Scroop, Luster, and Hand:
The Science and Sensuality of Silk

by

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Abstract

For five thousand years, silk threads have woven through the fabric of human history. Since its accidental discovery in China all that time ago, silk has played roles, major or minor, in many cultures. In both the East and the West, it has cropped up in some rather unexpected places.

Silk's molecular structure, unique among natural fibers, imparts equally unique physical and chemical properties. It is these properties that give silk the versatility and functionality of which such staying power is made. Its strength and resilience make silk valuable as a material, whether for body armor or contraceptive devices. Its low conductivity made it an excellent insulator for early electrical applications, and silk's hydrophilic nature make it comfortable to wear in hot weather. The list goes on.

Silk's appeal goes far beyond the practical, however. As a luxury good, it wordlessly signals the high economic status of its wearer. But perhaps silk's most profound attractions are aesthetic. The rustling scroop, the rich luster, and the soft hand are all products of science, but they appeal to the senses as well as the mind.

It is remarkable that one fiber can do so much. To fully grasp just how remarkable requires an appreciation of both the science and sensuality of silk. They are inseparably interwoven.

To the two people whose names belong on the diploma as much as mine:

Michael Benton Blanchard

My sun in the morning, my moon at night. The stars were surely smiling on your dad and me.

and

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My head is down; even through my sunglasses, the sunshine is dazzlingly bright for May in Boston. I also need to concentrate on Charles Street's quaint but treacherous brick sidewalk; it is ready to send me sprawling at any moment. I keep the corner of one eye on the shops that crowd up to the walkway, reading the signs and scanning the merchandise. Even so, I walk right past the door. I miss the discreet sign reading Baranzelli, but the display window brings me up short.

The window is full of silk: stand-up rolls, handmade clothes, and graceful drapings of some of the most beautiful fabric I've ever seen, in every color and every texture. A simple sheath dress, cut from a slinky silk incongruously printed with bright drawings of happy children, hangs in front of heavy slubbed doupioni in a ruby shade, glowing with a rich, subdued luster. For quieter tastes, an elegant celadon stripe in crisp taffeta stands behind. And all of it is calling me to come in and touch.

The sunshine that glared on the street streams into the shop's small front room, softened now to a glow by the room's contents. All Baranzelli sells is silk, and in this space it is everywhere—cascading from wall racks, stacked in bolts on every surface, draped across furniture, leaning in neat rolls in the corners. On one wall, panels stretching from floor to ceiling hang like the leaves of a book. A similarly equipped hall leads to two more silk-filled rooms. I am surrounded by silk, and the atmosphere is unlike that of any other fabric store I know.

Why silk? What is there about it that makes people like me so pleased to be in its presence, that motivates people to spend hundreds of dollars on a piece of cloth the size of a beach towel? Most of us enjoy looking at it, listening to it, and feeling it more than we do cotton, wool, or linen. Where does its mystique spring from? Some say silk is in high demand purely because of its image as a luxury commodity; the harder a thing is to get, the more people will want it, whatever it is. Others say silk has an ephemeral appeal that defies explanation; this argument boils down to 'we like it, but can't say why.'

Can science unravel the mystique? Can physical, chemical, or mechanical explanations translate the charm of silk into concrete, even quantifiable, terms? Or does silk—like true love, fine wine, or good art—somehow transcend the laws of physics to become more than simply the sum of its parts?

In the shop, I am greeted by Lucy, a sales associate. I tell her I am writing an article about silk and what makes it special. I have come to Baranzelli to immerse myself in it, to breathe it in, to hear what it can tell me about its own appeal. Lucy invites me to look and touch as much as I like. My eyes have adjusted to the different brightness in here; the textures in the fabrics are easy to distinguish now, and some cry out to be touched immediately. With one hand I shake out a length of slightly stiff pale-yellow broadcloth, delicate threads in a plain weave. I rub it between my fingers, feeling the vibrations and hearing the scroop, the distinctive sandpapery sound of silk.

With the other hand I drape a chair with a fluid café-au-lait satin; the satin promptly slides off to land in a puddle at my feet. I've spilled a good three yards on the carpet, yet the puddle is hardly larger than a big-city phone book. When I pick it up, the satin does its evanescent best to flow out of my hands again, just as water in a true puddle would. It is the softest, smoothest, lightest fabric I have ever held. Rubbing it between my fingers produces no discernible vibrations or scrooping noise. One fold glides over the other seemingly without friction, "as smooth as silk."

Anyone who doubts silk's unique appeal has only to check the hangtags in this shop. Baranzelli is a surplus outlet for Scalamandre, the renowned American specialty silk-weaving company. Scalamandre's upholstery and drapery fabrics adorn the White House, historic mansions, and opulent private homes, commanding prices as high as a thousand dollars per yard. The average American home-decorating budget isn't likely to stretch to those prices. But a business without customers won't stay in business long, and Scalamandre has been weaving and selling their wares for 75 years; clearly there are quite a few people who find a lot to love about this fabric.

Lucy reappears with a massive pair of shears, generously offering to cut a swatch of anything I might like to take with me. I ask her how she got into the silk business, or does she consider this a sales job like any other? She says she spent “four high-pressure years” working in advertising in San Francisco. Interesting, she says, but it wasn’t for her. Later she moved to New York to study architecture, another uneasy fit. Eventually she ended up at Baranzelli, “and for the first time, I actually love coming to work.” She likes the “tangible quality” of the job, and the enjoyment both she and her customers get from what she sells. “I’ve learned a lot about silk, and the more I learn, the more I like it.” I know what she means, as I start choosing and she starts clipping.

* * *

“Have you ever unwound a cocoon?” Marjorie Senechal asks me as she bounds up from her seat for the third time in as many minutes. From a shelf in her office at Smith College in Northampton, Massachusetts, where she teaches the history of science, she pulls a box of what appear to be ordinary white cotton balls and hands me one. As soon as I touch it, I know it isn’t cotton; it is firmer, much more compact, about the size and shape of a robin’s egg. The fibers feel just a bit tacky; my fingers don’t glide easily over the surface. Unlike cotton or wool, whose fibers go every which way until combed straight, these are neatly wound, like a ball of knitting yarn.

