"Timely, informative, and fascinating—a totally compelling work."
—Elizabeth Kolbert

The Alchemy of Us

How Humans and Matter Transformed One Another

Ainissa Ramirez

This book was set in ITC Stone Serif Std and ITC Stone Sans Std by Toppan Best-set Premedia Limited.

Library of Congress Cataloging-in-Publication Data

Names: Ramirez, Ainissa, 1969– author.
Title: The alchemy of us : how humans and matter transformed one another / Ainissa Ramirez.
Description: Cambridge, Massachusetts : The MIT Press, 2020. | Includes bibliographical references and index.
Identifiers: LCCN 2019029157 | ISBN 9780262043809 (hardcover)
Subjects: LCSH: Materials—History—Popular works. | Inventions—History—Popular works. | Technology—Social aspects—Popular works.
Classification: LCC TA403.2 .R36 2020 | DDC 620/.11—dc23
LC record available at https://lccn.loc.gov/2019029157

10 9 8 7 6 5 4 3 2 1

Contents

Introduction

Ever since I was four I wanted to be a scientist, which made me an unusual little girl in my corner of New Jersey. I was an inquisitive youngster who wanted to know why the sky was blue, why leaves changed color, and why snowflakes had six sides. With this perpetual curiosity, I eventually got the idea of becoming a scientist from watching television shows during the late seventies and eighties. Back then, I loved programs like *Star Trek* (with Spock), *The Bionic Woman*, and *The Six Million Dollar Man*, but the show that solidified my path toward science was a public television show called *3-2-1 Contact*. One of the repeating segments had a young African American girl solving problems, and when I saw her using her brain, I saw my reflection.

Science in my childhood was full of fun and wonder. Years later, however, my dreams of becoming a scientist nearly flatlined, as I sat in a science lecture hall with tears welling up in my eyes. The science lectures were far from being any fun or bringing any wonder. In fact, these classes were dry and the lessons were designed to weed out students. Chemistry courses were prescribed cookbooks; engineering exercises examined the steam engine; and math instruction was unmotivated. I knew these subjects were better than how they were being taught, and I suffered through with the help of mentors, tutors, and many hours in the library. Fortunately, I found a major that returned my wonder—a little-known field called materials science, where I learned that everything in our world is the workings of atoms.

Materials science is a bit like my home state of New Jersey, because it is wedged between two more well-known entities. For New Jersey, they are New York City and Philadelphia. For materials science, they are chemistry and physics, and just like New Jersey, materials science has not been able to make a case for itself of how great it is on its own. If there were no City of Brotherly Love or Big Apple, New Jersey would have been a fine and respectable state. It might have done well if it was located somewhere west, like next to Iowa, for New Jersey has its own history, its own culture, and certainly its own attitude. But the Garden State is overshadowed by its overpowering neighbors. The same holds for materials science.

Despite my penchant for unappreciated states and science majors, I loved materials science, in part because my college professor at Brown said something that blew me away. "The reason why we don't fall through the floor, the reason why my sweater is blue, and the reason why the lights work is because of the way that atoms interact with each other," said Professor L. Ben Freund. "And if you can find out how they do that, you can also change the way that atoms act to make them do new things." After he said that, I looked at everything around me in a new light. I stared at my pencil, which was able to make a mark because layers of carbon atoms slid over each other. I looked at my glasses, which helped my wretched eyes see, because the glass bent light to my distant retinas. I looked down at the rubber in my shoes, which brought a springy comfort to my feet, because of the twisted and coiled molecules inside them. Atoms did all this. This guy was telling me something that made the whole world make sense to me. My wonder was back, but it took most of my undergraduate years to get in touch with it again.

Had I been weeded out by those hard, introductory science courses, this opportunity could easily have been lost. When I graduated, I swore that I would do whatever I could to make sure that no one else suffered through science that way. This book is my attempt to fulfill that old promise.

Two decades later, long after I became a scientist, the idea for this book unexpectedly came to me. Here, as an adult, I was still fond of wonder, but I preferred the type that was part learning and part thrilling. Glassblowing fit that definition, so I signed up to take a few classes.

I was filled with awe in my glassblowing class, like when I watched my instructor, Ray, transform a clear lump into a galloping horse with a few short tugs. But I was also full of fear, like when Ray warned me that glass drips on the floor could melt a hole in the bottom of my shoe. Working with the glass, I gained a deeper appreciation for it than I had acquired in my studies. But soon I would learn something that I didn't expect.

One Wednesday night I arrived at my evening glassblowing class in a full-blown work funk. Usually, when I went to glass class, I treated the molten liquid with the utmost respect. As in every other class, I would dip my pipe into the vat, pull out a small dollop, blow a small golf-ball sized bubble, and shape a small vase. But during class that night, I didn't care to be so safe.

On that New England winter evening, I grabbed triple the amount of glass on the end of my pipe dripping some on the floor, and nearly maxing out my muscles. I didn't care. I puffed a bubble the length of two baseballs, and heated and shaped and heated and swung and heated and shaped. When my funk finally lifted, I noticed that this vase was one of the best specimens I had ever made. As I neared the final stages, I held my pipe with the vase inside the furnace, and struck up a conversation with a classmate. I began to think about other things besides my glass piece—and that's a big no-no.

