The Man behind the Microchip: Robert Noyce and the Invention of Silicon Valley

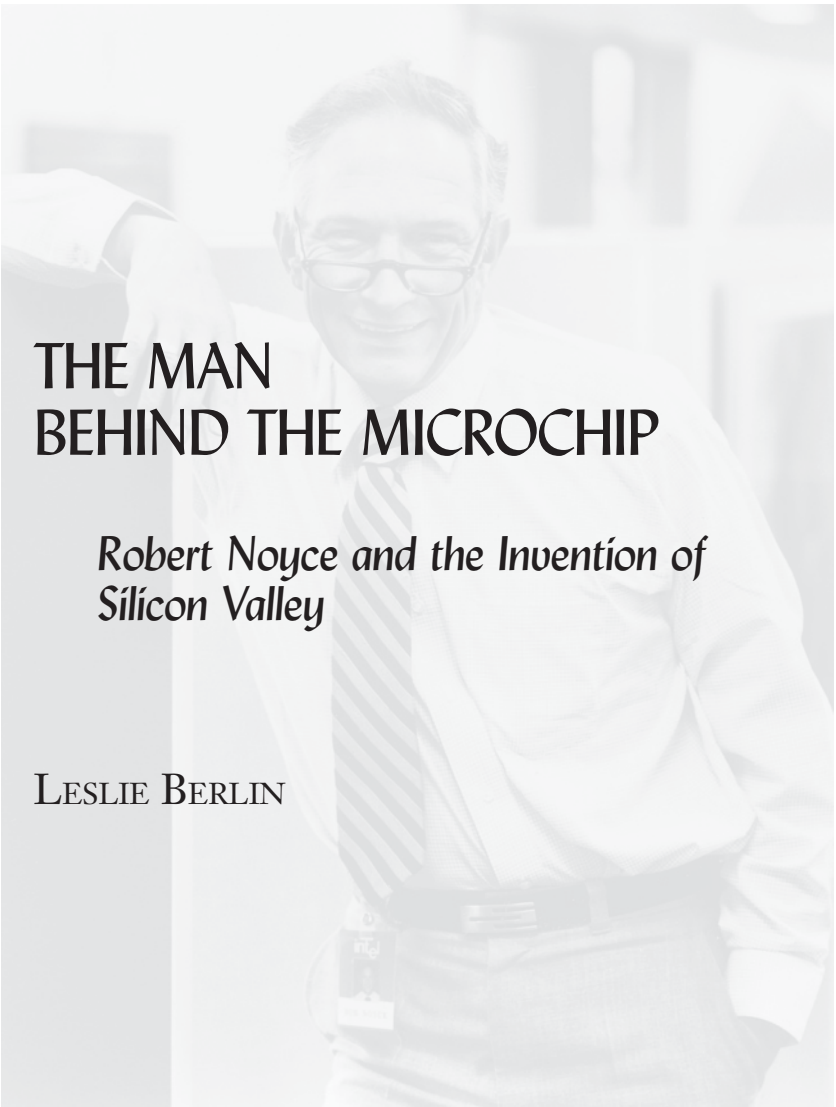
LESLIE BERLIN

OXFORD UNIVERSITY PRESS

THE MAN BEHIND THE MICROCHIP

He who lives to see two or three generations is like a man who sits some time in the conjurer's booth at a fair, and witnesses the performance twice or thrice in succession. The tricks were meant to be seen only once; and when they are no longer a novelty and cease to deceive, their effect is gone.

Arthur Schopenhauer, "On the Sufferings of the World"



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To Rick, Corbin, and Lily
My beloved ones

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Acknowledgments

One reason it took me several years to write this book was that before I could even start, I needed to create my own archive. Noyce's papers were not collected—he freely admitted he was "very sloppy in record-keeping"—and many important documents in the history of Silicon Valley have been lost, forgotten, or (I was dismayed to learn) destroyed. In the process of copying or gathering materials from basements and archives around the country, I have been fortunate to encounter more than a hundred people who were willing to share their documents and their memories of Noyce and the early days of the Silicon Valley semiconductor industry. The names of those generous people appear in Appendix A; to each of them, I am endlessly grateful. In addition, I would like to express particular gratitude to the following people who met with me multiple times or shared useful documents with me: Julius Blank, Roger Borovoy, Warren Buffett, Maryles and Mar Dell Casto, Ted Hoff, Paul Hwoschinsky, Steve Jobs, Jean Jones, Jim Lafferty, Jay Last, Christophe Lécuyer, Regis McKenna, Gordon Moore, Adam Noyce, Bill Noyce, Gaylord Noyce, Penny Noyce, Polly Noyce, Ralph Noyce, Karl Pedersen, Evan Ramstad, T. R. Reid, Daniel Seligson, Robert Smith, Charlie Sporck, Bob and Donna Teresi, and Bud Wheelon. Donald Noyce, Robert Noyce's older brother, was an amateur historian and—thank goodness—an inveterate packrat. Before he died quite unexpectedly in November 2004, he shared his collection of family memorabilia with me, a gift that contributed immeasurably to the early chapters of *The Man Behind the Microchip*.