“Come with me.” Dr. Senechal strides out of the office to the nearby kitchen, where she fills a mug with hot water and drops in my cocoon like a tea bag. The hot water needs time to work its magic on the stubbornly buoyant cocoon, to loosen the sericin glue binding the twists of fiber together. This is said to be a reprise of a scene first staged almost five thousand years ago. Sitting in the shade of a mulberry tree in an imperial Chinese garden, Empress Hsi Ling-Shi found a fallen cocoon in her teacup. It came out trailing a delicate fiber, and the writing of the role of silk in the pageant of human history was begun. Even in modern China, temples to Hsi Ling-Shi dot the landscape. She is revered as the Silk Goddess, in recognition of the vital part silk has played in that history, especially in China.

A few decades after the discovery of cocoon silk another Chinese empress, Si-ling-chi, is credited with inventing the forerunner of the modern loom to make silk fabric production more efficient. China kept the cocoon as the source of silk secret for more than two thousand years, to be revealed on penalty of death. This made silk extremely valuable to outsiders, and the Chinese used that to their advantage: as diplomatic gifts, as bribes to tribesmen in the remote borderlands in return for not raiding the nearby countryside, and as goods to trade with a new set of trading partners.

The Silk Road, a series of trade routes stretching from China in the East to the Mediterranean and on to Western Europe, had opened. "Silk Road" is a bit of a misnomer. Much more than silk moved along that route, including gold, gemstones, glass, bronze, furs, paper, and ivory. Tea was actually the most lucrative European import, yet it came to be known as the

Silk Road. (Apparently, Tea Road didn't have the same romantic ring.) Most traders never traversed the whole length; they merely moved the goods from one trading center to one a little further on, by camel, by cart, and by coastal boat. It was dangerous; both the terrain and the bandits were tough to handle. It says a lot about the money to be made in exotic goods like silk that people were willing to attempt it.

Inevitably, in the 6th century news of the silkworm's role in silk production leaked out-- or more accurately, was smuggled out. One story often told claims the smuggler was a Chinese princess, sent to India for an arranged marriage, who took along some silkworm eggs concealed in her headdress. The prevailing view, however, seems to be that it was an act of industrial espionage by two Nestorian monks on behalf of the Byzantine emperor, Justinian I. They managed to observe the entire silk-making process, then walked out of China with silkworm eggs concealed in their hollow canes, ending China's silk monopoly.

* * *

There was another, more modern, Silk Road, this one much closer to home. In the late nineteenth century, raw silk began to be exported to North America, to be thrown and woven into fabric in the silk mills of New York, New Jersey, and Quebec. Unlike the ancient Silk Road, however, this one ran on water and iron; it began with a Pacific crossing by steamship from

China or Japan into the ports of Vancouver, Seattle, and San Francisco. From there, it traveled to the East coast by fast trains known as silk trains, or "the Silks."

Speed was of the essence on these journeys; raw silk is perishable and delicate. If the long, continuous silk fibers snapped from rough handling, their worth was considerably diminished.

The freight was so valuable that it had to be insured at high rates charged hourly, another incentive to move fast. It was the "Lucrative Trade" in railroader's parlance. Special wood-lined, padded, and (later ice-cooled) boxcars were built to protect the easily-damaged bales of silk in transit. Armed guards rode the trains; the value of a freightload could reach as high as a million dollars at a time when a new Model T could be had for $560.00.

To ensure the silk's security and quick delivery, the Silks were "highballed" across the continent. A silk train took precedence over every other train on the line; passenger trains, military trains, even a train carrying Prince Albert (later King George VI of England) were shunted onto sidings to let the silk train dash past.

The fewer and shorter the stops, the fewer the opportunities for would-be train robbers; the Silks swept through stations, stopping only in well-guarded yards where the engine and crew could be replaced in five minutes before jumping back into the race – "hell-bent from Seattle to Chicago" and eastward, in the words of a rail worker's young daughter.

Nineteenth-century bandits were less fortunate, or less enterprising, than their counterparts on the ancient Silk Road; no silk train was ever successfully ever held up.

Though never robbed, the silk trains could still fall prey to the other hazards of travel through the rugged terrain of the Continental Divide. A British Columbian quilt from that era is described as having been pieced from the souvenir silk and flannel flags that came as premiums in tobacco tins; it was then stuffed with silk "collected" from a train derailed near Fraser.

The heyday of the Silks was the late 1920s, when the value of a pound of raw silk reached as high as $6.50. At 130 pounds per bale, and hundreds of bales per train, it was indeed a lucrative trade. Unfortunately, the silk trains could not hold out against their quicker competition sailing through the recently-built Panama Canal. They were dealt a mortal blow with the coming of the Depression, when Silk's price dropped to an anemic $1.25 a pound. Silk imports from Asia stopped after the bombing of Pearl Harbor, signaling the end of the Lucrative Trade. The post-World War II invention of nylon as a silk substitute ensured that silk prices would never rise to their previous heights.

* * *

Over the thousands of years and thousands of insect generations that humans have been cultivating Bombyx mori, the silkworm has become entirely domesticated, no longer able to survive without constant human attention. Although the adult moth has wings, it has lost the ability to fly, probably as a result of selective breeding of ever-larger individuals. It is blind in the pre-cocoon caterpillar stage, the longest of its life. Perhaps not surprisingly, though a silkworm is blind, it has an exquisite sensitivity to noise. Startled by sudden or sharp noises, it may stop feeding and prematurely discharge the gooey liquid that should have been extruded as silk later on. An event as loud and long as a thunderstorm can significantly reduce the yield for the season.

To move any distance the silkworm must be carried. It is incapable of foraging for mulberry leaves (a silkworm's lifelong diet), which humans must supply— freshly picked and chopped, to save the lazy things the trouble of gnawing on whole leaves. When it is time to spin the cocoon, the silkworm sometimes can't even find a suitable branch or twig to attach it to on its own; it must be placed on one by hand.

A Bombyx silkmoth begins its indolent life as one of hundreds of eggs laid by a single adult female on any available surface, including her own cocoon. Incubation of la graine takes about ten days. It is an indication of how important silk-rearing was to some rural economies in Europe, not so long ago, that women frequently incubated the eggs in specially made pouches hung between their breasts to maintain the proper temperature. Newly-hatched caterpillars are too small to be picked up by human fingers, but not for long. Their appetites are insatiable; the caterpillars eat so much so quickly that the sound of their chewing and the constant fall of the tremendous volume of droppings produced—the frass-- has been likened to the patter of raindrops on a forest canopy. This feeding frenzy supplies the fuel for the astonishing growth spurt to come.