As I chitchatted, the vase stayed in the furnace too long and came out an incandescent orange, hunching down at the end of my pipe. My pride for it evaporated. I spun the glass 180 degrees. But the vase countered by hunching down on its new lower side. I turned again. It hunched. I turned again. It hunched. I turned again. It hunched again. Sweat began to bead on the top of my lip.

My hope was that a winter breeze from the open window would save me from my dilemma by cooling and hardening the glass vase. But the studio's furnaces kept the inside climate tropical. I was in trouble, and the glass seemed to sense it.

Eventually, the vase took matters into its own hands. When I spun the pipe again, the vase dove to the ground. I checked my skin for glass shards and was fine. But the vase, throbbing on the cluttered floor, wasn't.

I yelled to my instructor, Ray, who swept in wearing asbestos gloves. He scooped up the vase, reattached it to my pipe, put it in the furnace, and brought it back to my bench. Rolling the pipe back and forth, Ray carved open the vase's sealed lips, and rounded the flattened side with a wet wood block. The glass was going to survive, but with a new physique.

After both the glass and I cooled off, I had a moment to contemplate what had happened and an idea came to me. I shaped the glass, and the glass was shaping me. I was giving it form, even when I dropped it, and the making of a glass vase on this Wednesday night was not only distracting me from a bad day, but forging a deeper understanding and appreciation of glass, and materials in general. Perhaps this thinking was a bit existential, but the event inspired this book. The notion that materials and humans are being molded by each other catalyzed me to explore how materials in history shaped us.

The Alchemy of Us shows how materials were shaped by inventors, but also how those materials shaped culture. Each chapter is titled with a verb to demonstrate how the meaning of that word was fashioned. Particularly, this book highlights how quartz clocks, steel rails, copper communication cables, silver photographic films, carbon light bulb filaments, magnetic hard disks, glass labware, and silicon chips radically altered how we interact, connect, convey, capture, see, share, discover, and think. *The Alchemy of Us* fills in the gaps of most books about technology by telling the tales of little-known inventors, or by taking a different angle to well-known ones. I chose to look at the gaps, at the silences in history, because they too are instructive about the makings of our culture. I highlight "others" to allow more people to see their reflection. I use storytelling with the hopes of bringing the wonder and fun of science to more people.

My wish is that you will come away with an appreciation of the technologies that abound—and also inherit a sense of urgency. In order to create the finest versions of ourselves, we need to think critically about the tools that surround us. This book aims to nurture that perspective. In these pages, you will pick up plenty of talking points for party conversations, but also some cud to chew.

Overall, *The Alchemy of Us* seeks to create a new connection to the world, to history, and to each other. Admittedly, the linkage between science and culture may seem a heady concept, but an erudite twentieth-century sociologist named Madonna sang about it when she crooned that we live in a material world. She was absolutely right. Everything around us is made of something. But not only do we live in a material world, we are in a dance with these materials, too. We form them, but they, in turn, shape us. This was the lesson that my deformed vase was trying to impress upon me on that wintery Wednesday night. Let's benefit from its sacrifice and see how.

Ainissa Ramirez, PhD
New Haven, CT

1

Interact

How better clocks, made possible by small metal springs and vibrating gems, helped us keep time, but also made us lose track of something precious.

Ruth and Arnold

Like clockwork, a recognizable knock came at the door. It was a Monday in the fall of 1908 and just like every Monday, a woman named Ruth Belville stood at the entryway of a London watchmaker. She wore a dark dress cinched with a broad waistband that offered a hint there was a slim shape underneath the thick fabric. Her ankle-length hem cast a wide shadow that obscured her shoes from sight. Her hair was gathered up neatly under her hat and on her arm hung a modest yet oversized handbag. There at the entrance, aware of the time, she eagerly waited. When the door finally opened, the storekeeper greeted the weekly visitor with "Good morning, Miss Belville. How is Arnold today?" She replied, "Good morning! Arnold is four seconds fast." She then reached into her handbag, grabbed a pocket watch, and passed it to the watchmaker. He used it to check the store's main clock and then returned the pocket watch to her. She left. Their transaction was now complete. Ruth Belville was in the unusual business of selling time with her watch named Arnold.

In the early twentieth century, the world struggled to know what time it was. The early sundial and water clock, and later the hourglass, showed the marching of time, with the motion of a shadow, the lowering of a liquid's surface, or the filling of space by sand. But knowing the exact hour and minute of the day required astronomical observations and calculations. Such information lived in observatories, such as the Royal Observatory in Greenwich, England. To know the exact time of the day, visitors would have to make a trip to Greenwich to this astronomical haven to obtain it.

Numerous businesses required knowing the precise time. As one would expect, railroad stations, banks, and newspapers needed to know what time it was. But they were not alone. Taverns, bars, and pubs needed to know the time, too, since strict laws passed in the 1870s in England prevented the sale of alcohol after set hours. Those who did not comply risked losing their license and livelihood. All these disparate businesses in London required the observatory's precise time, but they did not have the luxury of making the several-mile journey to get it.

