Archaeology* 20 (2005), 136–149, color plates 15.1–15.5.

[3] *Yevamot* 4b.

Rashi and his contemporaries, living in eleventh-century north-central France, undoubtedly never encountered an authentic *tekhelet* textile. Already in the early Geonic period, approximately the second half of the first millennium, we already have the statement from *Midrash Tanhuma*: "And now we do not have it [*tekhelet*], but we only have white [cords of the *tzitzit*] because the *tekhelet* has been concealed."[4]

Rashi consistently held that the color of *tekhelet* is green (*yarok*) from the first mention of *tekhelet* in the Bible and through the Talmud.[5] This determination undoubtedly stems from his misinterpretation of the following citation in the Talmud regarding the earliest time at dawn when one can say the morning's *Shema* prayer:

> From when may the morning's *Shema* be recited? When one can distinguish between [the color of] *tekhelet* and white. Rabbi Eliezer says: [When one can distinguish] between *tekhelet* and [the color of] leek.[6]

The analogy between *tekhelet* and the leek vegetable (*karti* or *karatei*), whose upper leaf sheaths are dark green,[7] can be misconstrued as if the color of *tekhelet* is nearly identical to the color of leek under all circumstances. A careful reading of the Mishna indicates that it is not that they are very similarly colored, but that in a setting with minimal light it is difficult to distinguish between them. There is a latent awareness in the statement by R. Eliezer that both leek and *tekhelet* have dark shades, and that only at dawn's early light can you differentiate between these two.[8]

A further direct statement from Rashi showing that he considered *tekhelet* to be green like *karti* is evidenced from his explanation of "*sarbela de-karti*" (a green cloak, or overalls): "The color of *tekhelet*, similar to *karti*."[9]

[4] *Tanhuma Shelah* 15. All translations throughout are my own, in order to be as exacting as possible to the original text, and may differ from other published translations.

[5] Exodus 25:4, Numbers 15:38; *Berakhot* 9b (Mishna 1:2), 57b.

[6] Mishna *Berakhot* 1:2.

[7] Greek philosophers, e.g., Democritus (about 460–370 BCE) and Aristotle (384–322 BCE), also used leek to describe a dark leek-green color (*prasinon*). See, e.g., P. Struycken, "Colour Mixtures According to Democritus and Plato," *Mnemosyne,* Fourth Series, 56, 3 (2003): 273–305.

[8] A modern analogy concerning the difficulty in discerning a dark-green object (leek) from a dark-bluish one (*tekhelet*), according to R. Eliezer, might be a man in a relatively dark closet trying to select a tie with one of these dark colors, without turning on the light so as not to wake up his sleeping spouse—a very difficult task.

[9] *Gittin* 31b s.v. *sarbela*.

Some have stated that Rashi's *yarok* can be a green-blue (turquoise-like) color, a possible outcome if we stretch Rashi's green into its neighboring blue hue in the visible light spectrum. However, his *yarok* cannot be "blue" as Rashi himself differentiated between them in his explanation regarding the Gemara's discussion of whether certain colors of animal lungs render the animal to be *taref*, or conversely, kosher: "[The meaning of] 'like *kohala*': blue (*kahol*) color similar to the appearance of azure, not green (*yarok*) and not black (*shahor*)."[10]

Rabbi Moshe HaDarshan

Rashi does present an opinion that the color of *tekhelet* is like the darkening skies at nightfall; however, it is not his interpretation.

The commandment to place a *tekhelet* fringe as a *tzitzit* on the corner of a garment appears at the end of *Parashat Shelah* (Numbers 15:38), and a cursory reading of Rashi's commentaries seems to indicate that he is describing two different colors for *tekhelet*. Specifically, after describing *tekhelet*'s color as green (in verse 38), just three verses later he seemingly attributes a completely different color to *tekhelet*—a night-time color.

A literal reading of Rashi shows that there is no contradiction. After he finishes his explanations (for verse 41) and concludes his discussion of the *parasha*, he adds an addendum, the introduction of the work of a respected source, R. Moshe HaDarshan.[11] Rashi mentions this Rabbi Moshe more than two dozen times throughout his commentaries. In Rashi's words, he writes: "From the work of Rabbi Moshe the Preacher I transcribed [the following interpretation]." That is, all the commentaries following this statement are not Rashi's position, but Rashi citing the interpretations of R. Moshe HaDarshan on various topics from the *parasha*.

In order to describe the color of *tekhelet*, R. Moshe HaDarshan undoubtedly borrows the etymological analogies made in *Sifrei*. The following midrashic passage uses phonetic wordplays around the word *tekhelet*, which may or may not stem from the same root:

> R. Elazar son of R. Shimon says: Why is it called *tekhelet*? Because the Egyptians were "bereaved" (*nitkelu*) [similar sound to *tekhelet*] of their first-born. As it states [Exodus 12:29]: "And it was in the middle of the night (*va-yehi ba-hatzi ha-laila*) that the Lord smote every first-born. . . ."

[10] *Hullin* 47b s.v. *ke-kohala*.

[11] R. Moshe HaDarshan was a French Rabbi from Provence, a preacher, exegetist, author of various works, and active in the first half of the eleventh century. See Hannanel Mack, *Misodo shel Moshe ha-Darshan* (Bialik Institute, 2010).

> A different explanation [for the name *tekhelet*]: Because the Egyptians "perished" (*kalu*) [– again similar sound to *tekhelet* –] in the sea.[12]

Besides the wordplays on *tekhelet* to phrases associated with the slaying of the Egyptian first-borns as well as with those chasing after the Israelites in the sea, the *Sifrei* does not explain the connection between these calamitous events and the color of *tekhelet*. It is up to R. Moshe HaDarshan to provide this association, and he adopts a similar phonetic interpretation to the word *tekhelet* as appeared in the *Sifrei*, but with one additional major difference that unites these wordplays:

> *Petil tekhelet*: a reference to the "bereavement" (*shikul* or *shekhol*) of the firstborn. The [Aramaic] translation of "bereavement" is *tikhla* [similar in sound to *tekhelet*]. And their plague was at night, and so, too, the color of *tekhelet* resembles the sky that darkens at evening time.[13]

Manuscripts also show the clear demarcation between Rashi's commentaries and his citation of R. Moshe HaDarshan. In these manuscripts, when Rashi wanted to emphasize the end of a section or *parasha*, he writes the word *haslat*, meaning "finished."[14] Thus, in one of the oldest surviving Rashi manuscripts from thirteenth-century Leipzig (B.H. 1), the word *haslat* is written at the end of a line that finishes Rashi's comments, and the opening of the next line begins with Rashi citing the commentaries of R. Moshe HaDarshan.[15] Another document clearly showing the beginning of R. Moshe HaDarshan's comments is from the precisely formatted Oxford University's Bodleian manuscript (Oppenheim 34), dated to 1201–1225, just a century after the passing of Rashi.[16]

Ibn Ezra

In a similar vein, it is interesting to note the dichotomy in the commentary of Ibn Ezra regarding his view about the color of *tekhelet*. Though he was born in Spain and lived much of his time there, he wandered about and dwelt in various countries. While in northern France, he was aware of the commentaries of Rashi and his grandson, R. Jacob ben Meir, also known as Rabbenu Tam the Tosafist. Ibn Ezra was conflicted as to whether to

[12] *Sifrei* Numbers 115:1.

[13] Though *Sifrei* did not explicitly state the color of *tekhelet*, but it could be inferred from its wording that it was like the night-time sky.

[14] *Haslat* has the same root as "*hasal*," as in the Haggadah, "*hasal siddur Pesah*" ("the Passover Seder is finished").

[15] Leipzig UBL Ms. B.H. 1, p. 278: https://tinyurl.com/2rz95e2p.

