Red can be the color of passion and danger, or luck and prosperity. Blue can be the shade of sadness—singing the blues—or a sign of tranquility and serenity. As the Russian painter Wassily Kandinsky once affirmed, in his 1911 treatise Concerning the Spiritual in Art, “Color is a power which directly influences the soul.” Color is also culture: we’ve colored our environments, clothes, and bodies for thousands of years, since early humans applied simple organic stains derived from the plants around them. The art and science of dyeing is an ancient one; today it’s an economic and commercial powerhouse. The arrival of the first synthetic dyes in the 1850s—discovered by happenstance from experiments with coal tar waste—brought us a rainbow of new possibilities for fashion and textiles, from color “fads” and trends to new means for self-expression. But synthetic color’s dark side lingers in polluted waterways. A new exhibit at the museum of the Science History Institute explores these complex legacies. Bold: Color From Test Tube To Textile takes visitors on a colorful 150-year journey through the history of synthetic dyes, examining the people and places who’ve shaped our modern understanding of color—from the laboratory to the factory floor, from the runway to retail, and beyond.

The Science History Institute is a museum, library, and center for scholars in the heart of Philadelphia’s historic district, Old City. We collect and exhibit a vast array of materials from the history of science, from instruments and labware to product samples to rare books, advertisements, fine art, and ephemera. Our museum, research, and programs share the stories behind the science—hidden histories, surprising ways that scientific questions have shaped our daily lives. As the curator of Bold, I wanted to encourage visitors to make connections between the colorful clothes they wear and the world of chemical innovation and experimentation that helped produce them. When we move through the world as consumers, we—myself included—often take our endless array of color choices for granted. Bold explores how fashion, taste, and self-expression can be shaped by new technologies, and reveals what’s lost or found in that process.

But where to begin? To set the stage for synthetics, Bold’s journey starts with a brief history of natural dyeing. This first section of the exhibition is devoted to the natural palette—blue from indigo leaves, yellow from saffron flowers, red from rose madder root or cochineal. Visitors are introduced to basic dye terminology—fixative, mordant, lightfastness—and shown representations of dyers at work.

Two dyer’s treatises from the Institute’s collections showcase the technical complexity of the dye process, step-by-step: the first is the Instructive and Practical
Treatise on the Art of Dyeing, a 1778 text by Spanish master dyer Don Luis Fernández, profiling the technologies of the Royal Dyeworks in Madrid. The second is The Story of Ramie From Seed to Finished Garment, a bound album of watercolors detailing each step in ramie weaving and dyeing, produced between 1830 and 1860 by the late Qing dynasty painter Sunqua, once active in what's now Guangzhou, China. In each of these volumes, annotated illustrations outline the major steps in the dye process: preparing the fibers through softening and spinning, scouring and soaking the yarns, applying the dye baths, rinsing and finishing. Both of these works, produced a continent apart, were designed for the same purpose: to show off the skill and expertise of master dyers and boost international buyers’ interests in, and appreciation for, their region’s dyed goods. Each volume and its illustrations promise their viewers high-quality textiles produced by supremely experienced craftsmen. I am especially excited by the inclusion of The Story of Ramie in Bold, as this is the first time the Institute has exhibited its images in our galleries since the album was acquired in 2001; this collection is an important reflection both of Qing-era China’s rapidly-growing manufacturing capability and the already globalizing textile and dye market, where competition between local and imported products generated curiosity as well as tension.

Any introduction to natural dyeing would be incomplete without the inclusion of indigo, an ancient dye derived from plants in the indigofera family, that was often at the center of culture and commerce. In Northern Nigeria, the Kofar Mata indigo dye pits (built in the 1400s) helped build the wealth of the Kano region. In Edo-period Japan, a law banning working-class citizens from wearing silk led to a boom in fine indigo-dyed cotton. During the American Revolution, indigo helped secure relations between the United States and France when Benjamin Franklin brought 35 barrels of dye on his 1776 visit to Paris. But indigo had a violent cost. During waves of colonization from the 1500s through the 1700s, European plantation owners in Haiti, Jamaica, El Salvador, and South Carolina grew wealth from indigo crops farmed by enslaved workers. In 1800s India, field workers in the Bengal region led the “indigo revolt,” rebelling against forced labor conditions under indigo planters from the East India Company. Today, most indigo on the market is synthetic. The top use for synthetic indigo is in manufacturing blue jeans and denim, an industry that uses more than 90,000,000 pounds of synthetic indigo per year.