Ruth Belville (1854–1943) brought time to her clients. Once a week, she would take the three-hour journey from her cottage in Maidenhead, thirty miles west of London, and then travel to Greenwich to the Royal Observatory. Reaching its gate by nine o'clock, she rang and was greeted by the gate porter, who formally invited her in. An attendant approached her and she handed over her watch, Arnold. While she waited and had a spot of tea and chitchatted with the gate porter, her watch was compared to the observatory's master clock. The attendant then returned Arnold to her along with a certificate stating the difference between its time and their main clock. With her trusty timekeeper and an official document in hand, Ruth made her way down the hill, walked over to the Thames to catch a ferry, and proceeded to her customers in London.

Ruth Belville brought time to her customers as society's habit of living by the clock came into full bloom. Life before clocks was different, and this evolution can be likened to what we experience as we mature from children to adults. When babies are born, they have their own clock—mealtime, sleeptime, playtime. But as we mature, life divorces itself from those biological cues as we adhere to the clock with school starts, recess, and dismissals. Society went through a similar metamorphosis, switching from nature's cues to the clock's. Originally, the sun was the main means of timekeeping—with sunrise, high noon, and sunset. Before the clock, society didn't have appointments within those bounds. The clock allowed us to meet and interact with each other at any time, but brought with it what Aldous Huxley called the "vice of speed." Before clocks, we would wait for long periods for someone to arrive. Today, in the United States, we will no longer wait more than twenty minutes after a designated appointment time. Accurate timekeeping changed society and touched all aspects of life. One of these changes brought by timekeeping keeps us up at night. Living by the clock has changed how we sleep.

A Distant Sleep

Our ancestors slept differently. They didn't sleep longer. They didn't sleep better. What they *did* do was sleep in a manner that wouldn't really be recognizable to us today. Before the Industrial Revolution, our ancestors slept at night in two separate intervals. If we looked back, we would see them retiring for the evening around 9 or 10 p.m. and sleep for three and a half hours. Then, unceremoniously, they'd wake up after midnight and stay up for about an hour or so. When they grew tired again, they would return to bed and doze off for another three and a half. These distinct doses of slumber were known as “first sleep” and “second sleep,” and this was the customary way of catching z’s.

Unlike how we feel about sleep today, our ancestors were neither anxious about waking up in the middle of the night, nor worried about having a medical condition. In fact, they felt the opposite about being awake: they savored it. They used their sleep half-time to write, read, sew, pray, pee, eat, clean, or gossip with next-door neighbors (who, chances are, were up in the wee hours before dawn, too). As soon as this midnight cohort felt drowsy again, the intermission was over, and they made their way back to bed to continue sleeping for the second act.

While sleeping in intervals, or segmented sleep, seems surprising to us today, it is actually quite old—over two thousand years old, at least. Since very few people remember segmented sleep, the best evidence for it resides in early books. Ancient texts like Homer’s *Odyssey* (written around 750 B.C.) and Virgil’s *Aeneid* (19 B.C.) mention “first sleep.” “First sleep” is also mentioned in a number of classics, such as *Don Quixote* (written in 1605), *The Last of the Mohicans* (1826), *Jane Eyre* (1847), *War and Peace* (1865), and Charles Dickens’s *The Pickwick Papers* (1836). Over a thousand newspapers from the nineteenth century cite first sleep and second sleep hundreds of times, too.

Segmented sleep was part of everyday life in Western culture. But by the early twentieth century, it was gone. The Industrial Revolution changed our sleeping patterns with a one-two punch: the first strike was tangible and direct, with the invention of artificial lights; the second blow was cultural and subtle, with the desire for punctuality brought by the clock. When artificial lights came into being, they pushed back the darkness and lengthened the day. Additionally, we grew obsessed with time, with being on time, and with not wasting time. As such, it was only a matter of time before this compulsion effected how we sleep.

When the Puritans arrived in North America in the seventeenth century, they brought many things with them. One of those was their time-sense and the belief in using time wisely. Later, these religious values were transmogrified with capitalism to the Benjamin Franklin adage that "time is money." With this thinking, we as a culture grew increasingly time conscious and our actions and interactions were ordered by it. At the heart of our culture was the factory, and the clock gave it its pulse. Clock bells rang out telling workers when to start, when to stop, and even when to produce faster. This pulse didn't beat solely within the factory's walls, though. Family life began to center around the factory, too. All events within the home accompanied that pulse, such as when to wake, when to eat, when to leave, when to return home, and when to turn in for the night.

For people born and bred in this modern day, our burgeoning obsession with time in the nineteenth century may be difficult to imagine. Ruth Belville's time-distribution business was of her era. One way to illustrate our newfound time mania rests in the creation of new words. For example, in sports, we paused a game with half-time (in football in 1867) or a time-out (1896) in other sports. Popular books in science fiction, like H. G. Wells's *The Time Machine* (1895), got us excited about time travel. Countries formed a worldwide network of synchronous clocks using Greenwich Mean Time (established in 1847) with the creation of standard time (1883), so we gained timelines (1876), time zones (1885), and time stamps (1888). People became aware of their mortality and described things by their time span (1897) or their time limit (1880). We were cognizant if something was old-fashioned and noted it to be behind the times (1831). When someone was sent away to prison they were said to be doing time (1865). Mostly, though, we lived in a society that was timewise (1898), kept to a timetable (1838), and desired to make good time (1838). We as a society increased our awareness of time. All aspects of our lives were touched by it, including our sleep.