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THE MAN BEHIND THE MICROCHIP

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Introduction

Bob Noyce took me under his wing," Apple Computer founder Steve Jobs explains. "I was young, in my twenties. He was in his early fifties. He tried to give me the lay of the land, give me a perspective that I could only partially understand." Jobs continues, "You can't really understand what is going on now unless you understand what came before."[1]

Before Intel and Google, before Microsoft and dot-coms and Apple and Cisco and Sun and Pixar and stock-option millionaires and startup widows and billionaire venture capitalists, there was a group of eight young men—six of them with PhDs, none of them over 32—who disliked their boss and decided to start their own transistor company. It was 1957. Leading the group of eight was an Iowa-born physicist named Robert Noyce, a minister's son and former champion diver, with a doctorate from MIT and a mind so quick (and a way with the ladies so effortless) that his graduate-school friends called him "Rapid Robert." Over the next decade, Noyce managed the company, called Fairchild Semiconductor, by teaching himself business skills as he went along. By 1967, Fairchild had 11,000 employees and $12 million in profits.

Before the Internet and the World Wide Web and cell phones and personal digital assistants and laptop computers and desktop computers and pocket calculators and digital watches and pacemakers and ATMs and cruise control and digital cameras and motion detectors and video games—before all these, and the electronic heart of all these, is a tiny device called an integrated circuit. The inventor of the first practical integrated circuit, in 1959, was Robert Noyce. It was one of 17 patents awarded to him.

In 1968, Noyce and his Fairchild co-founder Gordon Moore launched their own new venture, a tiny memory company they called Intel. Noyce's leadership of Intel—six years as president, five as board chair, and nine as a director—helped create a company that was roughly twice as profitable as its competitors and that today stands as the largest producer of semiconductor chips in the world.

But Noyce believed "big is bad"—or if not downright bad, at least not as much fun as small companies in which "everyone works much harder and cooperates more." When he left daily management at Intel in 1975, he turned his attention to the next generation of high-tech entrepreneurs. This is how he met Jobs. This is how he came to serve on the boards of a half dozen startup companies and informally provide seed money to many more. He did not think that all these companies would succeed—he filed his paperwork for several of them in shoe boxes that he kept in his closet—but he strongly believed that by investing, he was doing his part, as he put it, to "restock the stream I've fished from."[2]

Noyce was constitutionally unable to sit on the sidelines of any operation with which he was involved. He once called his invention of the integrated circuit "a challenge to the future," and turning away from the television interviewer, he stared straight into the camera to speak directly to the viewers: "Now let's see if you can top that one," he said, flashing a smile. At a father-son baseball game, which the dads traditionally allowed the boys to win, Noyce hit the very first pitch out of the park. "My poor father couldn't help himself," recalls his daughter Penny, who was in the stands that day. "He always threw himself entirely into the activity at hand—in whatever he did, he tried to excel."[3]

Robert Noyce's favorite ski jacket featured a patch that declared "no guts, no glory." It was a fitting motto for a man who flew his own planes, chartered a helicopter to drop him on mountaintops so he could ski down through the trees, rode a motorcycle through the streets of Bali in the middle of a thunderstorm, and once leapt with his skis off a 25-foot ledge into deep powder, exultant because he "had never jumped off a cliff into that much snow." His powers of persuasion were legendary. In 1963, he convinced the notoriously conservative board of one of his companies to start the semiconductor industry's first offshore manufacturing facility—at a site that was then completely under water, soon to be reclaimed from the bay by the government of Hong Kong. He talked a carload of traveling companions into joining him for a dip in a brackish Tibetan river, murky and, just a bit upstream, filled with crocodiles. He inspired in nearly everyone whom he encountered a sense that the future had no limits, and that together they could, as he liked to say, "Go off and do something wonderful." Recalls Intel's former chief counsel, "He was like the pied piper. If Bob wanted you to do something, you did it."[4]

Like so many others who spend their lives in the limelight, Noyce was an intensely private man. "He was the only person I can think of who was both aloof and charming," says Intel chairman Andy Grove. "I don't know how Bob kept you away, but you just didn't know anything about him. And this is the guy who would go down on one knee to adjust my skis, put my chains on, when I was a nobody."[5]

To be sure, Noyce's was not a simple personality. A small-town boy suspicious of large bureaucracies, he built two companies that between them employed tens of thousands of people, and he spent many years working through the maze of federal politics after he helped launch the Semiconductor Industry Association, today one of the nation's most effective lobbying organizations. He was a preacher's son who rejected organized religion, an outstanding athlete who chainsmoked, and an intensely competitive man who was greatly concerned that people like him. He was worth tens of millions and owned several planes and houses but nonetheless somehow maintained a "just folks" sort of charm: you half expected him to kick the ground and mutter "aw shucks, you guys," when his hometown declared "Bob Noyce Day" or an elite engineering group named him the first recipient of an award many called the Nobel Prize for Engineering. Recalls Warren Buffett, who served on a college board with Noyce for several years, "Everybody liked Bob. He was an extraordinarily smart guy who didn't need to let you know he was that smart. He could be your neighbor, but with lots of machinery in his head."[6]

It is easy to imagine Noyce, tuxedoed, smiling shyly, and desperately wanting a cigarette, in October 2000, when, had he lived, he undoubtedly would have shared the Nobel Prize for Physics awarded to his integrated circuit co-inventor, Jack Kilby. Amazingly, this is the second Nobel Prize that Noyce might rightfully have won. The first was in 1973, when a Japanese physicist named Leo Esaki was one of three recipients of the physics prize. Esaki was cited for his pathbreaking work on the tunnel diode, a device that provided the first physical evidence that tunneling, a foundational postulate of quantum mechanics, was more than an intriguing theoretical concept. Noyce had written a complete description of the tunnel diode nearly a year and a half before Esaki published his work in 1958. The two men's research was thus happening almost simultaneously on opposite sides of the Pacific. Noyce had not published his ideas, however, because his boss, the Nobel laureate William Shockley, discouraged him from pursuing them.