Four weeks later, the fully grown blue-white caterpillar is nearly as thick, and at least as long, as a human adult's finger; its body weight has increased 10,000-fold since it hatched. At this rate, it rapidly outgrows its own skin, and must molt four times within its short larval stage, a process known as ecdysis. As molting time approaches, the caterpillar stops eating for a day or two, then rears up on its hind legs, holding this position for several days. Since an entire generation of silkworms hatches at approximately the same time, they reach the molting stage roughly in unison, as well. Imagine the sight— rooms filled with tray upon tray of pallid, corpulent caterpillars frozen in this grotesque insect asana.

Eventually the too-tight skin splits along the nose, allowing the creature to wriggle out, ravenous and eager to make up for lost eating time. Three more times it poses and sheds its skin before it has eaten enough and can get down to business— the spinning of the cocoon.

The caterpillar's essential equipment consists of two bags of sticky fluid, one down each side of its body, and two openings beneath its lower lip. The liquid hits the air and is oxidized, only then becoming the unique fiber we recognize as silk. Like a spider spinning a web, the silkworm first constructs a silk framework on which to build the rest of the cocoon. Then, moving its head in a figure-eight motion, it spins the outer layers first. Continuing to spin from the inside, the caterpillar entombs itself as deeply as its silk supply allows.

Though the silkworm doesn't know it, "entombment" is not just a metaphor. In nature, when its metamorphosis from caterpillar to adult is complete, the moth is ready to break out of its cocoon. Its mouth produces an enzyme which dissolves one end of the cocoon, cutting a moth-sized escape hatch. Cocoons must be intact as they are unwound, so to prevent their emergence the silkworms must be "stifled"—a polite way of saying killed-- to harvest the silk. There are several methods of stifling: baking the cocoons, steaming them, leaving them out in the sun, even freezing them. "One New England farmer suggested steaming them with rum. Maybe he thought it would put them to sleep in a gentler way," Dr. Senechal tells me. Silkworms might like that; it seems to suit their lethargic nature and indolent life-style.

It is a testament to silk's fineness and tensile strength that a cocoon the size of a large grape may unwind to a single continuous strand more than a mile long. The creature's escape from the cocoon will sever that single filament. Cut silk is worth little, so unless set aside as breeding stock, the silkworm won't be allowed to reach that stage. Even the few chrysalides allowed to fully develop for breeding purposes don't live much longer than their stifled kin. They have emerged to mate, and mate they do. In the following hours, the moths pair up, the eggs are laid, their mission is accomplished, and so—they die.

* * *

Back in the Smith College office, the cocoon rattles as it rolls across my palm, telling me that this unfortunate dessicated silkworm is still inside—he wasn't one of the lucky ones. Dr. Senechal uses her pencil to snag one of the barely-visible fibers beginning to float free, no longer stuck to the cocoon. Sericin, the protein glue produced by the silkworm for just that purpose, is hot-water-soluble. In the cup on the desk, the cocoon bobs stubbornly to the steaming surface; with a pencil Senechal prods it deeper until the entire surface is wet. "Traditionally," she says of her pencil, "this should be a broom straw." The rougher surface of the straw is better than the glossy surface of the pencil at catching and holding the fibers now trailing from the cocoon.

Senechal demonstrates the basic technique of 'reeling' for me. Slowly drawing back on the pencil, she reels out a length of the almost impossibly fine filament, so laboriously spun by the silkworm in anticipation of his aborted final moment of lepidopteran glory. Handing me the pencil, she tells me to "wind it around your finger" and sits back as I take over.

Or try to. It looks simple enough—just pull up slowly and evenly on the gummy filament, which clings to my finger. In Senechal's hands, the silk is deceptively compliant; not so in mine. The winding is easy; it's the "slowly and evenly" that defeats me. Time and again I snap it. Even pulling several fibers at once, to reduce the tension on each one, isn't enough to make me a successful reeler. And this is the floss, the cocoon's coarse outer fiber; what might reeling the even finer inner silk be like?

* * *

The two very fine filaments extruded by the silkworm together form the core of the silk fiber. Each filament, more properly called a brin, has the cross-section of a rounded-corner equilateral triangle; arranged with their bases together, they form a diamond shape.

Silk's luminescence is created by light reflecting off the different faces of its polyhedral fibers. The rounded fibers of cotton and wool scatter light, reflecting it equally in all directions. Even viewed from different angles, the same amount of light is directed back to the eye, giving cotton and wool fabrics their uniform surface appearance. Their color and dull luster change only subtly with the light, in the diffuse sfumato style of a da Vinci landscape.

By contrast, the planar surfaces of silk's sharply angular fibers reflect light like mirrors; the light bouncing off them either reaches your eye or doesn't. So what you see in a length of finished silk fabric is some fibers directing light back to you; those fibers will appear incandescent from the reflected light. Fibers with a different orientation will not send light back, and will appear dull. As the silk moves, the orientation of the fibers to your eye is constantly shifting. Radiance and shadow appear to dance quixotically over the surface. This change isn't subtle at all-- those bold chiaroscuro effects make silk the Caravaggio of the textile world.

The brins in a silk fiber are held in place by sericin, the sticky substance I saw dissolving in Marjorie Senechal's steaming coffee cup. It coats the brins' every surface like glue; it encases the whole fiber, like insulation on an electrical wire. The sericin's gumminess not only keeps the fiber together, it will serve to stick one fiber to another in the cocoon.

Just as we did back in Senechal's office at Smith, the reelers must remove the sericin to begin unraveling the cocoon. The cocoons are placed in warm water and agitated, often with brooms, until a fiber end comes loose and catches on the rough broom straw. The end is attached to a reel, and the long continuous strand comprising the entire cocoon is unwound.

Reeling requires a delicacy of touch that I couldn't achieve in an afternoon, if ever. For thousands of years this was skilled labor, often the province of women and children because of their more delicate fingers. A professional reeler unwound each cocoon, monitoring the strands as they reel and separating the grades of silk. Even today, automated reeling machines need careful human monitoring because the strands are fragile and can easily snap.

