THE CHEMISTRY OF GUITAR STRINGS

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The field of chemistry pervades our every day lives in ways that may sometimes surprise even those in the profession. For example, consider a guitar string: does it seem possible that chemistry has played a major role in the silent evolution of this anything but silent item? Indeed, the seemingly simple musical instrument string has benefited from a 100 year progression of quiet improvements ranging from the use of synthetic polymer fibers, to the use of protective polymer coatings and galvanically matched, corrosion-proof materials - all products of chemistry.

Prior to the 1890's, guitar strings were predominantly made from natural biopolymers known as "catgut," or more specifically, fibrous polymers taken from the intestines of various animals (a few specialized products are still made from such materials). These strings were not only difficult to make, they were very sensitive to moisture and humidity, which made them difficult to keep in tune. They were also mechanically weaker than today's strings, and had the propensity to break at the most inopportune times.

The gut core and its deficiencies were eventually replaced by other materials including ferrous based alloys (in the 1890's), synthetic polymers like nylon (after the 1930's), polymer coated metallic strings (in the 1990's), and most recently, a titanium alloy (in 2001). Today's popular steel guitar strings are still made from geometric shaped steel core wires that are wound like springs, typically with copper or nickel alloy wires to control mass (a similar version was first patented in 1878[1]). These types of strings had the immediate advantage of staying in tune better than gut strings. They were also louder in volume as a result of their higher mass and tension. Indeed, the tension was so high, that instruments had to be redesigned with more structural reinforcements to combat warping and bowing. Unfortunately, the major disadvantage of these strings was and still continues to be corrosion.

The battle against corrosion was at first fought with a tried and true fifteenth century European chemical innovation[2] that is still being used to protect metals in a variety of applications even today. The steel core wire was coated with a thin layer of molten tin prior to being wound with the other copper and nickel alloy wires. The tin coating served the same purposes then that it serves now: it provided a soft base so that the winding wire could be firmly embedded, and it passivated the relatively anodic steel from the more cathodic winding wires. Although this vintage chemistry is still used to slow the corrosion process, it by no means has solved the problem.

The advent of a second chemical innovation in the 1930's (thanks to Carothers) led to synthetic nylon strings, which are still in use today. More apt to stay in tune and less moisture sensitive than their gut counterparts, nylon strings do not corrode, and their soft tones are aesthetically pleasing to many musicians and listeners alike. Several other synthetic fibers have come into use as well[3]; and like steel core strings, many are wound with both metal alloys and other synthetic fibers to control their mass and resultant tensions. These offshoots of polymer chemistry continue to fill a market niche, but there is still a large audience for the sound and playing characteristics of metallic strings. For this reason, chemists and inventors have been quietly occupied through most of the twentieth century in attempts to improve the performance of metallic strings.

As early as the 1930's, inventors were attempting to arrest corrosion by coating metallic strings with natural and synthetic polymer lacquers[4,5]. Unfortunately, such coatings also reduced the brightness of the strings during use. The perceived brightness of a string arises from its ability to excite the resonance vibrations of a musical instrument. Anything that interferes with these vibrations will deteriorate sound quality. Thus, corrosion byproducts, contamination from finger contact, and even coatings that are designed to help prevent corrosion can all contribute to the dampening of string vibrations.

When an ideal string under tension is plucked, struck, or bowed, it freely vibrates at a fundamental frequency **f**, which is controlled in part by the tension on the string **T** (higher tension produces higher frequencies), the mass per unit length **m** (heavier strings vibrate at lower frequencies), and the distance between its end points **L**, otherwise known as the string's speaking length. Analytically, the vibration of an ideal string can be expressed as follows[6]:

$$f(n) = n/2L\ (T/m)^{1/2}$$

where n = 1 for the fundamental tone. Note that in addition to the fundamental tone, a geometric series of overtone vibrations are produced at integer values of $n > 1$. These overtones excite a complimentary ensemble of instrument resonance frequencies whose amplitudes are very dependent on both the type of instrument, and the properties of its component materials. In fact, the overtones and the resultant resonance vibrations that they excite are responsible for each instrument's unique tone, or timbre. They are at least in part responsible for the audible difference between a note plucked on a guitar, and the same note struck on a piano or harpsichord. One might say that a vibrating string without its overtones would be like a filled cookie without the cream, or pasta without the sauce - the world of audible sound would be dull and boring without the overtones.

A string's overtone vibrations occur at higher frequencies than the fundamental tone, but their amplitudes are significantly lower. Hence the overtones are the first vibrations to be perceivably dampened by frictional losses from corrosion byproducts, or by mechanical losses from polymers that are otherwise designed to slow corrosion. This problem was in part overcome in the 1990's by a polytetrafluoroethylene (PTFE) coated string innovation[7] known as Elixir™ (from W. L. Gore & Associates, Inc.). The PTFE coating of this product is a thin film with very specific machine direction and cross-machine direction mechanical properties. The film is spirally wound around the traditional metallic string in such a way so as to minimize its dampening affect on the motions that produce the overtone vibrations. Although the dampening effects are not entirely eliminated, the resultant corrosion protection and longevity have enabled this product to become an important example of chemistry's influence on the evolution of musical instrument strings.

Perhaps the most recent application of chemistry has come from Rohrbacher Technologies' introduction of corrosion proof metallic strings with titanium alloy cores[8]. As opposed to addressing the corrosion problem with protective coatings, Rohrbacher Technologies has devised a string that eliminates the galvanic couple between the core and winding wires. Conventional steel core strings are comprised of materials that are galvanically mismatched, and hence the propensity for corrosion is always present. An electrochemical couple is established between the traditional materials when salt and moisture (from human hand contact) create a type of salt-bridge that completes the contact. Unlike traditional strings, the titanium core string is comprised of a relatively cathodic metal core, and a second metal winding wire, where the difference in galvanic potential between the two metals (as measured by the difference in galvanic potential with respect to a saturated calomel electrode in seawater) is as close to zero as possible. A special nickel wound titanium alloy core satisfies both the mechanical property requirements (to withstand the tension of tuning), and the galvanic requirements (to prevent corrosion). Such materials are more costly than those of traditional strings, but they provide even greater longevity since the problem of chemical corrosion is eliminated - electrochemically.

Thus, the field of chemistry has and continues to quietly impact an area of our lives that many of us have taken for granted. Much of the musical variety that we enjoy can be attributed to the vibrating overtones of seemingly simple musical instrument strings - thanks in part to more than 100 years of evolution driven by the field of chemistry.

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