Beginnings fascinated Noyce. He could imagine things few others could see. In 1965, when push-button telephones were brand new and state-of-the-art computers still filled entire rooms, Noyce predicted that the integrated circuit would lead to "portable telephones, personal paging systems, and palm-sized TVs." His sense of near-limitless possibility led Noyce to pursue technical hunches that his colleagues believed were dead ends. (Often his peers were right, but occasionally, spectacularly, they were wrong.) Ideas fell from Noyce like leaves from a tree. For his work to be successful, he had to be surrounded by people who could follow up on his thoughts, filter them, and attend to the detail-work of running a company, because almost as soon as Noyce mentioned an idea, he had left it behind in order

to explore another one. Noyce's peripatetic mental style could be maddening at times. Andy Grove likens it to "a butterfly hopping from thought to thought. Unfinished sentences, unfinished thoughts: you really had to be on your toes to follow him."[7]

Noyce was forever pushing people to take their own ideas beyond where they believed they could go. "That's all you've got?" he'd ask. "Have you thought about . . ." An exchange of this sort left Noyce's colleagues and employees feeling as though his blue eyes had bored right through their skulls to discover some potential buried inside themselves or their ideas that they had not known existed. It was exhilarating and a bit frightening. "If you weren't intimidated by Bob Noyce, you'd never be intimidated by anybody," recalls Jim Lafferty, Noyce's friend and fellow pilot. "Here is this guy who is so capable in everything he does, and here you are trying to stumble through life and make it look respectable, and now you're trying to keep up with him. And nobody can keep up with him."[8]

Indeed, Noyce can sound too good to be true. He was a brilliant, wealthy, generous, greatly beloved man gifted with enormous vision. But to leave a description of Noyce here would be to sell him short. He was not a superhero. He could be indecisive and would do almost anything to avoid confrontation, a trait that kept him from making difficult decisions and taking tough actions. His resolute focus on the future, his persistent gaze beyond the horizon, left him blind to many details and uninterested in the mundane minutiae of corporate management. This lack of attention had real consequences. He recoiled from strong emotions and would rather pretend a problem did not exist than address it head on. For many years, his personal life was difficult, and he was not entirely without fault in this area.

But these elements of Noyce's character make him more of a man, not less. And to watch him come to recognize—and then devise means of working around—his own shortcomings, particularly as a manager, is to observe an exceptionally creative mind in action.

NOYCE'S INNER CIRCLE included the best-known players in Silicon Valley—Andy Grove and Gordon Moore of Intel, Arthur Rock and Eugene Kleiner of venture capital fame, Steve Jobs of Apple, William Shockley, co-inventor of the transistor—as well as the inventors of the planar process (which made it possible to mass produce complex microelectronic devices) and the microprocessor. Some of the lesser-known Silicon Valley pioneers who worked with Noyce hold their own interest: among them are a monomaniacal genius, a Swiss with two doctorates, an aristocratic refugee from Nazi terror, and the son of a New York cabbie who really wanted to run a bed-and-breakfast. Most of the people who worked with Noyce admired him—some loved him—but a few resented his notoriety, which they felt

obscured their own contributions. "Credit floats up" was the only comment one would offer about his former boss.

Together these men built a network of specialized equipment providers, high-caliber technical trade schools and engineering programs, and tech-savvy financial, public relations, and legal support services that helped to transform the once rural Santa Clara Valley into a high-tech business machine called Silicon Valley. When Noyce arrived in the San Francisco Bay Area in April 1956, electronics was the fastest growing industry in the region, with government defense contracts and sales to the military accounting for well over half the business. But the plum, cherry, and apricot trees that had once anchored the valley's economy still dotted the landscape. Twenty years later, the orchards were gone, government purchases accounted for less than a quarter of integrated circuit sales, and the electronics industry that had been suckled on government work was now sustained by a complex private network founded on a culture of high-stakes risk. Noyce's career offers an ideal window into how this happened.

That Noyce and his contemporaries changed their world is only half the story. Their lives bear the marks of the monumental social, political, technical, and economic shifts that reshaped America in the second half of the twentieth century. When Noyce went west, he joined the massive postwar migration to California. His industry, launched in the torrent of defense spending and creative panic triggered by a tiny beeping satellite that the Soviets had lofted into orbit in 1957, placed itself at the center of the debate over industrial policy in the 1980s. Semiconductors also catalyzed the high-tech bubble in the 1990s.

Little more than a dozen years ago, the *San Jose Mercury News* declared Noyce the Thomas Edison *and* the Henry Ford of Silicon Valley. He received the National Medal of Science from President Carter and the National Medal of Technology from President Reagan. Noyce was featured in hundreds of newspaper and magazine articles. Peter Jennings profiled him as "the person of the week" on ABC. CBS anchor Charles Osgood called Noyce "the man who changed the world." Tom Wolfe, who knew a hero when he saw one, wrote about Noyce in a 1983 *Esquire* article that ran next to pieces on other "American Originals," including Jackie Robinson, John F. Kennedy, Betty Friedan, Walt Disney, and Elvis Presley. Futurist George Gilder called Robert Noyce "undoubtedly the most important American of the postwar era," while Isaac Asimov went even further by hailing the invention of the integrated circuit as "the most important moment since man emerged as a life form."[9]

And yet until now the story of Robert Noyce has not been told in full. "High-tech history' is almost an oxymoron," Noyce once said. "Our major activity is to make yesterday's 'gee-whiz!' mundane today." Writing the history of a man, an industry, and a place that consider self-obsolescence

the pinnacle of success is not easy. Companies routinely shred their paperwork, and those items not destroyed by corporate fiat are consigned to wastebaskets and dumpsters by employees unable to imagine that the world might one day be as interested in their past as these technologists are in the future. It is only now that the one-time young Turks of the semiconductor industry are entering their seventies and eighties that they have begun to look backward, and remember.