Each individual filament is too fine to be woven or even handled much, so after reeling the silk must be "thrown." A thrower works with several cocoons simultaneously, twisting their individual strands into thicker, stronger fibers. Senechal tells me that "No two cocoons are exactly alike, but an experienced person can tell by the feel" of the yarn as they twist when to add or remove strands to keep the quality of the fibers consistent. This is another job that required great skill; a thrower held a prestigious position. As with reeling, the process has been automated but its subtleties still require substantial human attention. Given that I can scarcely see the filament as it comes off the cocoon, I come away with a healthy respect both for those who produce and those who harvest this silk.

The cocoon spins in the water as I coax the filament to let go. I manage to produce a small skein of this raw silk, wound around two fingers. Stroking it with my thumb, I detect the fineness of the individual fibers by their seeming absence; to my fingertips they seem to have melded into one surface. Sericin residue has left the fiber a little sticky, so it doesn't yet have the smooth "hand" or bright luster we associate with silk cloth; even so, its promise is palpable.

Silk is composed of simple and quite common materials: primarily two amino acids, alanine and glycine, with two others, serine and tyrosine, replacing the occasional alanine. Amino acids are everywhere in life, simple molecules that are the building blocks of the proteins that are vital to every function of our bodies.

Yet our reaction to this particular collation of plebian molecular scraps is unlike our reaction to any other natural protein fiber—probably because its construction is very unlike that of any other natural protein fiber. It's not in the constituents themselves that the difference is made, but in the way the silkworm's glands put them all together. Like a soufflé, which also has only a few basic ingredients, the key is in the assembly; if put together right, those simple ingredients can produce a thing of glory.

In some ways silk is similar to two more familiar proteins: the collagen that, among other things, provides structural support to skin and bones, and the keratin that forms hair and nails. In describing a child's hair or cheek as 'silky', on one level the speaker is not too far from the truth.

Under a microscope, collagen, keratin, and silk are all seen to be fibrous proteins, or fibroins. All are durable and strong, which makes them ideal for one of their most important functions. Each is put to work in structures meant to protect the animal that made them, whether in skin, bones, and teeth, claws and quills, or a cocoon to shelter the transition between caterpillar and moth.

A closer look, however, reveals that although these fibroins are composed of similar materials and superficially resemble each other, on a molecular level silk is radically different. Collagen and keratin molecules coil into helices which run parallel to the fiber's length. Silk is different in two ways. Its molecules don't curl; rather they stretch themselves tight by folding into an accordion-like configuration known as a pleated sheet. What's more, the sheets run perpendicular to the length of the fiber, like potato chips stacked in a tube. "Thermodynamically, it's a tremendously stable molecular structure," says John Maggio, an organic chemist at the University of Cincinnati's School of Medicine. "None of the [common organic] solvents will dissolve silk." That would require dismantling the pleated sheets, and they do not want to let go.

A protein molecule holds its shape by forming bonds with different parts of itself or with its neighbors. Unlike collagen or keratin, in silk "virtually every possible hydrogen bond is made" according to Dr. Maggio. An individual hydrogen bond is weak, but in numbers they add up to enormous strength. Ironically, it is these tenuous individual bonds which collectively impart to silk greater tensile strength than a similarly-sized fiber of steel or bullet-stopping Kevlar. Dr. Maggio makes the comparison in more colorful terms: "A silk rope the diameter of an ordinary garden hose, if tied around the tail of a 737 jet, could be used to hoist it," courtesy of those stubbornly stable pleated sheets.

Not only silk's strength, but its ability to stretch and snap back and its strong affinity for certain dyes (and hence the rich colors of the finished fabric) are products of the pleated-sheet structure. Between the stacked sheets are amorphous regions of the silk fibroin molecule, areas in which the orderly arrangement of the pleated sheets is absent. Molecules here are less tightly bound together, allowing them to elongate when tension is applied to the silk fiber. It's as if layers of rubber were sandwiched between groups of chips in the tube: a few inches of chips, an inch or two of rubber, then a few more inches of chips, and so on. The chip sections would remain rigid, but the stack as a whole could be stretched, twisted, or compressed without coming apart. These regions of the fibroin are more inclined to break than the sheets, but since a silk fiber consists of many long molecular chains twisted together, the amorphous regions do not all line up with each other. This allows the fiber to stretch lengthwise without creating weak spots that could compromise its overall tensile strength.

The glowing colors of dyed silk prove that it takes color well, but that doesn't mean it takes it readily. Silk rejects many dyes that wool and cotton will easily accept, again because of the pleated sheet structure. X-ray studies show that adjacent sheets are not randomly spaced apart; there are only two separation distances which repeat regularly; both distances are tiny, although one is considerably larger than the other. The tightness of the intersheet bonds doesn't permit any other spacing, and it is the spacing that determines the efficacy of a particular coloring agent. Although only dye molecules which fit between the sheets can be absorbed, those that do fit are accepted with alacrity, accounting for the pure, rich colors of so many silk fabrics.

The absorbed dye molecules are there to stay, too; the same rigid structure that kept out many dyes doesn't easily release the ones it lets in. As a result, silk is generally quite fade-resistant, at least by laundering and ordinary wear. Most silks will fade quickly in ultraviolet light, however. The translucency of silk fibroin makes it a poor blocker of the UV rays to which the organic dyes often used on silk are highly susceptible. Although the silk continues to hold the dye tightly within its molecular structure, the dye molecules themselves are degraded to colors often quite unlike the vibrant originals. The French refer to these unpleasant hues as brouillard—foggy.

* * *

In Cymbeline, William Shakespeare used the characteristic scroop, or dry rustle, of silk as a metaphor for empty vanity, "prouder than rustling in unpaid-for silk." An ancient Chinese poet heard in its absence the stark silence of death. "The sound of her silken skirt has stopped...her empty room is cold and still." Silk doesn't always whisper; at times its murmur swells to a joyful noise. The French word for scroop is the more exuberant frou-frou, a term coined to capture the sound of the swish and sway of a can-can dancer's skirt over frothy tiers of silk petticoats.

The audible quality of silk is determined partly by the amount of sericin residue left behind in processing. Sericin has a high coefficient of friction-- the sticky protein resists the easy slide of one fiber over another. Vibrations created by friction produce the sound. The more sericin left in the silk, the greater the fiber's resistance to sliding and the louder the scroop. It's the same reason violinists resin their bows; by increasing friction between a violin's bow and strings, the vibrations are amplified, and the sound is enhanced.