When Ruth Belville got into the unusual business of selling time, her customers, sleeping differently than today, had a growing desire to know what time it was. For her line of work, Ruth was called the Greenwich Time Lady, bringing her watch with accurate time to those needing to know it. Ruth was able to offer her services with her watch, Arnold, but Ruth was not Arnold's first carrier. Her mother did the same work until her death and her father started this peculiar business before his widow. In total, Ruth's family was in the business of purveying time for nearly 104 years.

The Belvilles fell into this line of work accidentally. Ruth's father, John Henry Belville, was an affable man who acquiesced to the mounting work at the observatory as a meteorologist and astronomer. The demanding leadership grew increasingly frustrated by the numerous interruptions caused by local astronomers desperate to know the precise time for their observational work. Instead of having unannounced visitors coming to the observatory and disrupting their scientific activities, the plan was to bring time to those who desired it. The dedicated and gentle-mannered John Belville provided time to his nearly two hundred customers.

On July 13, 1856, John Belville died and left his watch to his third wife, Maria Elizabeth. She needed to find a way to support herself and her two-year-old daughter, Ruth, since her husband left no pension. So she sold time for the rest of her life to her one hundred customers. Arnold the watch was then passed down in 1892 to Ruth, who at age thirty-eight continued the family business.

Arnold was formally known as John Arnold No. 485 and named after its maker, who built it in 1786. This was a highly accurate chronometer, better made than a standard pocket watch. Legend has it that Arnold was originally designed as a gift for royalty, specifically for the duke of Sussex, a son of George III. The duke of Sussex thought the watch was too big, though; he likened it to a "warming pan" and refused it. As luck would have it, the duke of Sussex was connected to the Royal Observatory, which put Arnold on a path toward John Belville's hands when the time-distribution service was created. Arnold was originally in a gold case, but Ruth's father, John Belville, had it rebuilt and updated in a silver case so it would be less attractive to thieves. Arnold's beauty wasn't on the outside, however, but on the inside. Behind Arnold's white enamel face and gold hands sat a range of materials working in sync—brass gears, ruby pivots, and a steel spring. This timepiece from the eighteenth century clicks five times a second, which is a masterful performance even today.

Arnold the watch is part of an old tradition, for the telling of time has been a human pursuit from the beginning of antiquity. Sundials and water clocks give a sense of the hours passing. But to measure time like a yardstick, what was needed was a regular pattern that could be counted. According to legend, Galileo observed that the lamps in a cathedral in Pisa swung regularly. Using his pulse, he found that they moved back and forth with a stable and unchanged rhythm—a natural frequency. This simple observation was what society had been waiting for as a way to measure time. Soon, pendulum clocks and later smaller pocket watches, like Arnold, would use springs inside to provide the clock's ticks. But making small watches like Arnold would not be easy, for the spring inside had to be uniformly made to tell time accurately. Making watches was incredibly frustrating. One eighteenth-century clockmaker in England became so annoyed with his clocks that he did something about it.

Benjamin Huntsman's Clocks

Benjamin Huntsman was irritated by his timepieces. Born in 1704 in Epworth, England, Huntsman was known to be a clever, inventive, and handy clockmaker. In his village, he was a fixer of all things mechanical, from locks to clocks to tools to rotisseries. Yet, despite all his technical ability and acumen, he frowned on his clocks. They were poor timekeepers because their metal springs were inferior.

Deep in a clock is a gadget that ticks. In some clocks, a pendulum swings back and forth; in small pocket watches, it is a combination of a spiral metal spring and a balance wheel. The spring is coiled so that it expands and contracts, like a chest cavity, producing the clock's ticks and tocks. Clocks with springs that hiccup give a fast time; clocks with springs that breathe deeply supply a slow time. Accurate clocks require metal springs that are flexible and flawless, inhaling and exhaling steadily.

Unfortunately, the quality of the metals at hand for Huntsman was inconsistent, because the ingredients were not evenly mixed. Plus, these metals contained unwanted particles. The poor mixing of ingredients made watches behave irregularly and the particles caused the springs to snap. Neither boded well for good timekeeping.

In his quest to make better springs for his watches, Huntsman turned his attention to their starting material, a metal called blister steel. Blister steel was made by adding carbon to iron, which steelmakers accomplished by placing iron bars into a furnace, heating them until they were red-hot, and then surrounding them with bits of charcoal. After five days, the bars contained a lot of carbon from the charcoal, with most of it near the surface as on a poorly marinated steak. To mix these ingredients further, steelmakers had to heat the metal to soften it, beat the metal with a hammer to flatten it, and then fold the metal onto itself to blend it. This method was certainly beneficial for incorporating carbon, but it did nothing for getting rid of the unwanted particles. Huntsman had to come up with another way.

One day in his clockworks in Doncaster, Huntsman had a simple, but revolutionary, idea: melt the metal fully. When the metal was molten the ingredients would intermingle better and deliver a uniform mixture of carbon. Plus, the unwanted particles, which were lighter than the molten liquid, would float to the top, separating like oil and water, which Huntsman could then remove.

Beginning in secret and working with little interaction with the outside world, Huntsman failed hundreds of times. Although the records of his research were burned in a fire, artifacts of his attempts were buried outside his works in Doncaster. In these unsuccessful experiments, he aimed to blend in the carbon and he strived to eliminate those unwanted particles. After ten years of work, around 1740, Huntsman finally perfected his steel. He commemorated his achievement by making a clock.