Noyce did not live to look back. In 1990, at age 62, and just weeks after informing the board of SEMATECH—a two-year-old, billion-dollar, manufacturing consortium jointly funded by 14 semiconductor companies and the Department of Defense—that he planned to leave his job as the consortium's founding CEO, Noyce succumbed to a heart attack. Three thousand people attended memorial services for him. President George H. W. Bush phoned Noyce's widow to offer his personal condolences.

And yet even Noyce, the man who always looked forward, acknowledged that "roots are important." His core had been shaped by his Depression-era boyhood in the small town of Grinnell, Iowa, and by his birth into a family with deep Midwestern roots and a tradition of its men serving as teachers, ministers, or both. Noyce knew that his high-flying, high-tech adult self had its source in the Iowa boy who pedaled flat-rate annual snow-shoveling contracts to his neighbors and who spent every spare minute building motorized sleds and the town's best model airplanes. Surely the shape of the future electronics entrepreneur can be divined in 12-year-old Bobby Noyce's comment from a long-forgotten journal: "My hobby is handicraft," he wrote in 1939. "I like this hobby because it is useful. You can make things cheaply that are worth a lot."[10]

1

Adrenaline and Gasoline

Ask nearly anyone who lived in Grinnell, Iowa, during the 1940s and 1950s what they remember about Bob Noyce, and the answer is bound to involve a glider. In the summer of 1940, Noyce, who was then 12, built a boy-sized aircraft with his 14-year-old brother, Gaylord. This glider has attained mythic proportions among native Grinnellians, some of whom claim to have seen one of the Noyce brothers take flight from the roof of the Grinnell College stables, from the bleachers at the college stadium, from a large open window on the third floor of the Noyce home. The most dramatic story involves Gaylord and Bob convincing their seven-year-old brother to climb in the glider, which the older boys then tied to the bumper of a car that took off at top speed.

For Bob Noyce, the glider was "an all-time high" in "my long career of making things"—or so he claimed at 17. He had built a radio from scratch and motorized his sled by welding a propeller and an engine from an old Briggs and Stratton washing machine to the back of it. When the winter weather grew bitter and his hands cracked from one too many cold mornings delivering the *Des Moines Register* through the quiet streets of Grinnell, he had wired a car headlight to a battery that he found at the dump. Early risers could watch him precariously balance his way along his route, morning papers over his shoulder, warm headlight in his hands, ten-pound battery perched in the wire basket on his handlebars. He filled a scrapbook with *Popular Science* plans for constructing various ship models, a bed, a contraption that worked like a windsurfer but was used on ice, a skate sharpener, a xylophone, and a "half-horsepower sidewalk roadster."[1]

But always, his passion was flight. On summer evenings, he and Gaylord built balloons from wrapping paper and wire, lit oily rags underneath and watched their creations rise into the night skies like so many moons before drifting into a farmer's field when the rags burned out. They built innumerable balsa-wood model airplanes, the parts forever littering the window sills and steps of their house, to their mother's great displeasure. Bob

Noyce could spend weeks on a plane, perfecting the design, fine tuning the motor, and hunting it through the tall weeds that dotted the fields around town. But when a plane was shopworn, he showed no remorse. Grandly, boldly, he lit it on fire and sailed it from a window.[2]

When Bob Noyce was 11, he and a neighbor rode their bikes to a pasture where Grinnell's first barnstormer was giving 15-minute trips in his new Ford tri-motor for a dollar per ride. Noyce and his friend spent the day craning their necks upward, and when the line for rides had dwindled, the two boys convinced the ticket seller to let them share a seat. Perched on the edge of his half of the seat, Noyce watched the ground fall away, and soon he could see the Congregational Church where his family worshipped every Sunday and Grinnell College, where his oldest brother Don attended classes and his father, a minister, worked for the regional Congregationalist offices. Bob found his house, a modest one on a well-kept lot, just across the street from the college. And after they landed, after the two boys pedaled furiously home for dinner, after Noyce washed up and bowed his head for grace, he told his parents nothing of his great adventure. Keeping it secret made it that much more exciting.[3]

Bob Noyce was almost certainly remembering this flight when he proposed to Gaylord that they make their own glider. Bob had long ago proven himself the mastermind of mischief in their home, the daredevil forever pulling Gay, who would one day become a minister and who was already a very good boy, into impish hijinks. The two boys designed the glider themselves, working from their experience building model planes and from an illustration that they found in the *Book of Knowledge*, a multivolume encyclopedia that their parents kept deliberately accessible on a low shelf in the living room bookcase.