Indigo’s wide-ranging history made our selection of a single textile for this section quite difficult! But our choice emphasized indigo’s importance to culture, through the narrative patterns of adire. Adire, the
BOLD: Color from Test Tube to Textile

Yoruba word for “tied and died,” is both an artistic technique and a method of communication. Indigo dyeing was mastered in Western Africa over 1,000 years ago, and adire’s sophisticated patterns carry generational lessons. Paired with our sample of adire cloth is a small set of “cake” style dye pucks manufactured by Barlow’s around the advent of the American Civil War in the 1860s. Indigo dye provided the “blue” of Union army uniforms, and was at the center of “free labor” debates forwarded by abolitionists, who urged consumers not to purchase any goods produced by enslaved labor. Philadelphia was a central site for free labor fairs and free labor warehouses, many operated by Quakers. This box of Barlow’s indigo was intended for sale at Wiltberger’s Drug Store on North Second Street, only a few blocks away from the current site of our museum; the label reminds us that in the 1800s, dyes were often sold at pharmacies or “chemists’” shops, and many well-known modern pharmaceutical companies were originally dye manufacturers—including Bayer, Pfizer, and Novartis.

Philadelphia’s place in dye history is a crucial one. The Institute is located in the center of Old City, Philadelphia, once a thriving hub of the city’s early industries: tanneries and docks, glasshouses and sawmills. But Philadelphia was also a national and international leader in the textiles trade, the “workshop of the world,” producing a vast variety of fiber-based goods: yarns and woolens, bindings and braids, rope and surgical dressings, suits, chemises, gowns, carpets, blankets, laces, and ribbons. By the year 1900, Philadelphia was home to at least seven hundred textile and dye firms that employed over sixty thousand people. Bold offers a glimpse of this bustling industry through a set of surveys produced in the late 1800s by the civil engineer Ernest Hexamer. Between 1865 and 1896, Hexamer made more than 2,000 detailed diagrams of local factories and industrial sites. They were produced for fire insurance companies, but today, these drawings reveal exactly how historical Philadelphia-area dyeworks were built and used. Most sites were located by water—the Schuylkill and Delaware Rivers, Tacony and Pennypack Creeks, and countless more small waterways. Dyeing required thousands of gallons to dye, rinse, and wash raw materials, and shipping of finished goods was often done by boat. This practical choice would pave the way for unanticipated outcomes, including long battles over water management and water pollution.

In the next section of Bold, visitors meet the man whose accidental discovery kicked off the synthetic dye boom: William Henry Perkin. In 1856, London-born Perkin was eighteen years old, a student enrolled in the Royal College of Chemistry under the tutelage of August Wilhelm von Hofmann. As Hofmann’s assistant, Perkin had been tasked with examining the potential of...
coal tar, a sludgy waste product of the coal industry, left behind when fuel was burned for heat and light. Coal tar, when broken down, produced nitrogen compounds called amines. Pekin mixed one of the simplest amines, aniline, with oxidizing chemicals and sulfuric acid, hoping to achieve synthetic quinine—an important drug for treating mosquito-borne illnesses like malaria. His tests didn’t succeed. But when he washed out his glassware, a vivid purple stain was left behind. Perkin immediately saw its commercial potential—natural purple dyes were costly and difficult to produce, but his new synthetic color was vibrant and colorfast. After quickly gaining a patent, Perkin left school and established a dyeworks in Middlesex, England. He first called his new shade Tyrian purple, after the most precious purple dye of the ancient Mediterranean world: a color once reserved for royalty. But Perkins’ dye became famous under the name mauve, or mauveine. By 1861, mauve was an international fashion sensation. Our exhibit includes a small square of silk fabric colored with a batch of mauveine dye manufactured by Perkin himself. The sample was provided to a journal, published by the UK Society of Dyers and Colourists in 1906, in celebration of the 50th “Jubilee” year of Perkin’s Mauve. The bold, bright hue of this silk hasn’t faded—probably because it’s been safe inside a closed book for more than 100 years!