[16] Bodleian Library Ms. Oppenheim 34, Folio 86r: https://tinyurl.com/9b4fu92v.

concur with Rashi and his progeny, or with the phonetic explanation of Yefet, the Karaite exegetist who flourished in the second half of the tenth century, and whom Ibn Ezra cites several times in his biblical interpretations. Ibn Ezra's commentary in *Parashat Teruma* (Exodus 25:4), follows:

> And *tekhelet*: Yefet said that it is like the image of blackness (*shah'rut*) because it is the completion [or end] (*takhlit*) [similar sound to *tekhelet*] of all colors. And all will return to it, and it will never return by human action. But we will rely on our Sages [Rashi and family] of blessed memory, who said that it is green (*yarok*) and it is wool.

In summation, Rashi's viewpoint is that *tekhelet* is a leek-green color, but Rabbi Moshe HaDarshan comments that it is like the night-time sky. Similarly, the Karaite Yefet states that *tekhelet* is blackish, but Ibn Ezra respectfully follows Rashi's green interpretation.

Rambam's Color Characterization

For an understanding of Rambam's original viewpoint, unadulterated by later and modern commentators, it is vital to use the oldest hand-written manuscripts, as printed editions have sometimes significantly strayed from Rambam's original text.

Rambam states in his commentary on Mishna *Menahot* (4:1) that in his day there was no *tekhelet*. Thus, from the oldest surviving commentary on the Mishna penned by Rambam himself in Judeo-Arabic he writes:

> And it [*tekhelet*] is no longer with us today, because we do not know how to dye it, since not every "blue" (*azrak*) hue in wool is called *tekhelet*, but it is a certain "blueness" (*zarka* or *zerka*), which is not possible today.[17]

Rambam continues to use the Arabic term *azrak* in his description of *tekhelet* in his commentary on Mishna *Kilayim* (9:1).[18] Further, in *Mishneh Torah* he offers a more detailed description of the shade of "blueness" that he envisioned (discussed below).

[17] See Bodleian Library Ms. Pococke 295, folio 185r (https://tinyurl.com/ytv46hra), and also the modern Hebrew translation given by Rabbi Yosef Kapah. My translation of "not possible today" follows Kapah, but the exact meaning is somewhat unclear and may be translated as "unobtainable."

[18] Bodleian Library Ms. Huntington 117, folio 69r: https://tinyurl.com/2r47vdd4. This manuscript was also written by Rambam.

In the first chapter of *Hilkhot Tzitzit*, Rambam gives a very succinct explanation of *tekhelet*: "Wool that has been dyed like the color of the sky."[19] In the second chapter, he follows with much more detail regarding the color of *tekhelet*, though he does it in a circuitous fashion:

> *Tekhelet* mentioned everywhere in the Torah is the wool dyed [to a shade whose appearance is] as a "mix with kohl," (*ka-patukh she-ba-kohal*), and that is the image of the sky that is seen in its purest ("*be-tohoro shel rakia*"). And the *tekhelet* that is mentioned with regard to *tzitzit* must be dyed according to an established dyeing [procedure] that maintains the beauty [of the colored wool] without changing [its color]. And any [wool] that was not dyed in the same manner of dyeing is invalid for *tzitzit*, even if it has the color of the sky, as for example, it [wool] was dyed with woad" (*isatis*) or with others [dyestuffs] that produce blackish [i.e., dark colors] ("*ha-mash'hirin*"), it [the dyed wool] is invalid for *tzitzit*.[20]

There are a number of key points made by Rambam in his exegesis. Firstly, in the Bodelian and in other early manuscripts, the word used is "*kohal*"—etymologically equivalent to "kohl"—the black eye makeup, which typically consisted of the mineral galena (lead sulfide) and other compounds.[21] In some printed editions, *kohal* was erroneously replaced by *kahol* (blue), a problematic transcription mistake to make.

Linked to the word for kohl, Rambam uses the term *patukh*, which means a mix or blend. Rambam employed this mixing imagery of blending two colors in describing various reddish colorations of skin blemishes due to being afflicted with leprosy, and to whether such colorations render a person as ritually impure.[22] Some of these skin blotches can be pinkish or more reddish, and Rambam described how to visualize such colors by mixing small drops of blood (red) with much milk (white).

In the case of *tekhelet*, Rambam is using a virtual imagery of mixing with kohl, however, unlike the case of adding blood to milk, he does not specifically mention what is to be mixed with black kohl and how much. By analogy, it can be understood that in this *tekhelet* mixing process, only

[19] *Hilkhot Tzitzit* 1:1. Bodleian Library MS. Huntington 80, folio 140r: https://tinyurl.com/ytwt8fw5.

[20] *Hilkhot Tzitzit* 2:1. Bodleian Library MS. Huntington 80, folio 141v: https://tinyurl.com/7bsjb5wr; and cf. *Hilkhot Kelei ha-Mikdash* 8:11, https://tinyurl.com/4ksce3sy, fol. 19v, image 020.

[21] This black eyeliner was used by women for thousands of years, as apparent in many Egyptian wall paintings.

[22] *Hilkhot Tum'at Tzara'at* 1:4–6, 9; 7:2.

a very small amount—"a few drops"—of a color is to be added to kohl. Further, Rambam discussed a well-known indigo-producing plant (*isatis*) whose leaves were used for producing bluish dyeings that were "blackish" (*mash'hirin*).[23] Thus, it seems most likely that Rambam's *tekhelet* has the resultant color obtained by virtually mixing some blue with much black kohl, i.e., a dark-bluish appearance.

Interestingly, in both blending cases (blood to milk; blue to kohl), the medieval Rambam is actually applying modern color theory in describing the "tint" and "shade" of a color, respectively. Accordingly, tint typically refers to the mixture of a color with white to produce a lighter color (blood to milk); shade suggests a mixture of a color with black to produce a darker color (blue to kohl).[24]

A very serious problem encountered in many printed versions of Rambam in this context is the later insertion of the word "*shemesh*" (sun) into his description of "*tekhelet* resembling the skies." In the earliest hand-written manuscripts the word *shemesh* does not appear. Apparently, later copyists interjected their opinion as to the color of *tekhelet* into Rambam's words. If "sun" would have appeared in Rambam's statement, then the context would obviously refer to the color of *tekhelet* appearing like the sunlit sky. Because the word "sun" is missing from Rambam's original statement, it is likely that he is not referring to a daylight sky but to one where there is no sun, i.e., at night. This notion is consistent with his mentioning of dyestuffs that produce dark-bluish colors that would resemble that of *tekhelet*.

There is still some ambiguity in Rambam regarding his usage of the terms "purest sky" (*be-tohoro shel rakia*) and "the essence of the skies" (*ke-etzem ha-shamayim*), both phrases essentially referring to a "pure sky." Rambam's clear message throughout is that *tekhelet* is bluish—his reference to the *isatis* plant and his mention of blueness in Arabic (*azrak* and *zarka*). Rambam also effectively states that the shade of *tekhelet* is dark (as discussed). Therefore, I suggest, Rambam's "pure" sky refers

[23] *Isatis*, botanically known as *Isatis tinctoria* (commonly named "woad"), is mentioned in the Talmud as a dye plant. Dyeing with the bluish indigo pigment (also known as indigotin) is performed by the dual reduction-oxidation chemical process. In the ancient Near East and Europe, all blue dyeings were probably produced from this plant, as it is native to those wide-spread regions, though there are other indigotin-producing plants.

[24] Patti Mollica, *Color Theory: An Essential Guide to Color from Basic Principles to Practical Applications* (Walter Foster Publishing, 2013), 17.

to a sky devoid of any celestial bodies—sun, moon, clouds.[25] At night, a perfectly pure and clear sky indeed has a dark-bluish aura.