But leaving the sticky stuff behind isn't the only way to induce scroop. The rustling can also be induced by treating the fibers with organic acids to rough up the fiber's normally glassy surface. The rougher surfaces have greater sliding resistance which increases the abrading sound produced. Scroop is so integral to the silk experience that Japanese textile manufacturers use sound-wave tests on new fibers of imitation silk in an effort to match the susurrus of the real thing.

The shivery sound of silk is sometimes a by-product of treatments intended to play up some of its other desirable qualities. Certain metal compounds added to increase the fiber's absorption of dye and deepen its final color can coarsen it like acids do. Such chemicals also increase the fabric's weight, and hence its elegant drape, a quality much prized by the

Victorians in particular. My gorgeous silk shawl, handed down by an unknown relative of that vintage, looks like a typical piece of silk— deep black, with a richly subdued luster and the promise of a smooth hand— until I pick it up. It's startlingly heavy. The unexpected weight and ever-so-slight rusty tinge of the black suggest that the silk was treated with iron salts, now slightly oxidized.

As a very fine yarn, silk can be woven in a variety of ways, from the loose weave of the sheer floating chiffons to the tight, ridged pattern of the stiffer failles and the patterned brocades, whose contoured surfaces abrade each other to produce the distinctive sound.

As with so many pleasurable things, there's a trade-off. Leaving the glue behind promotes one desirable quality at the expense of another. Silk is valued for its softness as well as its scroop, and like scroop, its softness depends on the sericin content of the fiber. It's an inverse relationship this time, however; a soft fabric glides over itself and the skin with as little friction as possible. The less sticky sericin, the more glissade, as anyone who has ever tried to make a low-scroop chiffon scarf stay on a coat hanger can attest.

The surface of silk filament is smooth as ice even on a microscopic level; it is the only natural protein fiber that lacks tiny surface scales. For this reason, it is inherently softer than any other, unless the fiber's surface has been roughened artificially -- to increase scroop, for example. Softness and scroop are incompatible; silk clothing is often described as 'rustling' or 'fluid', but never both. And for some uses, soft is the only quality that matters.

* * *

History is made up of momentous events superimposed on the mundane background of everyday life; they are intimately and inextricably linked. Flitting across that background with surprising frequency is that most inconsequential of garments: underwear, particularly silk underwear, and even more particularly, men's silk underwear.

The struggle between men's desire to wear silk and enjoy its benefits has often collided culturally with its undeniably effeminate image. An 1897 issue of Vogue declared that a professional man "must attire himself in a sensible way. He cannot afford to be elaborate or effeminate in his dress." But the lure of silk against the skin is irresistible; it absorbs perspiration and doesn't irritate the skin like wool or starched cotton, the available alternatives of the time. It conforms to the anatomy and isn't bulky under clothes, allowing the wearer to present a more fashionable silhouette.

Silk next to the skin was even said to have tangible health benefits. The American Silk Journal assured readers in 1883 that medical "experience has demonstrated that silk underclothing will in some cases cure, and in all cases mitigate, the pains of rheumatism, neuralgia, and nervous diseases of many kinds, exacting an influence that is very beneficial in giving increased vigor to the patient." Of course, a magazine devoted to silk is likely to be a poor source of medical information.

Whether for reasons of comfort, or status, or an ordinary-appearing man's secret knowledge that he was putting one over on convention with his undercover rebellion, silk underwear for men was all the rage in the late 1800s, even following fashionable color trends. Remarkably, this was the Victorian era, not commonly thought of as a time that encouraged the indulgence of sensual pleasures. But human nature craves pleasure, and in the end, human nature usually trumps social mores.

In more modern times, gangsters Al Capone and Lucky Luciano were commonly known to be aficionados of silk smallclothes. It may have been a mark of their financial success, or of a general wish to thumb their noses at law-abiding society; presumably neither had to fear being labeled effeminate. At least not to their faces.

Politics didn't escape the baleful influence of silk underwear. In the presidential election of 1824, salacious vituperation flowed freely. Andrew Jackson was reviled as an adulterer, a bigamist, and a murderer. One of his opponents, John Quincy Adams, was accused of pimping for the tsar of Russia and of wearing silk underwear. Despite the charge, Adams won the election, although he did not win the popular vote. Apparently the American electorate preferred a reputed killer and sinner to a perceived sybarite.

Adolf Hitler derided Winston Churchill as a weak and effeminate man, as demonstrated by his preference for not only silk underthings, but women's in particular, a fact made public by his shocked wife after their honeymoon. Lingerie or no, however, history shows that Churchill came off much the better in their encounter, despite Hitler's bit of name-calling.

Silk underwear is not only soft, it benefits from another of the fabric's unusual properties, thermal insulation. It does not conduct body heat away from the skin, so even a thin layer is quite effective. The British expedition that first succeeded in climbing Mt. Everest was outfitted with silk longjohns, the best they could get in those pre-polypropylene days.

Evaporative cooling (sweating) robs the skin of heat, an undesirable characteristic at the frigid highest altitudes in the world. Silk performs yet again; it is hydrophilic, meaning it attracts water. Water molecules behave like magnets, with a positive pole at one end and a negative pole at the other. Electrical charges on the silk's surface grab onto the polar water molecules and hold them fast. In this way, silk can absorb up to a third of its weight in water before it even begins to feel wet. When a water molecule evaporates, as from the skin, it takes with it the tiny bit of heat it needs to move from the liquid to the gaseous state, leaving the skin just a bit cooler. Multiplied by the enormous number of water molecules on sweaty skin, the cooling effect is considerable. On a humid summer day, that's a process we welcome; on a snowy mountaintop, no. Silk interferes with evaporative cooling by absorbing water molecules and trapping them in their liquid state; no evaporation means no heat lost from the skin.

Even religion hasn't been exempt from the hovering shadow of silk as intimate apparel. Islam's Prophet Mahomet, who believed that "silk was invented so women could go naked in clothes," specifically declared the wearing of silk by men to be haram—prohibited-- saying it was "the dress of a man who has no character." He did, however, make an exception for silk undergarments in case of skin disease, in recognition of its mechanical properties: cool, breathable, and smooth.