The brothers pooled their combined savings of $4.53 to buy materials and sent word to their neighborhood pals that a great invention was under construction. Soon the friends were helping too. Bob Smith, whose father owned a furniture store that regularly received rolls of carpet wound around bamboo spindles, provided sticks for the frame. Charlotte Matthews, the only girl on their block of 17 boys, sewed the cheese cloth to cover the wings. When the Noyce brothers declared the glider finished, it stood some four feet tall, and its wings stretched nearly 18 feet from tip to tip. Constructed largely from 1′ ×2′ pine boards, it had neither wheels nor skids and ran entirely on boy power.[4]

The pilot moved and steered the plane by standing amidship in an opening, holding up the frame with his two hands, and running as fast as he could. "We succeeded in running and jumping to get a little lift as experienced by the pilot," Gaylord recalls. "In running off a mound about four or five feet high, we got more." This was not good enough for Bob. Together he and Gaylord convinced their neighbor Jerry Strong, newly pos-

sessed of a driver's license and the keys to his father's car, to hitch the glider to the auto's bumper. Jerry was instructed to drive down Park Street fast enough to launch the glider and keep it aloft. The experiment, which in no way involved a seven-year-old brother, proved more terrifying than effective.[5]

Still this was not sufficiently thrilling for Bob Noyce. He and Jerry Strong decided to try, as Noyce put it a few years later, "to jump off the roof of a barn and live." The barn in question was in Merrill Park, just across the empty fields and asparagus patch behind the Noyces' house. Word spread through town, and the *Grinnell Herald* sent a photographer.[6]

Bob clambered up to the barn's roof and a few other boys handed him the glider, which weighed about 25 pounds. Bob then took a deep breath, thrust his sturdy body against the glider's frame . . . and jumped. Then, for one second, two, three, young Bob Noyce was flying. He hit the ground almost immediately, but as he proudly reported in a college admissions essay a few years later, "We did [it]!" Even the boys' mother, who privately thought her sons' fascination with airplanes a bit frivolous, was impressed. "It was all their idea," Harriet Noyce later recalled with emphasis, "*but I made the paste.*"[7]

IT WAS UNDOUBTEDLY FROM HIS MOTHER Harriet that Noyce inherited his love of adventure. Growing up in suburban Chicago, the daughter and granddaughter of Congregationalist ministers, Harriet Norton had dreamed of work as a missionary—perhaps the most daring path available to church-going young women of her age. She could imagine herself in China, where her mother's alma mater Oberlin had established a mission school. Harriet would have made a good missionary. She was fearless, quick witted, studious, and voluble, with an opinion on nearly every subject and a habit of narrating her thoughts aloud so that she seemed never to stop talking. She often said that she liked to "do a lot and do it well." When she left home to attend Oberlin at the age of 17, it was with scarcely a backwards glance.[8]

In 1920, when Harriet was wrapping up her sociology major, her brother introduced her to Ralph Noyce, a shy, quiet man just finishing his studies at Oberlin's Graduate School of Theology. The soon-to-be Reverend Noyce, slight and barely over five-and-a-half feet tall in his Sunday shoes, was 28 years old, a veteran of the Great War. He had been raised in the northeast corner of Nebraska, where his father, an ordained Congregationalist minister, preached and ran a dairy. A careful, soft-spoken man, Ralph Noyce loved philosophy and fancied himself more an intellectual than a religious leader. He studied ancient Greek and Latin at Doane College and collected images of the Madonna on which he could discourse in the manner of an art historian.

The church centered their courtship, which is not to say that it dictated their beliefs. No Congregationalist creed or formalized set of rituals defined the religion, and the individual churches for the most part operated independently, with no bishop or synod above them. Instead, the religion offered Harriet Norton and Ralph Noyce a common language and set of values: tolerance, respect for education, egalitarianism, and a belief in an unmediated relationship between God and His earthly servants. As Harriet put it, she and Ralph shared the same dream: "to be Christian leaders, in the best sense . . . equip[ped with] a concern for the needy, [and] an attitude towards people as equals, sacred in some way."[9]

But Harriet, always independent and strong willed, insisted on working for a year after college before she would marry. She taught high-school Latin and English near her parents' home and proved to her own satisfaction that she was capable of caring for herself. As soon as the school year ended, on June 20, 1922, Harriet Norton and Ralph Noyce were married. Her father performed the service; his assisted.

After a short honeymoon, the young couple arrived in Denmark, Iowa, a town of about 250 in the southeasternmost corner of the state. The Denmark church was small but prestigious: the oldest Congregational church west of the Mississippi, it was crowned with a 250-foot spire visible from farms miles away. The families on those farms were Ralph Noyce's parishioners, and they braved icy country roads in the winter and sweltering heat in the summer to hear Ralph speak to them from his well-annotated outlines on subjects such as "Christian Optimism."[10]

Ralph and Harriet Noyce lived in the parsonage. With housing expenses covered by the church, his $1,500 annual salary could provide small indulgences such as barbershop haircuts, a secondhand car, and hospital births for Donald Sterling Noyce, who arrived in May 1923, and Gaylord Brewster Noyce, born in July 1926.[11]

When Harriet discovered that a third child would arrive around Thanksgiving 1927, she and Ralph decided that their family could benefit from an increase in pay and a move to a larger community. Ralph learned of an opening at the church in Atlantic, Iowa, a town roughly triple the size of Denmark and a few hours' ride west on the Burlington and Rock Island railroad. He arranged to "candidate" for the job, and when he was offered the position at a salary nearly twice his current pay, he agreed to start as soon as the new baby was born.

Meanwhile, Harriet prepared for the arrival of her third child. A friend came to help Ralph with the boys and, at the suggestion of her doctor, Harriet took a room near the hospital in Burlington, 18 miles from home. She told her mother, her in-laws, and her friends that after two boys, she desperately wanted a little girl. Hedging her bets, she did not even pick out a boy's name. On December 12, 1927, the Noyces' third son arrived in a

flash, beating his doctor to the delivery room. "Congratulations, and my sincere sympathy," read a letter from Ralph's brother. "Too bad he was a *he*." Harriet rallied soon enough, however. The healthy baby boy was named Robert, to be called Bobby.[12]

WHEN BOBBY WAS SIX WEEKS OLD, the Noyce family arrived in Atlantic. The church had 200 active members and a study for Ralph, who spent most days there, meeting with parishioners and clipping articles from *Life*, *Literary Digest*, and *Christian Century* for sermon fodder. Harriet found kindred spirits among a group of church women who organized Chautauqua-style study sessions for themselves. The two older Noyce boys—Don, who was nearly five, and almost-two-year-old Gaylord—delighted in the sanctuary's opera-style seats, which provided hours of slamming and clambering fun.