Integrating the various statements made by Rambam, who never saw an actual *tekhelet* textile, his viewpoint is that *tekhelet* was a dark-bluish color.

The Kala-Ilan Quandary

Among *tekhelet* aficionados, there is the popular notion that in order to identify the color of *tekhelet*, one need only look at the color of a dyeing that is produced by *Kala-Ilan*. "It's quite simple," goes the argument, for there is a clear admonition concerning using "fake *tekhelet*" produced from a dyeing that yields a color that is nearly indistinguishable to the human eye from the real *tekhelet*. This well-known warning is conveyed in the Talmud:

> Rava said: What is the reason that the Merciful One wrote about the Exodus from Egypt [in connection] with [each of the following: the prohibition of] interest, [the mitzva of wearing] *tzitzit*, and [the prohibition of adulterating] weights? The Holy One, blessed be He, declared: It is [only] I who [was able to] distinguish in Egypt between the drop [of seed that became] a firstborn [who was slayed] and the drop [of seed] that did not become a firstborn. [Therefore,] it is I who will punish one who ascribes [ownership of] his money to a Gentile and [unlawfully] lends it to an Israelite with interest, and from one who steeps his weights in salt [to artificially increase the weight], and from one who hangs *Kala-Ilan* [dyed fringes] on his garment and maintains that it is [authentic] *tekhelet*.[26]

A straightforward reading of this text implies that the color from *Kala-Ilan* is visually indistinguishable from *tekhelet*. However, there are problems with this coloristic equation. Firstly, even if *Kala-Ilan* is equated with the indigo-producing woad plant (Rambam's *isatis*), there is an inherent ambiguity as to the final color produced. The depth of color of any dyeing is dependent on various factors, such as the concentration of the dye solution, the quantity of textile, the duration the textile is dyed, and the temperature of the dye bath. Indigo-dyeings can range from light tints all the way to very dark (nearly "black") shades, depending

[25] This "purity" of an entity can also be regarded as in a chemical sense, i.e., only one component (the sky) exists without the presence of any foreign "impure" components (solar, lunar, and planetary bodies).

[26] *Bava Metzia* 61b.

on these dyeing factors. Thus, if a multitude of tints and shades of blue dyeings can be produced from *Kala-Ilan*, it cannot serve as an indicator of the coloration of *tekhelet*.

There is a second uncertainty regarding the *tekhelet* equals *Kala-Ilan* equation, and this concerns the chemical composition of indigo-dyeings. What many do not realize is that in the dyeings produced from indigo-producing plants there is another important constituent—the red indirubin dye.[27] Though bluish indigo is typically the main component, depending on how woad is processed, it is possible to also produce a significant quantity of indirubin in the dyeing. Thus, if a dyeing is composed of a mixture of red and blue dyes its resultant subtractive color property would be purplish, just like the mixing of paints. Hence, even in a dyeing produced from *Kala-Ilan*, the color may not be simply blue, but bluish- or reddish-purple.

Before discussing the third problem with coloristically equating *Kala-Ilan* with *tekhelet*, it is important to identify the etymology of the words *Kala-Ilan*. Probably the first to identify the meaning of *Kala-Ilan* was Rabbi Isaac HaLevi Herzog in his groundbreaking 1913 doctoral dissertation on *tekhelet* and *argaman*, which he titled *Hebrew Porphyrology*, because both sacred colors were produced from purple-producing sea snails.[28] According to R. Herzog, "*kala*" is a loanword in Sanskrit—the classical Indian language—meaning dark or even dark-blue.[29] Further, according to R. Herzog, the second word, "*ilan,*" may simply literally mean a tree, not in the strict halakhic definition of *ilan*, but from a visual

[27] Indirubin's name is derived from its reddish color ("*rub*-" in Latin, as in ruby) and "indi-" because its molecular structure is related to that of indigo. Chemically, they are structural isomers of each other: same number and types of atoms but having different geometric connectivities (chemical bonds) between these atoms. In my analyses of bluish archaeological dyeings, indirubin is often present, though usually as a minor component.

[28] See Isaac Herzog, "Hebrew Porphyrology" in *The Royal Purple and the Biblical Blue: Argaman and Tekhelet—The Study of Chief Rabbi Dr. Isaac Herzog on the Dye Industries in Ancient Israel and Recent Scientific Contributions*, ed. Ehud Spanier and Moshe Ron (Keter Publishing House, 1987), 94–95.

[29] Though I have not seen it mentioned elsewhere, it appears to me that "*kala*" and "kohl" are cognates as they both indicate blackish or dark colors and phonetically are very similar. That a Hindi word would enter the lexicon of the Talmud should not be surprising, as interactions between *Eretz Yisrael* and India are well-documented. Thus, the Talmud mentions such Indian products as *hinduyin* linen textiles worn by the High Priest on the afternoon of Yom Kippur (*Yoma* 34b), ginger (*Berakhot* 36b, *Yoma* 81b), a kind of a bread (*Berakhot* 37b), a bitter vegetable (*Bekhorot* 37b), iron (*Avoda Zara* 16a), and even the personage of Rabbi Yehuda, the convert from India (*Kiddushin* 22b, *Bava Batra* 74b).

standpoint as the woad plant can attain a height of about five feet, and thus may look like a small tree. Thus, *Kala-Ilan* may be translated as "dark (or dark-blue) from a plant," as opposed to certain mineral blues. R. Herzog offers another logical possibility for the etymology of *ilan* in that it is a textual corruption of the Indian or Sanskrit word for blue or indigo as *nila* and *nilan*. Thus, *Kala-nilan* (meaning dark blue indigo) could have easily become corrupted to *Kala-Ilan* to the ears of Aramaic and Hebrew speakers of the talmudic period.

I would offer another equivalent possibility for the root of "*ilan*" from Rav Amram bar Sheshna of the Geonic Period, head of the Talmudic Academy in Sura. In a Responsum dated from 857/858 CE, R. Amram Gaon interprets *Kala-Ilan* as "*lilang*, and in Arabic as *nil*."[30] The Persian word *lilang* has a few variants, such as *lilanj* and *lilag*, and they are associated with an indigo-producing plant, as is the Arabic *nil*.[31] Thus, as in the previous case, *lilang* easily became *ilan,* which gave it a Hebrew sound to once again denote that it is from a plant. Thus, from all the various equivalent possibilities for its etymology, *Kala-Ilan* means "dark-blue from a plant."

The third problem regarding identifying the color of *tekhelet* from *Kala-Ilan* is a textual omission. The earliest talmudic source mentioning *Kala-Ilan* is probably from *Sifrei* Numbers. The oldest surviving hand-written manuscript of *Sifrei* Numbers is from the tenth to eleventh centuries and is in the Vatican library. The extremely important pertinent citation regarding *Kala-Ilan* does not only mention it alone as a coun-

[30] Written in the manuscript (folio 64a), see below, as "Adar 169," which is actually year 1169 in the Seleucid calendar system. Genizah Fragments, Bodleian Libraries, University of Oxford, Ms. Heb. d. 63, Part 35, Folio 67b: https://tinyurl.com/d374hjxw. Also see: Louis Ginzberg, *Geonica II: Genizah Studies* (Jewish Theological Seminary, 1909), 301, 302, 309, 326, 333. Ginzberg notes that the Hebrew spelling is not clear from the handwriting in the manuscript, and that instead of *lilang*, it is possible that the scribe may have written it as *lilagg*. However, when magnifying the original text, it seems clear that the next to last letter is a *nun* and not the shape of a *gimmel*, so that *lilang* is the correct spelling in the manuscript.