Silk has been making sex safer for thousands of years. Mainly intended as protection against disease, some of the earliest prophylactics used silk, plain or oiled, alone or in combination with intestinal and bladder tissues of animals, or other materials. Its effectiveness is due to several of its distinctive characteristics. The fine fiber allows for an extremely tight weave, reducing the spaces between threads for undesirable substances to pass through. Silk absorptive quality minimizes the exchange of bodily fluids. Strength like silk's is an essential quality in such devices. Its low thermal conductivity makes silk feels warm; its elasticity enhances the condom's durability and fit; silk is imputrescible-- naturally resistant to rot. Silk's soft hand is probably its greatest aesthetic asset for this purpose.

* * *

Though not known as a snappy dresser despite having spent several years in the glittering court society of Louis XIV and Marie Antoinette, Benjamin Franklin valued silk; in fact, it may have saved his life.

His legendary kite experiment proved that lightning was the discharge of built-up electric charge in a cloud. In the same way that a shock 'jumps' from a doorknob to a hand in a dry room, static electricity jumped from the air to the kite. It traveled down the wet kite string to a metal key tied near ground level, making the key spark threateningly if anything conductive got too close. When static electricity in a cloud gets a chance to jump, it jumps big— up to a billion volts big, effectively turning the kite-string into a high-tension line.

Silk to the rescue. Unlike wet string and metal keys, which conduct electricity, dry silk is a non-conductor, an insulator. Electricity is the flow of electrons through a material; if the chemical structure of the material holds its electrons firmly in place as it does in insulators like silk, the electrons can't flow. Franklin tied one end of a silk ribbon to the key and held the other, sheltering under a cowshed to keep both himself and the ribbon dry. Although the key's sparking proved that it was conducting a great deal of electricity to the nearby air and any other conductors (like the human body) that came within range, the current could not move along the dry silk ribbon to the hand on the other end. Were it not for the insulating properties of silk, that hand might not have been around to sign the Declaration of Independence 24 years later.

Cautionary note: don't try this at home. Benjamin Franklin may have survived with the help of his silk ribbon, but people have been electrocuted trying to replicate his experiment; good insulator or not, a silk ribbon seems pretty insubstantial when it is all that stands between you and a billion volts of electricity.

* * *

Down from the attic, the open suitcases' silk linings are still intact, though faded now from a deep plum to a sickly shade of weathered brick. They make a weary foil to a frothy heap of feminine clothing from days long past. What had seven generations of my grandmothers saved? Some truly exquisite white work (fancy embroidery in white (silk) thread on white cotton or linen, on christening gowns, wedding dresses, trousseau pieces) and anything—anything!—made of silk, no matter how mundane or ragged. A quilted bonnet lining, a baby's hat, a simple girl's dress in a bilious shade of yellow somewhere between chartreuse and mustard, a torn black petticoat, a shawl, even an empty silk ring box in a sad state of disrepair. Of the silk, no piece was too pedestrian to save, it seems.

My grandmothers' choices of what to preserve may well have had nothing to do with silk, or any other fabric; it may have been motivated by sentimental value alone. I will never know, of course. But that silk was special I think I can say with confidence; how else to explain that hideous yellow dress?

The dress's generous taffeta skirt retained a crisp scroop and a pearly luster. Between my fingers it had a scratchy yet somehow pleasantly smooth feeling. Those qualities of silk seem timeless. Only the dress's color detracted from its beauty, so perhaps the dress had faded from a once-lovely shade. Possibly its dye molecules had fallen victim to destructive UV light. I hope that's the explanation, anyway; I'd hate to think that any of my female forbears could have had the bad taste to choose such a color on purpose.

* * *

To some, the only appeal silk holds is commercial; it is a luxury commodity like any other: precious metals, caviar, tulip bulbs in 17th century Holland, Boardwalk in a game of Monopoly. What is special about them is measured only by supply and demand; they're hard to get, so people want them and will pay to get them. Put a free Lexus in every driveway and it will become just another Toyota. From this viewpoint, we have it backward. We covet silk because it is a luxury, and our perception of the sensual appeal of silk serves only to justify our status-driven desire for it.

Marjorie Senechal, the historian of silk science, argues this case, and believes that if silk had been plentiful and available to all and sheep hard to come by, we would be singing the praises of wool instead. To illustrate, she points to Albania, which had an active silk industry until very recently. There silk was seen as "the poor man's cloth." Wool production requires the purchase of sheep, shelter, and pasture land, not to mention the labor needed to keep the sheep safe and healthy until its wool can be harvested. Cotton and flax demand large plots of land and an even greater investment of time and labor than wool to be economically viable. But almost anyone could afford to have a mulberry tree and a few silkworms in the yard; the capital investment was relatively small and there was plenty of cheap labor available. Though the quality of silk produced in this way was poor, and therefore of little export or luxury value, it did the job of clothing ordinary Albanians in a purely utilitarian way, and did it well.

But Madelyn Shaw, Curator of Textiles at the Museum of the Rhode Island School of Design, is convinced that silk does hold a unique appeal, although she acknowledges that it may be impossible to separate its status appeal from its other aspects. She isn't sure it even matters; we can appreciate silk on more than one level at the same time. "Historically, more expensive has meant more desirable, but if it did not also feel good and look good [we wouldn't want it so much] ...our experience of it as a sensual pleasure contributes to its appeal."

You might say that the fabric of human history has been woven in silk. As far back as history can recount, people have recognized silk's unique physical properties. Even more significant, perhaps, is silk's role in our social and economic evolution. Silk's allure crosses all boundaries, whether of nations, peoples, distance, or time, helping to place the bookmarks of history: war, peace, trade, science, exploration, class struggle, and of course, romance. Societies that had it treasured it; societies that didn't often went to great lengths to get it.

It is "a symbolic and subversive fabric. Empires were built on the stuff...Silk seems overly connected to feminine worlds, yet intimately bound up with masculine preoccupations" according to New Zealand writer Andrew Paul Wood. How can a substance sometimes mockingly referred to as 'caterpillar spit' exert such influence on the vast and complex enterprise that is human civilization? It's a practical, useful material—strong, lightweight, insulating-- but other materials are equally useful. Marble, for example; it's strong, durable, and sculptable. It's good stuff, but it just doesn't ignite the passions that silk does. Why not?