The parsonage in which the Noyce family lived was not only owned by the church, it was furnished and decorated by the Ladies Auxiliary, which meant that Ralph and Harriet were never comfortable changing things to suit their taste. Harriet ran the vacation bible school, headed the makeshift kitchens on church-sponsored camping trips, witnessed marriage licenses, oversaw the Ladies Auxiliary, and whispered forgotten lines from backstage at Christmas pageants.

For the boys, there were hymns and prayers most evenings at home, as well as Sunday services, Sunday school, and Sunday supper. Reverend Noyce devoted his ministry to the children of the church, and he assumed his own sons would participate in the classes, retreats, church youth group meetings, and Christmas plays he organized. Moreover, if no one volunteered to lead these activities, the Noyce brothers were expected to do so. And though neither Harriet nor Ralph emphasized them, the boys also had to contend with the intangible responsibilities of being a preacher's child: their behavior reflected not only on themselves, but on their father, their religion, and maybe even on God.

Ralph Noyce was a constant presence in his sons' lives. He often worked at home, in a room lined with his books in Greek and Latin. Even when he was spending his day at the church, he walked the three blocks to the parsonage at noon to eat with his wife and sons. The boys knew not to disturb Dad on Saturdays, when he finished his sermons, but otherwise, he was usually available. Bob Noyce's earliest childhood memory involves beating his father at Ping Pong and feeling absolutely devastated when his mother's reaction to this thrilling news was a distracted "Wasn't that nice of Daddy to let you win?"

Even at age five, Noyce was offended by the notion of intentionally losing at anything. "That's not the game," he sulked to his mother. "If you're going to play, play to win!"[13]

THE RAPIDLY DEEPENING agricultural depression fully descended upon Atlantic in 1932, when farm prices and income hit record lows. By 1935, a bushel of wheat still fetched only 20 percent of its 1919 price, and at ten cents a bushel, the most efficient use for corn was to burn it to save the need for coal. Farm foreclosures were common. A drought plagued the countryside. The Atlantic bank failed in February 1933, shortly before the birth of the Noyces' fourth son, Ralph Harold, taking with it the amount Reverend Noyce had borrowed against his government life insurance policy to cover hospital expenses.[14]

Ralph's church began "adopting" needy families, with one member paying the way to statewide Congregationalist conferences, another sewing school clothes, and the Noyces regularly inviting small children to play with Gaylord and Bobby while the parents did what work they could. The parsonage became a regular stopping point for hoboes. Harriet could almost always manage to offer them a sandwich and a glass of milk, or sometimes a short stint of labor in exchange for a meal and a spot to sleep in an unused chicken coop.

Although the Noyce family was initially blessed with a steady income and reliable housing, they too soon felt the pinch of the Depression. In 1932, the trustees closed Ralph's beloved church office to save the expenses of heat and a telephone. (They gave Ralph the telephone handset, which he and his boys promptly wired to ring in the study he set up at home—no easy feat at the time.) Ralph's salary, officially $2,400 annually, plummeted. In 1934, he was paid only $1,200. By mid-1935, the church was five months in arrears; often he was given a wagonload of corncobs or a ham in lieu of remuneration. The family found itself dipping into the GI life insurance benefits of Harriet's younger brother Don, who had died of meningitis shortly after introducing Harriet and Ralph. This money, now pressed into service for daily expenses, had been earmarked for investments and college savings.

The strain was too much. After eight years of service, Ralph preached his last sermon in Atlantic on October 25, 1936. The family strapped a Halloween pumpkin to the bumper of their old Ford and began a drive across the state to Decorah, in the northeastern corner of Iowa that had not suffered as badly from drought. The Noyces hoped the church in a less depressed area could meet its commitments to its minister, but within months of the family's arrival, Ralph's approach to religion had rankled several prominent congregants. Ralph was a humanitarian and an intellectual—Bobby was unsure if his father believed in an afterlife—who felt a minister, first and foremost, should be a listener, "someone to tell things to." The congregation wanted a bit more fire and brimstone, and so, less than two years after they came to Decorah, the Noyces were on the move once more, this time to Webster City, 65 miles north of Des Moines, a town roughly the size of Atlantic. Bobby was ten years old.[15]

Ralph's work and his relationship with his sons changed significantly with this move. The Webster City job was not a parish ministry but an administrative post with the Iowa Congregational Conference, the umbrella organization for the churches in the state. As associate superintendent, Ralph planned and ran meetings, filled in for absent ministers, and directed youth education programs throughout Iowa. In a single year, Ralph drove more than 25,000 miles of twisting rural roads and addressed 110 different audiences. His boys felt lucky if he made it home for Sunday dinner once every six weeks.[16]