So what followed Perkins’ purple? Countless chemists rushed to follow his example and discover their own coal-tar colors. This is partly due to a legal loophole: Perkin had patented his dye formulas in England, but these patents weren’t yet recognized internationally. Chemical firms in France, Germany, and Switzerland quickly started investigating his methods—and soon found success. After mauve came magenta, in 1858. And then methyl violet in 1861, “Bismarck” brown in 1862, and in 1868 alizarin crimson or synthetic madder. Alizarin crimson was the first synthetic dye developed to directly copy or replace a natural vegetable dye; it
was the discovery of Carl Graebe, a German organic chemist born in 1841, whose work investigated the hydrocarbon structure of madder dyes. New synthetic dyes were discovered every year between 1875 and 1900, and after the turn of the century this process only accelerated. The discovery of synthetic indigo, which soon replaced the world’s most famous natural dye, even helped win German chemist Adolf von Baeyer the 1905 Nobel Prize in Chemistry.

Synthetic colors helped grow the European dye industry into a profitable powerhouse—especially in Germany. One of the most successful German firms was the Badische Anilin-und Soda-Fabrik, or the Baden Aniline and Soda Factory (BASF). Founded in 1865, BASF quickly climbed to the top of the global dye market, where German companies would remain for decades to come: between 1880 and 1914, nearly 75% of the world’s synthetic dyes were manufactured in Germany. Our Bold exhibit features sample books, trade cards and tins from BASF. Sample books, curiously, weren’t designed to sell products to consumers. Instead, they were made by manufacturers to sell raw materials to other manufacturers: for example, dye makers sold raw dyes to textile companies, who in turn sold dyed thread, yarn, or fabric to clothing makers. These colorful artifacts remind us how complicated the world of dyeing is behind the scenes.

With the advent of WWI, the dye industry shifted its center from Germany to the United States. Blockades and boycotts of German products had American chemists scrambling into gear, producing new dyes for manufacturers—and for home dyers as well. RIT Dye, an inexpensive “direct” dye that debuted in 1916, and their competitors Diamond Dyes, Putnam Fadeless Dyes, Tintex, and countless other brands were available to home dyers at pharmacies and department stores. The appeal of these “direct” or basic dyes was their ease of use: the promised “easy” dyeing with no complicated mordant mixtures or long boils. Little knowledge of chemistry was required—only imagination and a fresh sense of style. Bold features a large sampling of these home dye packets and samples, as well as a 1928 informational booklet, The Charm of Color, produced by the Putnam Fadeless Dyes company to introduce consumers to techniques in dyeing, color theory, and “fashionable” dressing and decorating. This booklet not only showcases Putnam’s products, but gives us a glimpse of how colors were marketed, understood, and enjoyed. “Your home is the background for your personality,” it reads. “You need not have anything drab, dingy, or faded. Nature has given you the key to your most entrancing color harmonies. It is for you to work out your own symphony by letting color express your individuality—your varying moods—the tempo of your life.” The “Charm of Color,” according to Putnam, was not complicated, out-of-reach, or expensive. Synthetic


Badische Anilin & Soda-Fabrik Dye Labels (c. 1900) and Dye Tin (c. 1970s). Courtesy of Science History Institute.
color had become a playground for the 20th century consumer.

With all this innovation in color came great variation in quality. Not every new synthetic was as colorfast and lightfast as its competitors. How to answer the question of quality control? American color chemists responded in part by forming the American Association of Textile Chemists and Colorists (AATCC), a research organization that studied dye strength, light-fastness, and quality. Their research led to the creation of the first national standard test methods and measures for evaluating the durability of textile dyes; more recently their research has explored flammability, mildew-resistance, toxicity and safety in fabric dyeing. The AATCC also established indexes of commercial dyes, which by 1933 already numbered well over 4,000 distinct shades and brands. **Bold** displays jars of AATCC-formulated detergent that clothing makers use in wash tests, a tool that helps create field-wide standards for evaluation.