The secret behind Huntsman's success was the creation of a container to carry the molten metal. This container, or crucible, looked like a tall, ancient vase and was made of a ceramic that could withstand the fiery metal's heat as well as sustain the heavy metal's weight. To make his crucible he ground up imported pots from Holland and added graphite and a special clay from England called Stourbridge clay. Next, he added water to the blend and then one of Huntsman's trusted workmen stomped on the mixture with his bare feet for eight to ten hours. Bare feet permitted both the squeezing out of air pockets and the detecting of pebbles in the clay, either of which would cause crucibles to crack and leak out the steel.

After the clay was kneaded and shaped, the resulting containers were dried and then fired in a kiln. When these ceramic crucibles were completed, the steelmaking began.

Huntsman perfected his method in his new works near the city of Sheffield (a steelmaking hub). His workmen placed small bits of blister steel into a crucible and then lowered the crucible into a furnace, where it remained for five hours. When the crucible came out, a workman skillfully poured the steel into a mold, making sure to prevent the unwanted floating layer from falling in, too. When the pouring was complete, the final metal in the mold was crucible steel—a uniformly blended metal that was fashioned into fine watch springs that expanded and contracted consistently. Benjamin Huntsman's invention made for better watches, ones that could be carried in a pocket or hung on a wall or carried throughout London to provide the time, like Ruth Belville's Arnold.

After Ruth Belville acquired the accurate time from the Royal Observatory, she and Arnold headed toward the London Docks, and then crisscrossed the city and cut through different parts of society along the way. She started in the east to provide time to the vice-ridden and odorous docks. Tick. After that, she shot over to the fashionable west end of Oxford, Regent, and Bond Streets, to posh shops and fine jewelers (including the royal jeweler). Tick. Next, she turned north to Baker Street, to factories and commercial buildings. Tick. Then, she headed south, to individual customers in the suburbs. Tick. Later, she brought time to two millionaires who relished the status symbol of GMT in their homes. Tick. All the while, she intersected the center of London to provide time to banks. Tick. At last, she ended that long day and returned home to Maidenhead only to repeat the cycle again in seven days. Tock.

With Arnold in her handbag, she walked and walked over cobbled-stone roads coated with coal dust and dotted with horse manure. When she could afford it, she would take public transportation, including the tram, subway, and train. Life in the city was hard, dirty, and teetering at a flash point. The air was thick with smoke and fog. And there was a constant cacophony of shouting vendors, the click-clack of horses, and the rumble of an occasional motorcar as she carried the time. Ruth walked through miles and miles of the city eking out a living. She was a businesswoman in a time when women could not vote. Described as hale and hearty, Ruth was emotionally tough and resolute, and she had a common touch as she moved through a world dominated by men. Together, Ruth and Arnold were trusted fixtures in London life.

Day and night, he endlessly filled his lab notebooks with ideas that contained sophisticated circuit diagrams that allowed electrical signals to "talk" to mechanical parts. Soon, Marrison became enamored with using quartz for clocks.

Bell Labs had one of the first radio stations: WEAF, and the idea for the quartz crystal clock actually came from radio. Radio stations broadcast at specific frequencies designated by the numbers seen on a radio dial. It was hard, however, for radio stations to know if they were broadcasting at the right frequency, which was necessary to avoid interfering with neighboring stations. Marrison's project in 1924 focused on making a machine that produced accurate and unwavering signals that served as a standard frequency. Using a large quartz gem, Marrison sawed a sliver off and then mounted it into his electronics. Quartz is an unassuming mineral with an extraordinary secret—it vibrates when zapped by an electrical circuit. The quartz slice gave a beat at a specific rate, which became the radio station's standard. Marrison's frequency generator served as a North Star for those lost in a sea of radio waves.

After his success with the radio standard, Marrison had another idea. Instead of using the vibrating crystal to send a precise radio signal, he would vibrate the crystal, which produced a known number of vibrations in a second, and count the vibrations to mark off time. This way the counts become the "measuring stick" of time. With that idea, Marrison convinced natural quartz to beat. By fashioning a crystal into a doughnut shape, he was able to make quartz flap up and down like a drum head. His quartz rang one hundred thousand times in one second and those vibrations were counted to tell time. Quartz was able to do this because of its little known secret. It dances with electricity because of a weird phenomenon called *piezoelectricity*.

Piezoelectricity was discovered by Pierre and Jacques Curie in 1880 in Paris. While in their early twenties, these young men desired to make a name for themselves in the very crowded field of mineralogy. At the time, many other scientists excavated gems from the earth and studied and classified their color, clarity, and faceting. The Curie brothers wanted to go further and see what else these gems could do in different situations. Pierre was always fascinated with the symmetry of geometric shapes, particularly in minerals. Quartz lacks the simple symmetry of other gems, like diamond or salt. Facets on one side of a quartz gem were not matched with an identical facet on the other side. This meant that the atoms inside didn't have a mirror image, and that physical properties usually cancelled out by these mirror images could now appear. With this knowledge, they did something most mineralogists didn't do: they squeezed a gem hard to see what would happen. After a few turns of the handle of a vice, the jaws clenched down and Pierre and Jacques found something strange. Surprisingly, the crystal yelped and gave off a small bit of electricity. The Curie brothers discovered that quartz was piezoelectric.