Harriet called these the years of "Mothering with a Daddy on the Road." She was fiercely devoted to her boys, playing anagram games with them, listening to their troubles (always taking their side), and keeping watch over their friends and their homework. She schooled her sons in manners and social niceties, cautioning them again and again to speak only in ways that were "kind, necessary, and honest." It could not have been an easy time for her. Don developed asthma so debilitating that he could attend school only in the mornings. Bobby and Gaylord's early interest in science progressed from digging up earthworms, to taxidermy experiments with cats and saltpeter, to chemistry disasters involving nitrogen tri-iodide and exploding houseflies. Harriet nonetheless found this period strangely liberating. "I felt the sense of belonging as a person of worth for myself," she said, "and not just as the minister's wife."[17]

Webster City proved yet another temporary stop. Barely a year after their arrival, the boys were told they would be moving at the end of the school year. Their father's job had been transferred to the campus of Grinnell College, site of the state conference's headquarters. Ralph and Harriet had secretly been hoping for this outcome ever since Ralph accepted the Webster City job. Grinnell College offered all children of local ministers, regardless of denomination, a scholarship equivalent to roughly one-third the cost of tuition. For parents expecting to send three boys to college in the next five years, this was an attractive offer indeed. For the boys themselves, it meant yet another new school and another new set of friends, with no guarantee the family would stay any more than a year or two.

GRINNELL, at least for Bobby, became home in a way no other town had been. He had moved three times in the four years before he came to Grinnell, but he would stay in this town from the age of 12 until he graduated from college. Grinnell had 6,000 residents and 21 churches when the Noyces moved into a white Victorian they rented at the corner of Tenth and Park in the spring of 1940. The neighborhood, which abutted the college campus to the east and the city limits to the north, teemed with children—children tearing down the streets on bikes, or rushing in the front door when their mothers rang the cow bells they kept on the porch

to call them home for dinner. Parents worked as teachers or lawyers, or they owned one of the town's small businesses: the lumber yard or funeral home or feed shop. These people had felt the impact of the Depression but had not suffered inordinately during the past few years. Nearly everyone was white, and nearly everyone, whether or not they went to church, was Christian. The Noyces set up housekeeping quickly, and Ralph resumed his traveling, though at a somewhat reduced intensity.[18]

Grinnell sat in the middle of prime Iowa farmland. Scarcely a decade after the fiery Congregationalist minister Josiah Grinnell founded his namesake village in 1853 (choosing the site because it was rumored to become the crossing point of Iowa's main East-West and North-South railroads), homesteading farmers had cleared every tree within a three-mile radius of the town's borders. When the Noyces arrived nearly a century later, soybean, corn, and livestock flourished in the farmland that ringed the city limits. Farmers were a regular part of daily life and an essential part of the town's economy. Men drove to Grinnell for feed and fertilizer. The women sold their produce and handmade soaps at the market. Their children came to school in yellow buses paid for by the county.

HOW HIS OWN BRAIN stacked up against his older brothers' caused Bobby Noyce no small measure of worry as he prepared to start eighth grade in Grinnell. Harriet and Ralph Noyce expected their boys to be excellent students. Not only were Harriet and Ralph college graduates, but all four of their parents had also graduated college—a remarkable fact given that, at the end of the nineteenth century, less than 2 percent of the population received a university education. The boys' great-great-grandfather Reuben Gaylord had helped found Grinnell College in 1846, one of some 20 "prairie colleges" founded by Congregationalists in the mid-nineteenth century.[19]

Noyce's eldest brother Don set a blistering academic pace. Despite multiple moves and asthma-related absences, he managed to graduate second in his high school class and earn a generous merit-based scholarship at Grinnell College before the family left Webster City. Gaylord, just starting high school when the family moved to Grinnell, was poised to extend the family's intellectual honor. At 15, with a lean build and an unruly cowlick, he was a model student, polite and handsome with a near-perfect grade point average. He would graduate as valedictorian and would one day be nominated for a Rhodes scholarship, like his father before him. Bobby Noyce, on the other hand, was short, stocky, and sullen at 12. He brought home report cards marred with the occasional B, usually appearing in penmanship or conduct. He would delay doing his schoolwork until the last possible instant.[20]

He was three months into his freshman year at Grinnell High when Principal Cranny called a special assembly for all 400 students. It was the

day after the Japanese bombed Pearl Harbor. Cranny told the students that President Roosevelt had just delivered a speech declaring December 7 "a day which will live in infamy" and requesting that Congress "accept the state of war Japan had thrust upon the United States." Some of the boys whispered excitedly. Most of the students were subdued by the thought of the brothers they had at home or by their own proximity to draft age. No one knew exactly what war meant for the town of Grinnell, Iowa, but everyone knew what it meant for 18-year-old boys.[21]

Within months, the government had rationed rubber, meat, coffee, and gasoline. Nearly 2,000 men arrived on the campus of Grinnell College to participate in military training programs. The *Grinnell Herald Register* exhorted townfolk and farmers to bring iron, rubber, aluminum, copper, brass, and burlap to the World War One cannon in Central Park. The 250-ton take, along with a 500-pound fire bell that was lowered from the tower where it had hung for decades, was towed off for scrap. Druggists donated quinine to the government for war use. A group of 53 Grinnell women made sweaters, stockings, blankets, and clothes for refugee infants in England. The federal government issued a "Call to (F)arms!" urging farmers to "keep 'em eating" by upping production by ten percent; the county's farms were to expected to produce 2.2 million dozen eggs, nearly 10,000 acres of soybeans, and more than 66 million pounds of milk in 1942.[22]

Noyce and his classmates felt the effects of the war every day. On Tuesday mornings, teachers sold ten-cent stamps that could be pasted into a book and traded in for a war bond. The Grinnell High School newspaper carried stories of graduates in the war, and the yearbook began with a sobering series of photos featuring very young men in uniform who would never return for their reunions. Bobby volunteered for the civil air patrol, which was on alert during blackout drills. He and Gaylord compiled, annotated, and laboriously typed booklets of war poetry. Farm kids, whose parents were allowed unlimited gasoline for their tractors, suddenly found themselves uncommonly popular. Did they want to go to the football game, and by the way, would they mind driving?