Quality control and consistency is crucial work in dyeing. In the same section of **Bold**, visitors encounter industrial tools of color analysis, such as an optical DuBoscq type colorimeter manufactured in the early 20th century. The specific colorimeter displayed in **Bold** was owned by a dyeworks in Rensselaer, New York during the 1920s, where it was used to match dye samples and perform quality tests. Its later photoelectric replacement sits nearby in the same gallery, as does a contemporary lightbox used by dye labs to measure metamerism in fabrics: perceived changes in color under varied lighting conditions.

Speciality instruments developed for the dye and textile industries drove innovation and fueled competition between companies vying to create the most...
popular, durable new synthetic shades. *Bold* includes photographs of dye quality-testing laboratories from regional chemical firms, including the former Customer Service and Quality Control Laboratory at the Althouse Chemical Company plant in Reading, Pennsylvania. In various images, visitors will see technicians conducting vat tests with yarn, or gauging the colorfastness of dyes during a wash cycle in the Launder-O-Meter. (Yes, that’s really what that instrument was called!) Althouse was founded in 1915 by C. Scott Althouse (1880-1970) as a small, family-owned firm specializing in fabric dyes. In the 1930s, it specialized in fade-resistant dyes for viscose rayon and dyes for DuPont’s nylon products.

All of this industrial wizardry helped create synthetic dyes that were long-wearing and vibrant. But these advances came with a cost: *Bold*’s next section explores the “toxic beauty” of synthetic dyes and their effects on workers and our environment. As early as the 1890s, German physicians noticed increased cases of cancer—especially bladder cancer—among workers making synthetic dyes. Ludwig Wilhelm Carl Rehn’s 1895 article, “Urinary Bladder Tumors Among Fuchsine Workers,” argued that inhaling fumes sent noxious chemicals into the urine and kidneys. Further research proved that widely-used dyes derived from benzidine, naphthylamines, and others could cause tumors in animals and humans. Decades later, as the American dye industry boomed, American workers began to suffer the same ill effects. In 1934, company physicians from major chemical firms—including DuPont—joined with doctors from across the East Coast for a symposium to determine causes for bladder cancer among dye workers. Studies revealed that 339 out of 2000 DuPont workers exposed to β-naphthylamine during the years 1919 to 1955 were eventually diagnosed with bladder cancer. Many of the early dyes derived from coal tar were eventually phased out of production. Methyl violet, an aniline dye first synthesized by French chemist Charles Lauth in 1861 and later marketed under the name “Violet de Paris” or “Gentian Violet,” was revealed to be dangerously carcinogenic: it’s not
only a mutagen, but has “mitotic” effects that can alter or disrupt the division of organic cells. Synthetics like these pose a health hazard to humans, but also to other forms of organic life, when they’re released into the environment through the wastewater of dyeing. Even though major environmental regulations have worked to decrease wastewater and runoff pollution from dyeing over time, many former 20th-century dye industry “boom towns” continue to suffer the after-effects. Toms River, NJ, is just one of them. In 1952, Toms River welcomed a massive new chemical plant, operated by the Swiss firm Ciba-Geigy. It produced millions of pounds of dyes and chemicals—and hundreds of new jobs. But local residents later realized that their water was being contaminated. In 1992, company executives confessed to dumping chemical runoff into landfills and local waterways, including carcinogenic benzene dyes. The effects spread for miles, sickening humans as well as wildlife. Millions have been spent on lawsuits and cleanup. To date, more than 10 billion gallons of polluted groundwater have been treated and recirculated, but that work will take another 20 to 30 years to complete. While cases like Toms River have become more isolated on American shores, dye pollution has not been eradicated. Dye manufacturing has shifted in part to the global south, to regions struggling to enforce environmental regulations—in essence “outsourcing” the problem of dye pollution.

Southeastern China is currently one of the world’s denim capitals; its factories produce more than 300 million pairs of jeans per year and employ more than 220,000 garment workers. But this region also sits at the delta of the Pearl River—one of China’s largest and most vital river systems. So much denim wastewater and chemical runoff—including dyes, bleaches, and other additives—has entered waterways that certain waterways now appear indigo-dark in satellite images. A 2010 study by the environmental nonprofit Greenpeace discovered heavy metals (including cadmium, chromium, mercury, lead, and copper) in 80% of the water and sediment samples taken from the region. Journalist Dan Fagin observed connections between this part of China and places like Toms River, NJ in 2013, writing that, “The reality of 21st-century globalism… is that none of us can pretend that by pushing the chemical industry out of our communities we have stopped enabling its dangerous practices. The [chemical] industry jobs that started in Basel, and then migrated to Cincinnati and Toms River, are now in… coal-rich areas of China.”