[31] See, e.g., Reinhart Pieter Anne Dozy and Willem Herman Engelmann, *Glossaire Des Mots Espagnols et Portugais Dérivés de l'Arabe*, 2nd ed. (Leyde: E. J. Brill, 1869), 297. Also, Immanuel Löw, *Aramaeische Pflanzennamen* (Verlag von Wilhelm Engelmann, 1881), 347–348. During the Geonic Period, these plant names may have not specifically referred to woad but to another popular plant, the indigo plant itself (*Indigofera tinctoria*) or to others. Both *lilang* and *nil* with their variant forms are etymologically equivalent; see Walter William Skeat, *An Etymological Dictionary of the English Language* (The Clarendon Press, 1924), s.v. LILAC.

terfeit *tekhelet* color, but includes other dyestuffs as well: "I am giving colorants (*tziv'oni*) and *Kala-Ilan* and they are similar to *tekhelet*."[32]

The mentioning of "*tziv'oni/n*" together with "*Kala-Ilan*" in *Sifrei* Numbers, about two centuries before Rava's "fake-*tekhelet*" admonition, implies that their combination can imitate the color of *tekhelet*. This is apparent from the various archaeological textile dyeings from Ancient Israel and beyond that I analyzed, where combinations of red dyes with indigo produced dark bluish, violet, and purplish colors.[33] Perhaps Rava's main point was that there is imitation *tekhelet* available, and he omitted the "other dyes" phrase, since they were not specifically named, as his major aim is to forewarn people to use the real *tekhelet*. Alternatively, it may have been a later copy editor who decided to omit the non-specific "other dyes" from Rava's statement.

Summarizing, deducing the color of *tekhelet* from *Kala-Ilan* is highly problematic. If used alone, and depending on the manner in which it was processed, *Kala-Ilan* could have either produced light- or dark-blue, blue-violet, or bluish-purple colors. If *Kala-Ilan* was combined with other dyes, then assuredly the dyeings would not have been just blue, but either blue-violet or bluish-purple.

The Snail (Ha-Hilazon)[34]

The well-known reference to the animal source for *tekhelet* is from Tosefta *Menahot*:

> *Tekhelet* is not kosher unless [dyed with the pigment] from "the" *hilazon*; if one produced [similarly colored wool, but] not [dyed] from "the" *hilazon*, then it is disqualified [for use as *tekhelet*].[35]

[32] Biblioteca Apostolica Vaticana Vat.ebr.32: https://digi.vatlib.it/view/MSS_Vat.ebr.32, folio 61r. An additional text confirming this phrasing with the word "*tzivonin*" is a fourteenth-century manuscript in the Berlin State Library. Staatsbibliothek zu Berlin, Sifre Ms. or. quart. 1594: https://tinyurl.com/38dn36m9, scan page 82, folio 39v.

[33] This is known as "overdyeing" or "double-dyeing." See Zvi C. Koren, "Archaeological Shades of Purple from Flora and Fauna from the Ancient Near East" in *Archaeological Chemistry: A Multidisciplinary Analysis of the Past*, ed. Mary Virginia Orna and Seth C. Rasmussen (Cambridge Scholars Publishing, 2020), 256–300.

[34] I will use the transliteration as per the modern Hebrew pronunciation for the word snail—*hilazon*. However, throughout the Talmud the word is spelled without the letter "*yod*." Thus, it is not clear how "*h-l-z-o-n*" was pronounced in the talmudic period; perhaps closer to the Arabic *halazon*.

[35] M.S. Zuckermandel, Tosefta, *Menahot* 9:16 (1963), 555.

The definite article "the," appearing in the translation, matches the Hebrew word "*ha-hilazon*" – "the" snail – which would imply the use of a specific snail and not just "a" snail, as explained below.

> Some of the characteristics of this *hilazon* are described in the Talmud:
>
> The Rabbis taught: This is the *hilazon*: Its "body" resembles (*domeh*) the sea, and its "beingness" (*beriyato*) is like a fish, and "comes up" once in 70 years, and with its "blood" (*damo*) we dye *tekhelet*; that is why its costs [or "blood"] (*damav*) are expensive.[36]

Though there is the mention of a "fish" in that reference, it must be noted in the proper context. The talmudic description regarding the *hilazon* does not state that it is a fish or even that it resembles a fish.[37] A precise inspection of the text shows that the word used is "*beriyato*" meaning "its beingness"—its "existence," the way it lives—"is similar to that of a fish." That is, it lives in the water—it is a sea snail and not a land snail.

The other characteristics describing the *hilazon* have been previously addressed and can be briefly summarized. That "its body resembles the sea" is obvious to those of us who have collected snails from the seabed with the algae and minerals adhering to the shell, resembling the colors and contents of the sea. Its "coming up" out of the sea "once in 70 years" is obviously an exaggeration since it can only live in the water, so don't expect it to crawl up to you; you have to come to it if you want it. In the talmudic formulation, the word "*dam*" should obviously not be taken literally, but refers to an essential glandular fluid—like blood—into which the purple pigment is produced and oozes out of the injured snail, resembling the color of blood. Further, it is a small amount of pigment that can be extracted from the snail so that its "blood"-colored pigment—and its "monetary" cost—is expensive.

Historically and archaeologically, it is well-known that in the Eastern Mediterranean there were three different species of snails from which a purple or violet pigment can be produced by extracting the colorless fluid

[36] *Menahot* 44a. There is a subtle alliterative wordplay in this segment: *domeh, damo*, *damav*.

[37] That Rambam used the word *dag* (fish) to describe the snail should not be taken literally, just as he also wrote that the *hilazon* is found in *Yam ha-Melah*, the "Salt Sea" (mistaken here as the Dead Sea, which is of course impossible). Rather, Rambam meant the "salty" waters, i.e., the sea, and not in freshwater lakes. Similarly, when it comes to the word "fish" it is also loosely used even in today's vernacular, as for example, "shellfish" and "starfish." Though their names include "fish" they are definitely not a fish.

from their hypobranchial glands. These molluskan species belong to the *Muricidae* family and thus have often been called *Muricid* or "*Murex*" snails, and are: *Hexaplex trunculus* (formerly called *Murex trunculus*), *Bolinus brandaris* (or *Murex brandaris*), and *Stramonita haemastoma* (also *Purpura haemastoma*).[38] However, "not all snails were created equal,"[39] and the important point for understanding *tekhelet* and *argaman* dyeings will be the chemical constitutions of the pigments that they produce, which is discussed below.

Rabbi Herzog's Snail[40]

Rabbi Dr. Isaac HaLevi Herzog considered the *Murex trunculus* as a serious candidate for the *tekhelet-hilazon*, but, in his doctoral thesis, in his published articles, and in a letter written shortly before his passing, he proposed that the source is probably a sea snail of the *Janthina* species.

R. Herzog wrote in his doctorate that "of the three *Muricidae* species," the *Murex trunculus* is the likeliest source of *tekhelet*; however, he notes that "a fourth species" may be the source.[41] In a 1919 publication, R. Herzog made his point even more clearly, saying that there is a "serious difficulty in the way of the identification with *Murex trunculus*," and that the *tekhelet* species may be "within the confines of the genus *Janthina*."[42] Even until the end, in a letter that R. Herzog wrote in 1952 (less than seven years before he passed away), he maintained that the *Janthina* is the likeliest source for *tekhelet*: "My *hilazon* is from the Genus *Janthina*.... I only speculate from the signs given by our Sages that the *Janthina* is the *hilazon* of the *tekhelet*."[43]

[38] Though there is a new taxonomic designation for the commonly named *Murex trunculus*, readers familiar with the topic of *tekhelet* still often refer to this species by its former name; thus, I will too.

