COLORFUL CHEMISTRY IN HALAKHA: THE MYSTERY OF TEKHELET

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Color plays a prominent role in many aspects of Jewish law (*halakha*). The details of ritual observance often include a description of a distinguishing color, which separates clean from unclean, as in the laws of *negaim* and *niddah,* and mandate the required color of some ritual objects, such as *tefilin*. The chemistry of color change can be used as a tool in the observance of *halakha*. For example, modern scholars have been using color chemistry in their search for the lost *tekhelet*, the blue dye of one of the four strings on each corner of *tzitzit*.

An early example of the use of color chemistry in aid of *halakhic* observance was the preparation of ink for Torah scrolls. Iron gall ink was in popular use from the 12th century to the 19th century for Torah scrolls and other manuscripts because it was easy to make, it was permanent, and it adhered well to parchment. The galls, abnormal outgrowths of plant tissues caused by parasites, that were used to make the ink were obtained from oak trees and were crushed to yield gallotannic acid. When mixed with water, the ester links break and yield gallic acid. Gallic acid was then mixed with water and iron (II) sulfate, resulting in iron gall ink [1]. When it was first applied to the parchment, the ink was a light brown or sepia color, but as it dried it turned purplish-black. Over time, as the ink began to corrode, it oxidized, turning back to its brown-red color, and after a while the ink detached from the parchment [2]. This last color change was caused by the iron in the ink, which underwent an oxidation-reduction reaction when exposed to oxygen to form iron oxide, also known as rust, which imbued the ink with a reddish-brownish hue [3]. These color changes were crucial from the *halakhic* perspective: since the Torah scrolls must contain black ink, the sepia-colored ink which was first applied was invalid until it dried and turned black; similarly, when the ink began to oxidize and turn brown again, the scrolls were invalid [4].

Another important example of the use of color-related chemistry in the observance of *halakha* is the *ptil tekhelet*, the blue string on the *tzizit*. God commanded Moses, "Speak unto the children of Israel, and bid them that they make them throughout their generations fringes in the corners of their garments, and that they put with the fringe of each corner a thread of blue" (Numbers 15:38). Though there was once a detailed process to creating the *tekhelet* dye, this integral part of the *mitzva* of *tzitzit* was lost many centuries ago. The *gemara* in *Menachot* discussed *tekhelet*, indicating that the method of dyeing the *tekhelet* was available until at least the fifth century, but the method was lost in the middle of the Gaonic period, during the eighth century. Two specific components of the *tekhelet* process were lost: the method of dyeing of the *tekhelet* and the identity of the species that provided the dye, the *chilazon*. The *chilazon* had not been available to the Jews in Babylonia, where a large portion of the Jewish population lived at that time, and it had to be imported from the Jews living in Israel. When the settlement in Israel was lost, the *tekhelet* disappeared [5].

In this state, when the dibromoindigo is exposed to ultraviolet light, the bromine bonds break and the dibromoindigo transforms into indigo, changing the purple-blue color to blue.

The rediscovery of *tekhelet* required going back to ancient Torah and secular sources, so that the scientific discoveries regarding *tekhelet* could be verified by comparing newly unearthed possibilities for *tekhelet* to the original. In ancient times, *tekhelet* (royal blue) and *argaman* (Tyrian purple) were used in the garments of kings and priests and other highly placed people because of the dyes' rarity; therefore a Jewish man wore a thread of *tekhelet* to remind him of his stature and responsibilities. The dyes for both *tekhelet* and *argaman* were obtained from the glands of snails found in the Mediterranean Sea. One of the major problems of reproducing the dye is distinguishing between *tekhelet* and *argaman* [6]. An important aspect of identifying the source of the original *tekhelet* is ensuring that the color of the dye produced is in fact the authentic blue color and not purple or a different shade of blue.

The Talmud in *Bava Metsia* explained that because the *tekhelet* dye was a scarce resource, a cheaper counterfeit dye, obtained from a vegetable source, surfaced. The cheaper alternative, *kela ilan,* is usually identified as the color indigo, the color of the clear sky. The Talmud stated that this dye was outwardly indistinguishable from the true *tekhelet*, but it was forbidden to be used in place of *tekhelet*: the proper source of the *tekhelet* was the *chilazon*. The Talmud provided us with several details regarding the *chilazon*'s identity. It is found along the northern coast of Israel and its color is similar to the color of the sea. It has a shell, but its form of procreation is similar to that of a fish. The Talmud additionally noted that the dye must be taken from the *chilazon* while it is alive. The characteristics of the *chilazon* described in the Talmud have been used in modern efforts to find the source of *tekhelet* [6].

In the mid-nineteenth century, Rav Gershon Henokh Leiner of Radzin (known as the Radziner Rebbe) took it upon himself to find the long-lost *chilazon*. He had heard that a type of squid, the cuttlefish, *Sepia officinalis*, fit the description of the *chilazon*, and was convinced that this was the source of the dye. Rav Isaac Herzog, the first Chief Rabbi of the State of Israel, suggested that the Radziner Rebbe consulted with chemists and determined how to transform the black ink excreted from the squid into a blue hue. Within a year, ten thousand of his followers were wearing the blue strings on their *tzitzit* [7].