Bold’s final section shifts away from stories of toxicity and pollution to the question of sustainability and renewal: in a world of rising landfills and polluted waterways, where over 50% of fast-fashion purchases are discarded during their first year of use, how can individuals and communities make an impact? How

can reimagining our relationship to dyes and dyeing become part of a global revolution in fashion? Major international campaigns, such as Greenpeace’s Detox My Fashion, the Clean Clothes Campaign (a global alliance of garment workers and health advocates), Fashion Revolution (a fashion sustainability nonprofit), and the United Nations Alliance for Sustainable Fashion are working to set new standards for health, labor rights, resource management, and anti-pollution measures in the textile and garment industries. Bold’s vision of “sustainable futures” highlights these efforts and features case studies of innovative processes and innovative makers changing the way we think about fast fashion, natural and synthetic dyes, and textile manufacturing.

One case study features Green Matters Natural Dye Company, located in Lancaster County, Pennsylvania. Green Matters was founded to develop natural dye solutions for the fashion industry’s manufacturing needs—without sacrificing the health of the planet. One initiative tackles food waste, by collecting avocado pits from commercial use and turning them into tannin-rich dyes. Green Matters also provides consumer education through natural dye tutorials and workshops. Founder Winona Quigley maintains that this work can help individuals “have the power to make their wardrobe more sustainable by understanding how to mend, dye and care for their garments.”

Reclaiming traditional dye knowledge is another piece of the sustainability movement. In Japan, kakishibu dyeing uses fermented unripe persimmons to create amber-colored fabrics from their sun-reactive tannins. Persimmon dyeing’s secret advantage is that it both colors and “finishes” cloth, making it more water-resistant, mildew-resistant, and insect-repellant. It’s also non-toxic, unlike synthetic coatings or insecticidal treatments; these unique qualities have inspired eco-conscious designers to seek more solutions from historical methods. Bold includes dyecloth and liquid dye from the Onomichi Persimmon Studio in Hiroshima Prefecture, established on the grounds of a former 100-year-old orchard.

In South Korea, indigo is sometimes called the “thousand-year color” for its long history and lasting beauty. Today, indigo is regaining popularity with artists, designers, and consumers: national initiatives such as the Naju-si Natural Dyeing Cultural Foundation, as well as independent companies like KINDIGO, are working to preserve, share, and teach traditional methods. Bold features natural dye kits produced and sold by KINDIGO, that encourage home dyers to participate in an organic dye revival by refreshing and personalizing their clothes without contributing to fast-fashion waste.

Natural indigo may be biodegradable and nontoxic, but it currently requires significant resources to grow, in the form of land, water, and labor. One future for natural
dyeing may actually lie in the laboratory: vat-grown microbes that can produce high-quality, low-impact natural indigo dyes. Huue, a California-based dye startup co-founded by Michelle Zhu and Tammy Hsu, has begun producing “biosynthetic” indigo for the textile industry through engineered microbes. Genetically programmed to consume simple chemical building blocks—like sugars—these microbes produce an enzyme-based indigo dye. Huue claims its biosynthetic indigo exhibits “five times less toxicity potential” than other synthetic indigos, and can be adopted as “one-to-one” solution for manufacturers. Future combinations of bioengineered dyes and other environmentally beneficial manufacturing standards—such as low-water dyeing and washing techniques—may soon mean that one of the most globally popular garments, blue jeans, is no longer also one of the most environmentally harmful.

The history of humanity’s long journey to capture color is still being written. Our drive to imitate the rainbow, and to innovate beyond it, has fueled chemical industry, avant-garde fashion, and creativity in every form. As the painter Andrew Wyeth once remarked, “If one could only catch that true color of nature—the very thought of it drives me mad.” We hope that *Bold* will provide visitors with an accessible entry-point to global dye stories and the urgent contemporary conversation around synthetic color and its impacts, but we also hope *Bold* will inspire and fascinate. Color, after all, is a power: so how will you use it?


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