[39] Zvi C Koren, "Modern Chemistry of the Ancient Chemical Processing of Organic Dyes and Pigments" in *Chemical Technology in Antiquity*, ed. Seth C. Rasmussen (American Chemical Society, 2015), ch. 7, 197–217.

[40] The Radzin *tekhelet* topic has already been well covered, but briefly, the blackish pigment that the cuttlefish, *Sepia officinalis*, expels is not the final blue pigment, known as Prussian Blue (also Berlin Blue), first synthesized in the early 1700s. In order to produce the blue pigment, external ingredients (such as iron and potassium compounds) need to be added to the raw pigment and are subsequently chemically incorporated into it to form the final blue compound. Nearly any organic source containing the elements C, H, O, and N, can be used to produce this pigment, so that this "ink fish"' is not unique for being the talmudic *hilazon*.

[41] Herzog, 64.

[42] Isaac Herzog, "The Dyeing of Purple in Ancient Israel," *Proceedings of the Belfast Natural History and Philosophical Society, 1919–1920,* vol. 2 (1920), 21–33.

[43] Isaac Herzog, letter dated 25 MarHeshvan 5713, available at: https://www.tekhelet.com/pdf/Herzog-LaterTekheletLetters.pdf, p. 64.

Rabbi Herzog chose *Janthina* as the *hilazon* for *tekhelet* because its shell was a bluish-violet color, like the sea, and also because it excretes a similarly colored pigment, which R. Herzog believed may have been used for such a colored dyeing. He never actually performed a dyeing with this species. My experiments with this pigment from more than two decades ago showed that though you could stain, not dye, a textile with this colorant, this coloration is not stable, and thus this pigment could not have been used in textile dyeing. In addition, there are no historical reports that this pigment was ever used for dyeing, and no archaeological dye vats have shown the residual presence of this pigment.

The Murex trunculus

Some who have written and spoken about this topic believe that identifying the malacological source of *tekhelet* as the *Murex trunculus* species is a relatively new breakthrough made in the last few decades. Firstly, whether it is correct that every *M. trunculus* species is the actual source of *tekhelet* will be discussed below, but suffice it to say that the earliest published work stating that *M. trunculus* is the source was authored at the end of the nineteenth century by the Austrian Egyptologist Alexander Dedekind. His publication dealt with purple-producing sea snails in general and he also mentioned the *tekhelet* and *argaman* dyes. Thus, in his 1898 French article, he mentions "*tekhelet* or the purple matter of *Murex trunculus*."[44] He mentioned again, in his 1911 German book, that the *M. trunculus* is the source of *tekhelet*, though he included two other snail species as possible sources.[45] He also noted that the color of *tekhelet* is "violet or blue purple."

However, Dedekind's reasoning for choosing this *M. trunculus* snail was not based on an actual dyeing that he performed with its pigment, but rather on the color of the stains that the glandular fluid produced. This is an important fact because the coloration of the final product—dyed wool—is not necessarily the same as the color of the raw pigment itself.

i) Compositions of M. trunculus purple pigments

It is crucial in fully understanding the ramifications involved with the processing of the snail's pigment for *tekhelet*—and *argaman*—to recognize the colorants present in the raw pigment extracted from the snail.

[44] Alexander Dedekind, "La Pourpre Verte et Sa Valeur Pour l'Interprétation Des Écrits Des Anciens" in *Archives de Zoologie Expérimentale et Générale*, ed. Henri de Lacaze-Duthiers and G. Pruvot, series 3 (Librairie C. Reinwald, 1898), 467–478.

[45] Alexander Dedekind, *Ein Beitrag Zur Purpurkunde*, vol. 4 (Mayer & Müller, 1911), 226.

My analyses identified about ten yellowish, reddish, violet, and blue colorants in the pigment produced from *M. trunculus* snails.[46] When mixed together in the raw pigment the human eye can only observe the purplish color, which is the combination of all the colorants.

Only about three constituents are usually of major abundance in the *M. trunculus* pigments, and these are responsible for the final color on dyed wool:

Bluish indigo (abbreviated as IND):
Chemically identical to the component from all indigo-producing plants (e.g., woad), and its molecular skeleton consists of two connected moieties that can be schematically represent as: ▢▢

Violet monobromo-indigo (MBI):
Has one bromine atom attached to the indigo mainframe: Br–▢▢

Reddish dibromo-indigo (DBI):
Has two bromine atoms attached to the indigo structure: Br–▢▢–Br

Because all three components have a common indigo molecular framework, they are called "indigoids," and are always present with varying quantities in pigments from *M. trunculus.*

ii) Two different "subspecies" of M. trunculus

In my visual and chemical examinations, I have found that there are two chromatic types of the *M. trunculus* species of snails and they may be "sub-species" of this species. Though on the macro level the shade of the bulk solid pigment is very dark (almost blackish), on the micro-level, however, the pigment's color can be observed to be reddish-purple or bluish-purple (violet), depending on the "sub-species" of *M. trunculus.* In the bluish-purple pigments, the quantity of bluish IND is naturally greater than reddish DBI. Logically, these bluish-purple pigments were used for *tekhelet* dyeings, which would explain Dedekind's conjecture. Other *M. trunculus* snails produce reddish-purple pigments, due to a greater quantity of DBI than IND, and these pigments were utilized for *argaman.* Coloristically, the presence of the violet MBI colorant, whose color is approximately between the other two indigoids, tempers the pigment's purplish color so that it will not be very blue or very red.

[46] Zvi C. Koren, "Archaeo-Chemical Analysis of Royal Purple on a Darius I Stone Jar," *Microchimica Acta* 162 (2007), 381–392.

These two chromatic varieties of *M. trunculus* species depend on a number of factors: biological (age, size, gender), environmental (seawater properties, depth), and geographic (different regions). The ancients undoubtedly knew how to exploit these differences.

iii) Non-trunculus snails

"Why is the *Murex trunculus* different from all other snails?" My chemical analyses have shown that in all other purple-producing snails from different seas around the world, the overwhelming dominant colorant in their pigment is DBI, and thus all their pigments are reddish-purple colored. Because the *M. trunculus* pigments consist of the multi-components mentioned above, its pigments can be either reddish-purple or bluish-purple.

An additional singularity regarding the *M. trunculus* species is that though the quantity of dye produced from it is small, it is still greater than from the other two Mediterranean Sea snails. Hence, it is logical that chemical analyses have shown that probably all molluskan-dyed archaeological textiles were produced from *M. trunculus*, either alone or sometimes with other dyestuffs.[47] This is also evident from findings of overwhelming amounts of *M. trunculus* shells, as opposed to all other species, in archaeological excavations,[48] as well as the iconic image of specifically this snail depicted on Phoenician coins.

Talmudic Tekhelet Dyeing Recipe

The well-known succinct talmudic recipe in *Menahot* (42b) for dyeing *tekhelet* is from the early fourth century and relates to a question asked of Rabbi Shmuel after he returned from *Eretz Yisrael* to his homeland in Babylonia:

> Abbaye said to Rabbi Samuel son of Rabbi Judah: That *tekhelet*, how do you dye it? He said to him: We bring sea snail "blood" [the purplish pigment in water] and substances (*samanin*) and put them into a vat (and we heat [literally boil] the mixture). We then take out a little [of the liquid] into an eggshell and test [the dyeing quality of the liquid] with a fleece

[47] Zvi C. Koren and Chris Verhecken-Lammens, "Microscopic and Chromatographic Analyses of Molluskan Purple Yarns in a Late Roman Period Textile," *E-Preservation Science* 10 (2013), 27–34. See also Koren, "Archaeological Shades of Purple."

[48] David S. Reese, "Murex Use in the Eastern Mediterranean" in *The Materiality of Purple Dye Production and Use in Cyprus and the Aegean from Prehistory to the Late Roman Period*, ed. D. Mylona et al., (Åströms Editions, 2021), forthcoming.

of wool. We then throw away that eggshell and burn the [trial sample of dyed] wool.