Decades later, Marrison was revisiting quirky quartz; he fashioned it into a small doughnut-shaped slab and zapped it with alternating current. This caused the quartz gem to vibrate steadily, like a piece of Jell-O. Those wiggles could be counted to tell time. But just as a bowl full of Jell-O bounces to its own rhythm, convincing quartz to vibrate accurately was not easy.

By 1927, Marrison had to learn everything about quartz's behavior. His efforts prepared him for the next stage of his work, to create electrical signals to coax quartz to jiggle steadily. While vibrations surrounded Marrison all the time from the rumbling of the elevated train, the buzzing bees from his youth, and his own bellowing voice, he harnessed the vibrations in quartz to do one more thing—tell time. By the end of 1927, Marrison got his quartz clock. This clock employed a quartz ring that was an inch thick and a few inches across in diameter. The clock was so successful that New Yorkers could call the phone number ME7-1212 to get the precise time. A little more than ten years later, time-seeking pedestrians, standing close together but with little interaction with each other, would go to the window display at the corner of Fulton Street in Manhattan to get it.

By the time that New Yorkers made their way over to Marrison's clock, the notion of segmented sleep was a distant memory. The conversion from time taken from natural and biological cues to clock time was complete. Before life was ruled by the clock, segmented sleep was the way of life all over the globe, exercised on several continents. While the way these cultures slept differed, segmented sleep was universal. Since segmented sleep seemed ubiquitous, this raises the question: "Is this the natural way of sleeping?" Anthropologist Matthew Wolf-Meyer, the author of *The Slumbering Masses*, stated that humans "are the only species that seem to consolidate sleep." Researchers found that people living in industrialized cultures, living by the clock, can revert back to segmented sleep. A National Institute of Health (NIH) study by psychiatrist Thomas Wehr plunged seven males into fourteen hours of darkness a day for a month. By the end of the trial, the subjects slept in four-hour segments, with a drowsy state in between. Several researchers and historians believe some of our modern sleep disorders, particularly waking in the middle of the night and the subsequent difficulty returning to sleep, harkens back to the foregone segmented sleep. A. Roger Ekirch, a Virginia Tech professor of history and the author of *At Day's Close,* said that this might be "a remnant of a very strong echo of this older pattern of sleep." What is clear is that the struggle between natural time and clock time resides in our slumber. Our internal sleep clocks differ from the mechanical clocks we obey.

We should sleep better than our ancestors. Yet, fifty to seventy million American suffer from sleep disorders or sleep deprivation.

Nearly one in eight Americans who have trouble sleeping use sleep-aid prescriptions. That number is one in six for those diagnosed with sleep disorders. The National Sleep Foundation implores that we get a minimum of seven hours of continuous sleep, but most Americans get only about six. Poor sleep is not because of our beds. "Our sleep conditions have never been better in all of history," says historian A. Roger Ekirch. Poor sleep seems to be the cost of our inability to get off the clock.

Sleep is a biological necessity. In 1983, scientists illustrated this fact. Researcher Allan Rechtschaffen and coworkers demonstrated the effects of sleep deprivation with rats in a laboratory experiment. In this study, rats were not permitted to sleep, and a range of medical issues emerged, from weakness to poor balance to weight loss to malfunctioning organs. Within fourteen to twenty-one days, many of the rats were dead. In humans, sleep deprivation has been linked to a loss in brain function, obesity, and psychological issues.

Sleep is also cultural. In some countries, naps, siestas, midday breaks, and public napping are part of the social fabric. In contrast, Americans are exhausted, yet unwilling to waste time napping, thanks to our Puritan heritage. Decoupling from time, with a nap or any restorative break, needs a champion for society to embrace it. Although Edison took naps, Churchill took naps, and Einstein did, too, drowsy workers opt to caffeinate. What is clear is that getting some sleep is a deliberate choice. It requires a better understanding of our relationship with time.

For eons, we've looked to make better clocks, but we have lost sleep along the way. What lies at the heart of our sleep dilemma is our culture's view of time. The clock is a yardstick. And for generations society has struggled to make better and better clocks, so we can coordinate our interactions during the day. In our pursuit of better clocks, however, we forgot to look at time itself. That work began around the period of Ruth Belville's business. In another part of Europe the product she sold, time, was being put under the microscope.

Albert and Louis

Uniform timekeeping was always in high demand for office work and for daily affairs, but knowing the precise time was becoming an important need for the biggest business of the day—the railroads. With synchronized clocks, locomotives could run on time, which meant there'd be fewer accidents and more passengers could arrive unharmed.

In 1905, the patent office in Bern, Switzerland, received quite a few applications for inventions with methods to synchronize clocks, particularly for the railroad. To make the synchronization of clocks a reality, eager inventors wrestled with how to set two timepieces that were far apart from each other to the same exact time. Their answer could be the difference between life or death for travelers, and the difference between an unremarkable existence and one of wealth for the inventor. To make sure that the submitted designs were credible, a little-known twenty-six-year-old patent officer acted as a gatekeeper, and dutifully scrutinized whether these inventions were unique, whether their solutions were the cleverest, and whether their embodiments were workable. This patent clerk's efforts could easily have faded into the annals of history, except that his name was Albert Einstein.