In 1913, Rav Herzog sent samples of the Radziner Rebbe's *tekhelet* to be examined by chemists and dye experts. The results, rather than confirming that the Radziner Rebbe's *tekhelet* as the organic indigo, showed that it is an inorganic dye known as Prussian blue, or ferric ferrocyanide. The process that the Radziner Rebbe used to produce his dye was to heat the squid ink to very high temperatures and then to add iron filings. Under these conditions, the organic molecules break down and the carbon and nitrogen recombine with the iron, which yields the Prussian blue dye. The test results proved that the *Sepia officinalis* was not the *chilazon,* because any organic substance could have been substituted for the squid ink [7]. For example, the original Prussian blue was manufactured using ox blood [5]. The structure of the squid's molecules do not factor into the process, which is dependent only on the elemental components – iron, carbon, and nitrogen. Therefore, Rav Herzog determined that the *Sepia officinalis* could not possibly be the *chilazon* [7].

A few additional discrepancies questioned the identification of the source of *tekhelet* as the *Sepia officinalis*. First, cuttlefish are very common and were a common source of ink in ancient times, which is inconsistent with the Talmud's description of *tekhelet* as very expensive. Second, the Talmud says that the *chilazon* can be found buried in the sand, but the cuttlefish cannot exist in sand. Third, according to the Talmud, the *chilazon* has a hard shell that must be cracked, and the cuttlefish does not have an external shell. Last, *tekhelet* is supposed to be a permanent dye, but Prussian blue washes out with soap. For these reasons and because of the vague and indirect relationship between the Radziner Rebbe's source of *tekhelet* and his final product, Rav Herzog concluded that the *chilazon* was not the *Sepia officinalis* [5].

After disproving the Radziner Rebbe's *tekhelet*, Rav Herzog attempted to find a different possible source of *tekhelet*. Rav Herzog looked into the *Murex trunculus* in particular, and showed conclusively that these snails were used in ancient times as a blue dye. He noted that it is very difficult to argue that the Jews used a different source of blue dye than the rest of the ancient world and that this source was unknown to ancient scholars and left no archaeological evidence. He could not conclusively prove that the *Murex trunculus* was the *chilazon* due to a few inconsistencies, which were later resolved by modern experts. The biggest problem was that the dye obtained from the snail was a blue-violet color and not the sky-blue color with which the *tekhelet* is generally associated [7].

In the early 1980s, Otto Elsner of the Shenkar College of Fibers discovered the solution to Rav Herzog's problem. He noticed that wool that was dyed from the *Murex trunculus* on cloudy days tended toward purple, while wool that was dyed on sunny days was pure blue. After investigating the photochemical properties of the *Murex trunculus* dye, he found that the dye was in a reduced state, and it was the exposure to ultraviolet light that would transform the blue-purple color to blue [7].

Precursors to the dye exist as a clear liquid in the hypobranchial gland of the *Murex trunculus*. The indigo molecule contains indole, a toxic waste product, so the *Murex trunculus* neutralizes the indole with sulfur, bromine, and potassium, and these resultant molecules are the precursors to the dye. When the precursors are exposed to sunlight and air, in the presence of the enzyme purpurase, which also exists in the gland, they turn into the dye material. The dye must be taken from the *chilazon* while it is still alive, because the purpurase quickly decomposes, so the gland must be smashed soon after it is taken from the live snail. The reactions that occur when the precursors are exposed to sunlight in the presence of the enzyme result in a mixture of dibromoindigo (purple) and indigo (*tekhelet).* The dye is reduced and put into solution so that it binds tightly to wool. In this state, when the dibromoindigo is exposed to ultraviolet light, the bromine bonds break and the dibromoindigo transforms into indigo, changing the purple-blue color to blue [7].

Elsner's results were consistent with a study by Wouters and Verhecken using high performance liquid chromatography, which determined that the dye from the *Murex trunculus* contained indigotin, 6-monobromoindigotin, and 6,6'-dibromoindigotin. They discovered that the *tekhelet*, indigotin, gets its color from a strong absorption peak centered at 613 nanometers. This is a significant discovery, because many scholars had struggled with matching the colors of dyes, but an absorption peak is like a fingerprint for the molecule in that it is a unique way of identifying the molecule by color. For example, an absorption peak would be one way of distinguishing between Prussian blue and *tekhelet* [8].

Although it cannot be determined with absolute certainty that the *Murex trunculus* is the source of *tekhelet*, this identification has much merit. *Murex trunculus* fits the criteria set forth by the ancient sources. The shells have coatings that have a blue or green coloring which fits the description of "similar to the sea." The snail is also extremely rare, making the dye very expensive, as the *tekhelet* is said to be in the ancient sources. In the late 19th and early 20th century, archaeologists found a large number of broken *Murex* shells, consistent with the method needed to extract the dye. In addition, if one opens a *Murex trunculus* snail and squeezes the hypobrachial gland, one will obtain clear mucus which will eventually change in color to purple. When the purple mucus is exposed to direct sunlight during the dyeing process, the dye is changed from purple to blue [5]. Although many *poskim* agree with the identification of *Murex trunculus* as the *chilazon*, this identification is likely to remain a controversy for a long time, because it cannot be made with absolute certainty, and it will likely take years of debating before a consensus is reached. ■

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