In order to fully understand the talmudic prescription, it is crucial to comprehend the essential bio-chemical processing involved, as follows.

i) Pigment production

Though *tekhelet* and *argaman* dyeings use differently colored pigments from the beginning, the overall complex dyeing process for both consists of similar biological and chemical procedures. The pigment is produced from the still-alive snail by breaking its shell at a strategic spot in order to puncture the hypobranchial gland containing the colorless components (the "precursors"), which will eventually form the final purplish pigment.[49] This rupture causes the gland's enzyme to activate the precursor components, enabling them to interact with each other and chemically combine to form the final pigment.

ii) Natural processing of the purple pigment

In order to perform any enduring dyeing, whether in antiquity from a natural dyestuff or in modern times with a synthetic dye, the colorant must be dissolved and be able to form strong chemical bonds with the textile material. For the water-insoluble molluskan pigment this is the most difficult—and sensitive—stage of the overall dyeing process. The method by which this dissolution is performed today for the modern production of blue-colored *tzitzit*, and its subsequent processing, is significantly different from the manner *tekhelet* was produced in antiquity. The conditions necessary for dissolving the pigment in water, as would have been performed in antiquity, are discussed below and include: alkalinity, reducing bacteria, nutrients, anaerobic environment, and heat.

iii) Talmud's "samanim" and Pliny's "salem"

Diverse explanations have been offered as to the nature of the *samanin* (the "substances") necessary for the process, and they can now be iden-

[49] *Shabbat* (75a) mentions this necessary "injuring" *("ha-potz'o"*) of the snail. Further, the Gemara indicates that the snail must be alive: "For as long as the *hilazon* lives, it is more convenient [for the gatherer] since the dye will be 'clear' (or 'successful') [to collect]." Commentators have struggled with the meaning of this phrase. From my experiments, it seems clear that the talmudic reasoning is that when the snail expires in the sea it expels the pigment, which will be dispersed into the waters and thus lost.

tified based on the chemical requirements. The alkaline (basic) environment required for dissolving the pigment's components (the "indigoids") is easily satisfied as there were/are a number of natural alkaline-producing materials.[50] These include the ashes of certain plants,[51] "*mei raglayim*" (stale urine releases ammonia), or a readily available alkaline salt mineral, such as limestone (calcium carbonate) or *neter* (sodium carbonate).[52]

Pliny the Elder wrote a much more detailed, but parallel, accounting of the practice of dyeing with sea-snail pigments as practiced in the Roman Period of the first century CE, and a critical analysis of his descriptions has been published.[53] His account of purple dyeing mentioned the use of a "salt" (*salem* in Latin). With the understanding that an alkaline "salt substance" is chemically necessary for the dissolution of the purple pigment, Pliny's *salem*-salt and the talmudic *samanin*-substances are, therefore, equivalent. This *samanin* ingredient is thus the white alkaline salt and is the only external material needed for producing *tekhelet* and *argaman*; it is colorless in water, does not add any color to the pigment, nor is it incorporated into the final product.

iv) Natural reduction via anaerobic bacteria

Another condition necessary for dissolving the molluskan pigment is to alter the molecular structures of its indigoid constituents. This can be achieved by a chemical process known as "reduction,"[54] and the substance that causes this is known as a "reducing agent." Modern experiments that reconstructed an all-natural dyeing process as would have been practiced in antiquity, showed that the bacteria present in the rotting flesh of the snail served as the reducing agent.[55] Thus, each deliberately injured snail, forced to produce the pigment in its gland, is placed in the vessel—the vat—into which water and the alkaline substance will be added. Subsequently, the bacteria, feeding on the snail's meaty flesh as a nutrient, slowly multiply to the numbers needed to reduce the whole pigment.

The absence, or dearth, of air (oxygen) was necessary for the successful reduction of the pigment by these "anaerobic" bacteria. The

[50] The chemical role of the alkaline medium (pH above 7) is to ionize each "reduced" indigoid by removing a proton from it, and thus making it water-soluble.

[51] These contain raw potash ("potassium ash"), i.e., the potassium carbonate salt.

[52] Ordinary table salt, sodium chloride, cannot be used as it is a "neutral" salt – i.e., does not change the pH of the water mixture.

[53] Koren, "New Chemical Insights."

[54] The "reduction" process occurring here is the uptake of hydrogen (H) atoms; the opposite process, "oxidation," as its name implies, is the uptake of oxygen (O).

[55] Koren, "The First Optimal."

presence of air will hamper their growth and will also prevent their ability to reduce the pigment by re-oxidizing it. The ancient dyer fulfilled this anaerobic condition, as archaeological evidence has shown, by filling the liquid in the vat nearly to the brim.[56] Further, the vat must have been covered—probably with a wooden or stone lid—in order to prevent the entrance of air into the dye bath. Additionally, any modicum of air occupying the small headspace above the liquid would have been driven off by the noxious gasses emitted by the transpiring fermentation process.

v) Moderate heat

An additional condition required for these heat-loving ("thermophilic") bacteria to be bio-chemically optimally active is moderately hot temperatures of approximately 50–60° C. Very high temperatures will denature these bacteria. Hence, the word *martehinan* ("we boil the mixture") appearing in some versions of the talmudic *tekhelet*-dyeing recipe should not be taken literally, but is to be understood more generally to mean "heating." Pliny's description of dyeing with the purple pigment also mentioned heating at moderately hot temperatures.

vi) The vat ("yora")

Large thick-walled clay vats, containing hundreds of liters of liquid, were the vessels used for dyeing with the snail pigment. Various archaeological examples of such vats have been excavated and residual molluskan purple pigments adhering to the inside walls of the vessels are visible to this day.[57] Such clay vessels are obviously opaque (non-transparent) and thus no sunlight could enter these vats from the sides. Additionally, because the vessels were mostly covered to maintain as much of an air-free environment for the anaerobic bacterial-reduction, these vessels would not have been deliberately left uncovered, so no sunlight would enter the vat from the top, preventing the dye from exposure to light.

vii) Dyeing of the wool

The dyeing of the wool in the hot dye bath was performed by repeatedly immersing the same textile in the solution and removing it in order

[56] Zvi C. Koren, "High-Performance Liquid Chromatographic Analysis of an Ancient Tyrian Purple Dyeing Vat from Israel," *Israel Journal of Chemistry* 35 (1995), 117–124.

[57] Koren, "New Chemical Insights."

for the dye to undergo air-oxidation. This "dye exhaustion" procedure removes most of the dye from the bath and produces relatively dark colors, with the dye compositions in the wool similar to those in the original raw pigment.

This multi-dip process performed with the same textile is permissible for authentic *tekhelet* dyeings performed with the proper intention (*lishmah*), but also was chemically necessary in order to produce the bluish shades. The indigoid-dye components in the pigment have different affinities (or attractions) to wool and experiments have shown that the affinity of reddish DBI to the wool is greater than for the bluish IND.[58] Thus, after the first round of dyeing, the wool will be somewhat reddish because more DBI has bound itself to the wool than IND. In the next cycles, more IND that remained in the dye bath will be bonded to the wool and thus, the final dyeing will be more bluish than the previous cycle.