Einstein was a bright and precocious young man who wasn't a fan of authority or discipline. He preferred to work alone, so he didn't do well in his studies. After he graduated with a certificate in math instruction, he tried to get a faculty position within the university, but the best employment that young Albert could get was a position at the patent office. For those in the academic ivory tower the patent office was a place for scholarly misfits. Among his peers, Einstein was seen as no Einstein.

and how the basketball fans in the bleachers see it. As a basketball player goes down the court, they see the ball bouncing up and down vertically. The same goes for the person on the train, who would see the light signal going up and down vertically, too. Basketball fans sitting in the bleachers, however, see the basketball going up diagonally and coming down diagonally. A person at the train station would see a light signal on the train with a similar path as the basketball—going up at one angle and coming down at another.

The diagonal path is longer than the vertical path. And this is where Einstein rubbed his chin. The speed of light never changes, but one path was longer than the other. To make the unit of time square up between the person on the train and the person at the station, something had to change. To account for the difference, Einstein found that a moving clock is slower than one that is stationary. Time isn't fixed. It stretches.

For generations, scientists such as Sir Isaac Newton believed that time was immutable and unchanging. Newton was of the school of absolutes; Einstein was of the school of relatives. In Einstein's special theory of relativity, our precious unit of time was not the same on one occasion as in the next. A second's duration depended on the speed of the observer.

Humanity preferred certainty in culture and life. However, Einstein uncovered that a second is *not* a second is *not* a second. The time that it takes for a tick followed by a tock will not be identical for a person moving and another person standing firmly on solid ground. Time is elastic. The thing that was so precious for society wasn't exactly what we thought. For generations we have worked to make better clocks from the sun's shadows, to pendulum clocks, to coiled springs, to jiggling gems, and eventually to vibrating atoms in atomic clocks, only to find that what we aimed to measure acts like a rubber band.

Einstein was changing our understanding of time with physics. But just a few years later, in the 1920s, Louis Armstrong altered our experiences with time with music. To many, Armstrong (1901–1971) was a wide-smiling, handkerchief-toting, jazz trumpet player, who crooned "Hello Dolly" and "What a Wonderful World." But Armstrong was much more than the friendly persona that helped his genius navigate an age of Jim Crow. Armstrong was a time traveler, and his vehicle was jazz.

Armstrong came from nothing. He was the grandson of a slave and born in the toughest neighborhoods in New Orleans. According to his biographer, his "small world was bounded at its four corners by the School, the Church, the Dive and the Prison." But, just as he overcame those constraints in his life, he overcame the confines of a musical score. For Armstrong, each eighth note did not need to have the same weight or duration on every occasion that an eighth note appeared. He played them a few hundred milliseconds longer, or shorter, or sooner, or later than what was written on a page. He stretched, squeezed, or shifted notes, giving the music a richness, a feeling, and a forward motion.

Armstrong's attack was a departure from how Western music was usually performed. Western music hinged on accuracy. Marching bands focused on having musicians execute like clockwork. John Philip Sousa, like Sir Isaac Newton, loved precision. Armstrong, like Einstein, found beauty in the lack of it. An eighth note wasn't played exactly as written but swung, and how the note was executed was decided "in the spur of the moment."

Western music and jazz have different approaches to time, fashioned from the cultures from which they originate. In Western music, the notes are an ever-continuous progress to a resounding conclusion; the focus is on the future. In jazz, the focus is on the present. Jazz is an African-American dish that combines European, Caribbean, Afro-Hispanic, and African ingredients. African traditions have a different sense of time. The present is to be savored and expanded. In fact, several African languages have words for "past" and "present" but not for "future." And, it is through this heritage that Armstrong made every note do something, allowing him to stretch the present time with his music.

This African approach to time was transplanted to the New World and took root in the African-American experience. Ralph Ellison captured this black sensibility best in *Invisible Man* when he wrote about the asynchrony of the black experience, existing out of step—before or after—the pulse of time. A listener to Armstrong's work can hear and feel that sentiment embodied in the notes. In Armstrong's *Two Deuces* (1928), he is continuously behind the beat, shadowing it. The notes are delayed and compressed, which creates a gap between Armstrong and his band. To meet up with them again, Armstrong revs up and then hits the gas.

Armstrong stretches not just the notes, but also the listener's sense of time. While the songs on a 78 rpm disc are three short minutes, they are so rich with information it causes our brains to believe the recording is longer than it takes to cook ramen noodles. By playing slower or faster, Armstrong's audience loses track of clock time and the moment speeds up or slows down as they experience it. Einstein showed us that time is relative for the observer; Armstrong made time relative for the listener. How Armstrong shifts our sense of time has been pondered by poets, penned by critics, and probed by musicologists. While the research is still in its infancy, Armstrong's time-shifting abilities might get some support from science.

Timekeeping is ever present in our society. One question that comes to mind is "does timekeeping affect the brain?" The short answers are "yes" and "we don't know." We don't know how the brain was changed as the institution of timekeeping solidified over the span of the nineteenth century, in addition to the loss of segmented sleep. The field of studying the brain's temporal response is fairly new and mostly a twenty-first-century pursuit. What we do know, however, is that the brain gets cues about time from its environment.