The answer is that we like silk — we like it a lot. It holds a special appeal; it pleases us. Our senses seem to respond to it in some fundamental way that no other fiber has ever been able to match. History supplies the evidence; many cultures have coveted silk, warred for it, used it to purchase peace from their enemies, even set off across uncharted expanses of sea and desert in its pursuit. There are few other materials for which people have gone to such lengths to acquire.

Silk is a paradox. It can be utilitarian or luxurious, an indicator of honors or a symbol of decadence. It can keep us warm in the winter and cool in the summer. It, too, is pretty good stuff.

* * *

Madelyn Shaw shared with me a long-ago personal experience with silk to illustrate why she believes silk is special, "an exotic luxury." She had been invited to a party held in conjunction with a reenactment of a Revolutionary War battle— period dress required. In her borrowed theatrical costume, described as "yards and yards of satin and stiff petticoats" and the strait-lacing to go with it, she said she "felt like a million bucks. You didn't have to flirt at all; the dress did the flirting for you. You could be whatever you wanted to be."

I asked her if she thought she would have felt the same had it been made with yards and yards of cotton or linen. She replied "Maybe, but this was satin and-- it rustled. It reflected light off your complexion. It all reflected, all shimmered... There was a definite sensual aura" about that dress.

She pointed out that even today many evening clothes are made of silk; "a simple slip dress in satin can still make you feel like a million bucks; the same dress in linen makes you feel like you're dressed for the beach. It's not just tactile— there's an emotional response to it. It's the Orient, it comes from far away, it's mysterious-- it has all that going for it."

Walking out of Baranzelli into the bright sunshine once again, it's hard to keep silk's mechanical properties, molecular structure, role in history, or technology in mind. Back there, silk is not a chemical structure or a sophisticated biomaterial, it is a sensory experience. I think I've answered the question I went there to ask, not with my brain, but with my ears tuned to the scroop, my eyes dazzled by the luster, and my skin still tingling from the hand of the truly unique fabric I have just left behind.

Trouvelot's Mess

Not all moths are suitable for commercial silk production, but that hasn't stopped people from trying, sometimes with disastrous consequences. In 1852 a Frenchman named E. Leopold Trouvelot immigrated to Medford, Massachusetts. An artist by profession, Trouvelot was also an amateur entomologist. His particular interest was in finding a native American silkworm whose cocoons would be suitable for commercial production. He had little success. One cocoon type was too heavily gummed to be reeled, another too small to be bothered with, a third had overly-delicate caterpillars, and so on, according to his 1867 account in American Naturalist. "Who will ever know the difficulties, the hardships, and discouragements which I encountered?" he lamented. They would prove to be nothing compared to those his quest for silk was about to unleash on America's defenseless forests.

On a trip to France, it occurred to him that cross-breeding the gypsy moth, a native of Europe, with one or more of the American species he had studied, he might develop strains with increased disease resistance and a wider range of diet. He brought some eggs home to Medford. But Trouvelot was apparently unaware that the gypsy moth and the New World strains he had in mind belonged to two distinct families and could never interbreed.

In the ordinary course of science, lack of success might have led Trouvelot to abandon the project, a little chagrined, perhaps, but with no harm done. Unfortunately, the artist/entomologist made a fatal mistake – he left some gypsy moth pupae on a windowsill. The enterprising caterpillars made good their escape, leaving a horrified Trouvelot, fully aware of the potential threat, to report the danger to authorities. They took no action.

For a decade or so, little was heard from the escapees, but in time Massachusetts woodlands experienced a full-blown infestation. Gypsy moth caterpillars, like silkworms, eat voraciously as they prepare for metamorphosis. Unlike silkworms, however, who restrict themselves to mulberry or oak leaves, gypsy moths have catholic tastes in food; almost any deciduous tree species will do. The caterpillars can defoliate an entire tree astonishingly quickly, then move on to the next, and the next. Since their forbears decamped from that windowsill in 1869, gypsy moths have managed to munch their way up and down the Eastern Seaboard and as far west as Colorado, a devastating example of the damage an invasive foreign species can do.

What became of Leopold Trouvelot? He and his family remained in Medford during the period of the gypsy moth's quiescence. They fled to France twenty years after the "escape," just as the first signs of invasion reached their own neighborhood, leaving behind what came to be known as "Trouvelot's mess."

A Slender Thread: other silks in surprising places

In both quantity and quality, the Bombyx silkworm dominates textile-fiber production. In terms of making silk, however, it is far from the only game in town. Several other species of silkworm can be found in the wild, or cultivated on a local scale. Although their numbers are small in terms of percentage of total silk production worldwide and the quality of their silk is generally inferior, these other silk producers have local advantages in disease resistance, climate adaptability, and diet.

The number two source of textile silk is the Tussah, or tussore, silkmoth (Antherae mylitta), producer of "wild silk." These moths are undomesticated, originally found in the jungles of India. Though the Tussah moth cannot be farmed, their silk can be harvested from the trees in which they spin cocoons. A large moth with a 6-inch wingspan, it produces large brownish cocoons to match, up to twice the size of a Bombyx cocoon. Less tightly wound, the larger cocoon does not necessarily yield more silk, and what it does produce is darker and coarser than typical silks. Though strong, the fiber is uneven, producing a slubby fabric that lacks the luster and soft hand of Bombyx silks, making it less desirable for apparel; nevertheless, it is still in demand for some clothing, drapery, and upholstery fabrics because it is washable, durable, and relatively inexpensive.

The tussah way of producing silk has advantages. The undomesticated caterpillars eat leaves other than the mulberry, primarily the more common oak; it is the different diet that accounts for the difference in fiber quality. Wild silkworms care for themselves in their natural environment, saving money and labor. Thus finished tussah pieces, truthfully labeled "pure silk," may be surprisingly cheap even in Western markets.

Another wild silkworm family, Samia cynthia, is known colloquially as Eri. Like its Tussah cousins, this insect is a native of India but has been exported to southern Europe and the warmer regions of the United States, where it has made itself at home. Eri silk is unusual in that it cannot be reeled, or unwound intact from the cocoon. It comes off in short pieces; like wool, Eri silk must be carded and spun into yarn. Spun silk lacks many of the qualities continuous-filament silk has; it is less strong, and the presence of so many more fiber ends reduces both its softness and its reflectance, giving it a dull, diffuse luster.