Synthetic Processing of the Purple Pigment Today

The profound differences between what was done in yesteryear and what is practiced today for the processing and dyeing with the purple pigment may have consequences as to the validity of the way that blue-colored *tzitzit* are produced today.

i) Modern synthetic reducing agent

In order to considerably hasten the process of the reduction-dissolution of the pigment to a matter of minutes instead of days, a strong synthetic reducing agent is used in its processing today. This well-known substance is sodium dithionite (also known as sodium hydrosulfite), which is also used in the industrial processing of indigo in the dyeing of blue jeans among other modern fabrics.

ii) Dye decomposition via photo-debromination

The opinion among many rabbinical authorities and learned laypeople is that biblical *tekhelet* was a daylight sky-blue color; however, of the three major snail pigment components, only one is indigo-blue. Thus, in order to satisfy their perception, it was necessary to determine a way to convert the non-blue components to indigo. This transformation was re-enacted, not accidentally, by the late Prof. Otto Elsner, a colleague

[58] Koren, "The First Optimal."

of mine for a few years in the early 1990s, who utilized the results from previous publications from as early as the 1930s.[59] These experiments showed that if you irradiate a dissolved brominated-indigo with sunlight then bromine atoms can be cleaved from the parent indigo molecule. This process, known as "photo-debromination," is effective for the two brominated components of the purple pigment. The longer the exposure to sunlight the more decomposition occurs, and thus more indigo will be produced, according to the following successive breakdown scheme:

Br–□□–Br (Reddish) ⇨ □□–Br (Violet) ⇨ □□ (Bluish)

This photo-debromination progression is the crux of today's processing of the purplish pigment for blue-colored *tzitzit*. In order to accomplish it and enable sunlight to penetrate the dye bath prior to the wool dyeing itself, the synthetic reduction-dissolution of the pigment is conducted in a transparent glass vessel. However, as noted above, this photo-debromination process would not have been possible in antiquity as non-transparent clay vats were used.

Additionally, the critical "molluskan-source" problem with this photo-debromination method of producing mainly indigo from a brominated indigo, is that one can use any snail that produces a purple dibromo-indigo pigment, such as from the other two Mediterranean species or those from other seas. In fact, synthetic dibromo-indigo can be photo-debrominated to yield mostly indigo. Thus, according to the modern method of producing blue-*tzitzit*, *M. trunculus* would not be the only source, and thus there would be nothing unique about *M. trunculus*.

The Talmudic Color of Tekhelet

The rabbinic literature contains variant literary traditions, in the name of Rabbi Meir, of the colorful imagery of *tekhelet*. It is an ascending and intensifying poetic tour de force, ending with a crescendo in its revelation of the ultimate color of *tekhelet*. One such version reads:

> It is taught [in a *Beraita*] that Rabbi Meir would say: Why is *tekhelet* different from all other types of colors? It is because [the color of] *tekhelet*

[59] Otto Elsner and Ehud Spanier, "Dyeing with Murex Extracts: An Unusual Dyeing Method of Wool to the Biblical Sky Blue" in *Proceedings of the 7th International Wool Textile Research Conference, Tokyo 1985*, ed. M. Sakamoto, vol. 5 (Society of Fiber Science and Technology, 1985), 118–130.

> is similar to that of the sea, and the [color of the] sea is similar to the sky, and the [color of the] sky is similar to the Throne of Glory. As it is stated, ["And they saw the God of Israel] and under His feet was like a paved work of the *sappir* stone, and like the essence of the skies in their purest" (Exodus 24:10); and it is [also] written, "The likeness of a Throne has the appearance of the *sappir* stone" (Ezekiel 1:26).[60]

The ancient *sappir* stone is not sapphire, even though they have similar phonetics, but is properly identified as the lapis-lazuli gemstone, and though its name literally means the "blue-stone," its color is not simply dark blue, but the higher quality stones have a beautiful dark blue-violet or blue-purple coloration. The biblical imagery is that the Heavenly Being reigns from a virtual Throne encompassing the Heavenly Skies, and both are constructed of precious lapis-lazuli. Thus, according to R. Meir, the supreme color of *tekhelet* resembles the dark blue-purple lapis-lazuli, which appears like the clear nighttime sky with traces of golden pyrite flecks in it like twinkling stars.

Archaeological Text for Imitating Tekhelet and Argaman

The British Museum has a unique seventh century BCE Late Babylonian tablet with cuneiform text containing various dyeing recipes.[61] The general motif of these formulations is directions for producing pale- and dark-blue woolen dyeings, and using them with other dyes to produce more colors, such as imitation *tekhelet* (*takiltu* in Akkadian) and *argaman* (*argamannu*).

This dyeing manual has been mentioned by others as an archaeological item without explaining the specifics of the recipes. The text in the tablet is broken in many places; however, based on the available partial translations of this tablet,[62] the formulations given can be understood from a comprehension of natural dyeing principles. These instructions are extremely important because they explicitly indicate

[60] *Menahot* 43b.

[61] Western Asiatics section, two joined fragments numbered BM 62788+82978; see: www.britishmuseum.org/collection/object/W_1882-0918-2757.

[62] One unpublished translation was produced by Dr. Irving Finkel of the British Museum, the other is of one fragment by Erle Leichty, "A Collection of Recipes for Dyeing" in *Studies in Honor of Tom B. Jones*, ed. Marvin A. Powell Jr. and Ronald H. Sack, *Alter Orient und Altes Testament* 203 (Butzon und Bercker, 1979), 15–20. A partial translation is also in *The Assyrian Dictionary of the Oriental Institute of the University of Chicago* (The Oriental Institute, University of Chicago, 2006), vol. 18 "T", s.v. "*takiltu*," 72–73.

the specific color-components constituting various simulated colors. Hence, according to the tablet's directions, the resultant color of *takiltu* (= *tekhelet*) completely contradicts those who claim that *tekhelet* is a "pure indigo" color. This tablet provides unequivocal literary evidence that *tekhelet* was dark bluish-purple, not just blue, and so too that *argaman* was reddish-purple, because both contain reddish and bluish components, though logically in different proportions.

A non-archaic paraphrasing of the relevant parts of the tablet for producing *takiltu* and *argamannu* woolen dyeings reads:

> For *takiltu*: Begin with a dark-blue wool (*uqnâtu*) produced by multiple immersions of the textile in the dye bath [probably from woad]. Then you mordant[63] that blue-dyed textile [necessary for the next step] by immersing it in a hot alum-water solution, followed by immersion in a dye bath containing the red dye from the roots of the madder plant, *ḫaṯḫūru* [or *ḫaṯḫurītu*, probably *Rubia tinctorum*].[64] Thus, the dark-blue and red combination will give you bluish-purple, i.e., *takiltu*.
>
> For *argamannu*: Begin with a pale-colored wool, *urrīqu* [presumably pale-blue as the tablet's recipes generally begin with blue colorations], and then after mordanting this dyeing you add it to a red madder bath and you will get reddish-purple, i.e., *argamannu*.

Thus, the archaeological text is very clear as to the ratios of the dyes needed to produce imitation colors:

Tekhelet = dark-blue + red = dark bluish-purple
Argaman = light-blue + red = dark reddish-purple

It is then logical that the Chicago Assyrian Dictionary defines "*takiltu*" not as "blue," but as "a precious blue-purple wool."[65]

Archaeological Colors of Tekhelet and Argaman

Misleading reports have touted two archaeological textile dyeings as containing daylight sky-blue yarns that were dyed with *Murex* snails, and thus the claim is that *tekhelet* is daylight sky-blue. One textile is a first-century CE greenish-blue woolen weave found in Wadi Murabba'at, a

[63] A mordant is a "bridging agent," typically an aluminum salt, like alum, that can bind to the textile fibers as well as to the dye molecules.
[64] The dyer's madder plant is known as *pu'a* in the Talmud.
[65] CAD, vol. 18 "T," 70.

ravine south of Qumran in the Judean Desert, and the other one is from far away Siberia, a polychromic saddle-cloth from the Pazyryk culture of the fourth century BCE. I have re-analyzed both of these textiles with the following results.