Neuroscientists such as David Eagleman have done studies to examine the brain's internal clock. In one experiment, subjects watched a movie with fast-running cheetahs, with their legs coming off the ground, like Trinity in the *Matrix*. During the movie, a red dot of a fixed duration is flashed, when all four legs are suspended in midair. The same experiment is repeated with a small twist; in the second experiment, the same cheetah movie was played in slow motion, and the same annoying red dot blinked for the same duration as it had before when the cheetah caught air at normal speed. After the tests were compared, moviegoers believed that the red dot during the slow motion movie was shorter. "Your brain says I need to readjust my sense of time," said Eagleman. Our brain determines the time based on our knowledge of the laws of physics. Our perception of time is shaped by the events it uses to measure time—the landing of a wildcat's paw or perhaps the duration of an eighth note.

On a personal level, we have always been aware of the elasticity of time. Good times seem short and bad times seem to last forever. Neuroscientists have shown that in some respects this is not fiction. The length of our memories is linked to how good or bad the occasions are. What neuroscientists have found is that we don't perceive time slowing down in the moment, *but* our recall of the event makes us believe that time has slowed down. To understand what is going on in the brain, imagine that the brain acts like a computer that stores information on a hard drive. When life is boring, the hard drive stores a regular amount of information. When we are scared, however, as during a car accident, the brain's amygdala—our internal emergency operator—kicks in. Our brains collect finer details like the crumpling of the hood, the breaking off of side-view mirrors, and the changing of the expression on the other driver's face. The amount of detail gathered is increased, as if two hard drives are storing the data. "You're laying down memories on a secondary memory system now, not just one," said Eagleman.

More data gets stored. When the brain recalls the event, it interprets the large amount of information as a longer incident. The shape of the memory becomes the brain's yardstick of time.

Science shows that the size of a memory and our perception of time are coupled like gear teeth in a bicycle chain. Rich and novel experiences, like the recollections of the summers of our youth, have lots of new information associated with them. During those hot days, we learned how to swim or traveled to new places or mastered riding a bike without training wheels. The days went by slowly with those adventures. Yet, our adult lives have less novelty and newness, and are full of repeated tasks such as commuting or sending email or doing paperwork. The associated information filed for those chores is smaller and there is less new footage for the recall part of the brain to draw upon. Our brain interprets these days filled with boring events as shorter, so summers swiftly speed by.

Despite our desire for better clocks, our measuring stick of time isn't fixed. We don't measure time with seconds, like our clocks, but by our experiences. For us, time can slow down or time can fly.

For ages, humans have had an evolving obsession with time. Time helped us understand the world, helped us make appointments, and helped us interact. In our pursuit for precise timepieces, we abandoned nature's cues, of sunrises and sunsets—and we lost sleep—in hopes of possessing time with great precision in timekeeping. But time is not something that can be possessed. Einstein showed us that time is elastic, and what time it is depends on who you ask. Armstrong demonstrated our brains are faulty clocks, speeding up and slowing down with outward cues. But both Einstein and Armstrong, using science and jazz, showed that we are the time we keep.

2
Connect

How steel stitched the country together with rails, but also how steel helped to manufacture culture.

The Connector

In the early hours of Friday, April 21, 1865, bodies began to pack into the streets of downtown Baltimore. As sunlight broke through the light rain, the thick gathering of humanity near Camden Street train station made the roads impassable. Work stopped. Schools closed. Stores emptied. The people, waiting eagerly for the arrival of a train, wept.

That anticipated train chugged into the station containing the remains of President Abraham Lincoln. He died on April 15, a few days after the end of the Civil War. Now, inside this train, dubbed "The Lincoln Special," the late president's body sat dressed in the same suit he wore six weeks earlier at his second inauguration.

The grief-stricken public begged that Lincoln's funeral services be extended beyond Washington. In an age before television or radio, the only way for a person to participate in his memorial service was to leave her farm or close his shop and travel to go where Lincoln

Bessemer's Volcano

Henry Bessemer dreamed about steel. He longed to make an unlimited supply of it. Although in 1855 he didn't know much about the science of steel or the recipes for steelmaking, that didn't stop him from trying. It never had.

Bessemer was a prolific English inventor with over one hundred patents to his credit. His most famous invention to date was a gold-colored paint that didn't contain any gold. In the 1840s, metallic paint was the must-have item in England and used to gild ordinary frames, converting them into ornate ones. When buying this paint as a gift for his sister, he was flabbergasted when he found it cost as much as a laborer's day wage. So he figured out how to machine bronze into a powder that glittered like gold at a fraction of its cost. When he added this powder into paint, he made an inexpensive alternative that anyone could buy. And everyone did, making him rich. But soon Bessemer's thoughts turned away from gold and its glitter for decorations and toward steel with its strength for weapons. Little did he know that his imaginings for making steel would take him on a journey that would change the world, too.

In 1853, England and its allies (France, Turkey, and Sardinia) were at war in a conflict known today as the Crimean War—a battle to let Catholic pilgrims have access to the Holy Land. The allies supported the Catholics; the Russians didn't and wanted to preserve the Holy Land for Orthodox Christians. This tension ignited into combat and many inventors, like Bessemer, focused on making better weapons for the military.

To win the war, England needed steel—and lots of it. Steel is a strong metal that could build powerful cannons. Unfortunately, the creation of certain types of steel, like blister steel, proceeded at a glacial pace, while other processes, like making crucible steel, were difficult to scale up. In 1855, two years into the war, it became clear that the inventor who found a way to make steel quickly and

Index