A minor player in the silk industry, the Atlas silkmoth deserves mention because the moth itself is anything but minor. Its nearly foot-wide wingspan makes it the largest moth in the world. The fiber is not remarkable, but since a very large moth needs a very large cocoon, the quantity of silk in each makes its production on a small scale attractive, despite the low quality of the "fagara" silk produced.

A wide range of animal groups make silks similar in molecular structure to the product of the silkworm, and they use it for much more than spinning cocoons. Sessile mollusks such as mussels attach themselves to rocks by means of a byssus, a tether of silk filaments. It's a clever adaptation; silk resists decomposition by water, and its strength and elasticity keep the shell securely anchored through crashing waves and changing tides. Some large Mediterranean mollusks are sought out for this silk, which is harvested and woven into a fabric known as byssus cloth. It's a traditional craft on the island of Sardinia.

Beside the silkworm, the most familiar producer of silk is the orb-weaver spider. It spins silk into webs for catching prey, and for the draglines that allow it to travel on the breeze or drop down on startled passersby. What chiefly sets the spider apart from the silkmoth is its ability to make silk with different properties for different purposes. For instance, dragline silk, which is literally the orb-weaver's lifeline, must be strong and inelastic. Webs, on the other hand, catch moving prey. To absorb the kinetic energy of those who fly unwarily into a sticky web, this capture silk must be extremely stretchy, able to be pulled to maximum length, yet able to snap back almost immediately. Radius threads must be rigid enough to support the capture silk ribs yet flexible enough to transmit vibrations to the spider, announcing the arrival of dinner. Still more types of silk are used to bind prey after it has been immobilized in the web as well as to anchor and protect the spider's egg sacs. Species vary, but some can spin seven or more distinct silks, each from a different set of glands. The spider maintains silk's basic pleated sheet molecular structure, but makes slight adjustments in their exact composition and arrangement.

How does a spider do it? How does a common arachnid perform such a feat of precision manufacturing? How does it know what kind of silk it needs, and when? How does it shut down one set of glands and activate another, seemingly able to change the properties of its silk at will?

"It's remarkable— animals can do so many fantastic things. Humans are just beginning to understand how beautiful and wonderful it is. How do they do it?" Dr. Shuguang Zhang, Associate Director of the Center for Biomedical Engineering at the Massachusetts Institute of Technology, speaks with sincere admiration. "We may never understand it."

From an ancient natural substance extruded by simple creatures to a sophisticated 21st century biomaterial commanding the attention of researchers like Dr. Zhang is a long leap, but silk has made it. Both spider and silkworm silk are hot topics of research, with the goal of understanding, and possibly imitating, silk—not for fashion's sake, but to use its remarkable characteristics in new ways. Their strength, elasticity, and resistance to decomposition make it a natural for medical applications such as surgical repair material or a new implantable drug delivery system. Silk's resilience in relation to weight and volume has prompted military research into more effective and lighter-weight body armor. Remember the spider's capture silk, catching a projectile, stretching to absorb its kinetic energy, then snapping back to its original shape?

Not that any of this is completely new. Mongol warriors used silk for both these purposes. They were known to take silk underwear from Chinese adversaries, and for reasons beyond simple comfort. The Mongols found that a layer of silk could deflect a spent arrow that might otherwise have hit its target. Sometimes the arrow managed to pierce the flesh without tearing the strong silk covering it. The fabric entered the wound still intact, encapsulating the arrow tip and any poison it might carry.

Despite its versatility as a material, spider silk is unlikely to be produced commercially in the near future. There's no cocoon to be tidily unwound, so the way to get long continuous fibers is to "silk" the spider: the "silker" literally pulls the silk from one anesthetized spider at a time, one set of glands at a time. Not only is such a method impossible to imagine on a large scale, the fiber is of lower quality than the spider produces on its own. Even so, scientists hope that understanding what the spider does will make possible synthetic substances that mimic spider silk – but are a whole lot easier to produce.

Wagnerian Obsession: an aria of silk

One of history's most devoted proponents of silk was the operatic composer Richard Wagner, the self-proclaimed "most German of men." In a contemporaneous cartoon, he was christened Frou-frou Wagner, shown poised atop a stack of fabric, presumably silk. He was a rock star of his day, inspiring collectibles such as trading cards and figurines, and his predilection for silk was widely known. His fans were fascinated. Not only did he wear it, he insisted that he could create only in an entirely silk-draped room, claiming to be inspired by its rich colors and luxurious luster. "I'm inclined to order 30 metres [of the brocade], but perhaps the colours can be changed to flatter my taste even better; in other words: the fawn striped material would be silver-grey, and the blue my pink, very pale and delicate..." he wrote in a letter. "I have three years of [the opera] *Parsifal* ahead of me, and nothing must tear me away from the peaceful tranquility of creative seclusion."

Silk may even have replaced sex for Wagner. While composing *Parsifal*, he carried on an affair with Judith Gautier, a Frenchwoman with whom he shared his fabric obsession. She appears to have been his procurer, and that may be all; many historians suspect that the relationship remained unconsummated, though it went on for years. His letters to her are filled with descriptions of the silks he hopes she will bring him and panegyrics of love and gratitude; the gratitude is undoubtedly directed at Judith, but whether the love is inspired mainly by the woman or by the cloth is a little harder to discern. "Above all - be so kind as to let me know immediately and in a word if you have found the lilac satin (Ophelia!) since my decision to buy it depends upon your answer." Almost as an afterthought, he adds "Dearly belovèd!" then later, "But now to more serious matters: first of all, the two chests which have not arrived. Well! They will arrive, and I shall immerse myself in your generous soul. Cancel the pink satin entirely..."

Silk even guided Wagner's composition. He declared that the music of *Parsifal* "was to have the softness and the shimmer of silk, like cloud-layers that keep separating and combining again."
He tells Judith that the word Parsifal translates from the Arabic as "pure" and "mad, in a higher sense...genius"; it is tempting to wonder whether Wagner is unconsciously describing himself.

Eventually Wagner's wife Cosima discovered the affair, which he ended at her behest. His adieu to Judith made his priorities clear; he tells her that Cosima will be supplying his silk needs from now on. "Dear soul, I have asked Cosima to take charge of these errands from now on, or rather to make the final arrangements with regard to the various errands with which I have been troubling you for so long." Apparently, Judith is to infer from this that the relationship is over. Only after that vital business has been settled does he refer to his broken heart: "Take pity on me! Do not stop loving me. Yours, R."

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