Firstly, the Wadi Murabba'at textile's greenish coloration is an artifice; its blue yarns, mixed with undyed yarns that have yellowed over time, produce the greenish optical illusion effect. Secondly, although the light-blue yarns were dyed, at least in part, with a *Murex* snail, and since the dye bath could not have been exposed to sunlight, as detailed above, the amount of blue indigo present in the dyeing is much greater than normally possible in an all-natural purple dyeing. The overly abundant indigo can be due to the use of a plant-based indigo in addition to the *Murex*-dyed wool in order to produce bluer dyeings. Alternatively, this could have been a secondary dyeing with a new piece of wool from a purple dye bath that was previously used; thus, much of the reddish DBI dye was already removed, leaving residual indigo in the dye solution (as discussed above). In short, this greenish-blue textile is not *tekhelet.*

In the Pazyryk saddle-cloth housed at the Hermitage Museum in St. Petersburg, there are areas that are colored daylight sky-blue, but the whole textile consists of many other colors. In the original Russian publication, it was reported that some yarns of this textile were dyed with a *Murex* snail. My results were that some of the violet and reddish-purple yarns were indeed dyed with *Murex*, but not the blue yarns, which were dyed from a plant source, e.g., woad, as mentioned above. Again, these blue yarns are not *tekhelet.*

The archaeological proof of what I believe are the correct perceptions of *tekhelet* and *argaman* are the two archaeological textiles that I analyzed (see the figure), both from the famous palatial fortress of Masada, and both would have been produced via the "dye exhaustion" method described above.[66] One textile fragment is the late-first-century BCE reddish-purple weave, very possibly from the cloak or mantle of King Herod the Great.[67] My dye analyses showed that this Royal Purple textile has a similar composition to the pigment produced from the variety of *Murex trunculus* sea snails that produce reddish-purple pigments. Thus, this color, and similar shades, would be the color of *argaman* for royalty and for priests.

[66] Koren, "Archaeological Shades of Purple."

[67] Zvi C. Koren, "The Unprecedented Discovery of the Royal Purple Dye on the Two Thousand Year-Old Royal Masada Textile," *American Institute for Conservation: The Textile Specialty Group Postprints,* vol. 7 (1997), 23–34.

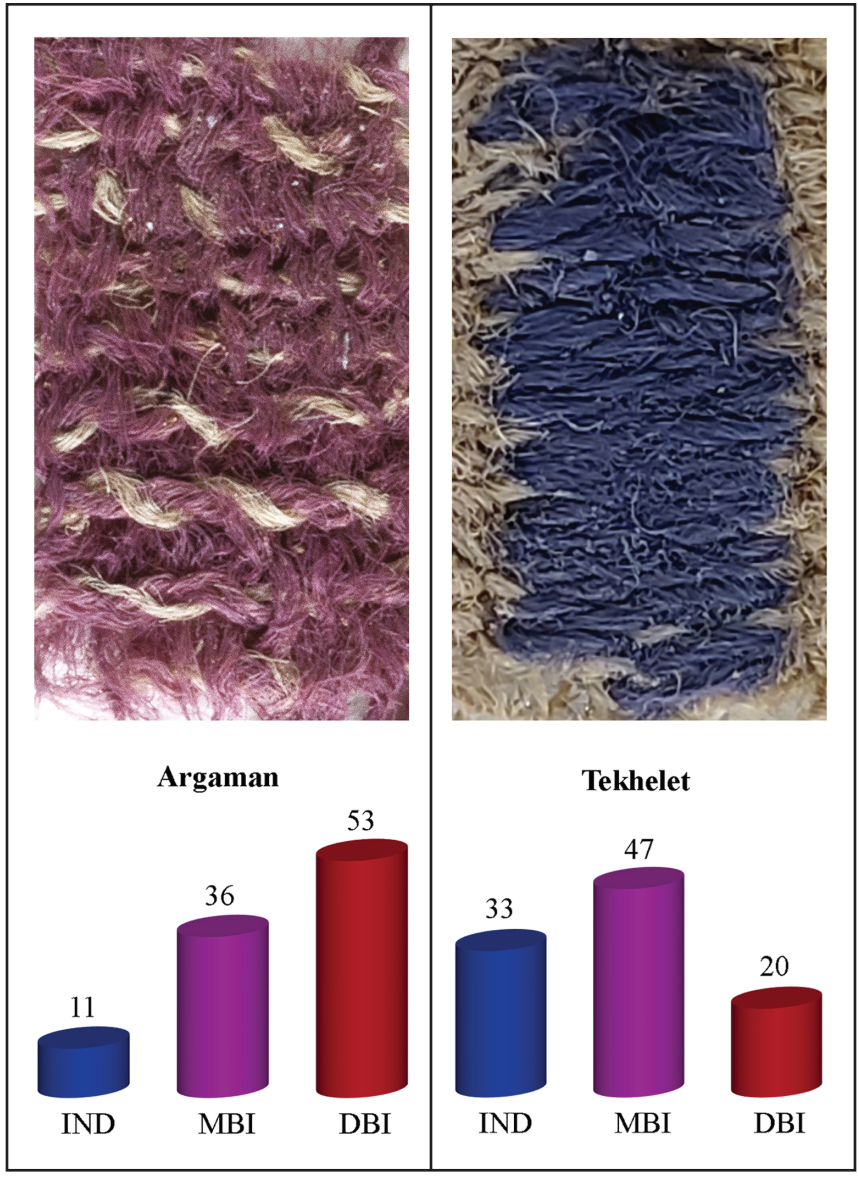

Figure: 2,000-year old *argaman* and *tekhelet* yarns from Masada with their average standardized chromatographically-measured dye ratios.

The second Masada textile, dated from between the first century BCE and the first century CE, may have belonged to Herod, or a member of his royal court, or to the Jewish rebels atop this mountain fortress. The dark blue-purple embroidered yarns on this textile fragment have shown that they too were produced from *Murex trunculus* snails, albeit from those "sub-species" that produce bluish-purple pigments. This dark blue-purple color (and similar shades) is then the authentic color of *tekhelet*. It is the color resembling the awe-inspiring "midnight-blue" heavenly skies as a remembrance of the miraculous events that "happened in the middle of the night" ("*va-yehi ba-hatzi ha-laila*").

The function of this *tekhelet* textile, which was found in one of the rooms close to the synagogue, is not clear. Were these yarns part of the embroidery work (*ma'ase rikma*) for a screen as used in the *Mishkan*? Or, were they to be extended to a corner of the garment to be a *tzitzit*? We may never know.

Conclusion

I am a chemist, not a *posek*, but after integrating the talmudic, historical, archaeological, and scientific evidence presented, it seems clear to me that there should be two kosher pathways for producing authentic *tekhelet*. In both, the bluish-purple pigment extracted from "the" specific "sub-species" of *Murex trunculus* must be used. Subsequently, dye-dissolution and exhaustion must be performed under reduced lighting conditions to prevent photo-debromination. The resulting dye make-up of the dark bluish-purple *tekhelet* produced by both dyeing methods would then be similar to that of the original pigment.

For those interested in producing the most authentic *tekhelet* the fermentative bacterial reduction-dissolution method is the choicest. Alternatively, uniting modern science with the ancient craft, any pre-dyeing reduction-dissolution method should be acceptable because none of these ingredients are incorporated into the pigment itself but are only used for dissolving it. Following that, the dye exhaustion process should be performed under minimal light to produce the dark blue-purple color.

Gazing in daytime upon the *tzitzit*'s nighttime bluish coloration evokes the reverential image of the *sappir*-colored skies upon which the Heavenly Being reigns, and instinctively, by association, a reminder of all of His commandments and their performance. This triple biblical message—seeing, remembering, doing—is the supreme idea embodied in *tekhelet*.