In many ways, though, life for Bobby Noyce proceeded in much the same way as it might have without the war. Midway through high school, he started calling himself Bob. He played the oboe in the band—Gaylord was on bassoon—and proudly labeled the band photo in his freshman annual "STATE WINNERS SINCE '39!" Afternoons were filled with taffypulls, hayrides, play rehearsals, parties, and listening to Tom Mix, Jack Armstrong, and Little Orphan Annie on the radio. Noyce spent his share of time at Candyland, the soda fountain on Fourth Street, eyeing the girls in wool skirts and bobby socks crammed together in the high-backed booths.

Bob Noyce also worked nearly 20 hours each week beginning in very early adolescence. He threw the *Des Moines Register* on porches in the mornings before school, and he worked almost every afternoon either at Bates Flower Shop downtown, where he arranged flowers and corsages, or at the post office, where he delivered special orders on his bike. He developed a flat-rate annual snow shoveling contract that he would offer his neighbors—and then he would hope for mild weather. These jobs were his primary source of spending money. He later said he felt no particular deprivation as a child, but finances were tight in the Noyce household.

Reverend Noyce's employment was precarious. Shortly after the family moved to Grinnell, he suffered a mild cerebral hemorrhage that damaged his short-term memory and left him partially blind. Harriet did not want to assume the debt they would need to buy a home, which meant that nearly every year, the family moved to a new house.

"Harriet had her hands full," recalled a Grinnell neighbor. "Those boys, especially Bob, were into devilment." Noyce would show up at neighbors' houses, his pockets full of wires and clips, and ask to borrow the 220-volt outlet for the kitchen range so he could try to build the electrical arc *Popular Science* claimed was capable of burning a hole through steel. He started smoking cigarettes. He and his friends enjoyed tipping over outhouses on the nearby farms, though attacks of conscience often sent them back to the scene of the crime, swearing and sweating in the stench as they righted the wooden building. They shot firecrackers off the slides at Merrill Park and from the roof of Gates Hall on the college campus. And while his older brothers' commitments to Congregationalism deepened in high school, Bob began spending less and less time at the old stone church at the corner of Fourth and Broad.[23]

At 16, Noyce was one of the select few in his class to have a car at his disposal, a '39 Plymouth that belonged to his mother but that she rarely drove. (His father put the miles on the old family Ford.) Noyce was not beyond sneaking off to a farm and siphoning a bit of precious gasoline from the tank of an unprotected tractor. He drove like a man possessed, taking ditches at 40 miles per hour and racing his friends down Sixth Avenue, one of the town's two main drags. "It seemed like he was always in a hurry to get somewhere," one of his friends observed. "And he got there."[24]

By the time Noyce was a junior in high school, "all the girls were crazy about [him]," recalls one of his classmates. "They though he was the most handsome thing on the face of the earth." The quick lopsided smile, the good manners and fine family, the wavy hair high on his forehead, the dash of rapscallion—it made for an appealing combination. He was not tall, only 5'8", but his childhood pudginess had hardened into muscle, and he had acquired a visible confidence in his body. "He was probably the most physically graceful man I've ever met. Just walking across the lawn . . . on a

horse, even driving a car," recalls Marianne Standing, Noyce's steady girlfriend for several years of high school. Marianne was the glamour girl of the class of '45: a gorgeous brunette with smoky eyes, a biting wit, a penchant for unfiltered cigarettes—and, most shocking of all, a divorced mother. Harriet Noyce, who thought Marianne "had a gift for trouble, learned from playing one divorced parent against the other," made sure the family sang hymns after dinner whenever she joined them for a meal.[25]

His high-spirited antics did not keep Noyce from practicing his oboe, doing his homework (and sometimes his friends' homework, too), or maintaining a reputation among teachers as a "very fine boy." The yearbook called him "the Quiz Kid of our class, the guy who has the answers to all the questions." He maintained a straight-A record in high school and demonstrated an astonishingly intuitive sense for science and math, never earning less than 96 percent in either subject. Although he spent much of the first semester of high school physics dismantling and rebuilding a watch under his desk during lectures—he had the audacity to use a jeweler's loupe when the teacher's back was turned—he nonetheless aced every test.[26]

Harriet may not have known about the watch or Noyce's other antics, but she well understood that high-school physics bored Bob and that he would create his own special brand of challenge in the absence of more appropriate alternatives. This was especially true after Gaylord, who had always moderated Bob's tendencies towards excess, had left home in 1944 for the navy's V-12 officer training program. Gaylord had read about the Nazis' concentration camps and decided this war was a moral imperative. Bob admired his brother's ideals, but Gaylord's departure left him bereft and even more restless than usual.[27]

Desperate for a productive time-filler for Bob, Harriet Noyce took it upon herself to pay a call on Mr. Grant Gale, the physics professor at Grinnell College. The Noyces and the Gales attended church together, and Bob or his brothers went to the Gales every few weeks to help with babysitting, snow shoveling, repairing the lawn mower, or installing screens on the windows.[28]

In her characteristically straightforward way, Harriet asked Gale to let Bob join his introductory physics course. After verifying that a few other high school students had taken an occasional course at Grinnell College over the years, Gale agreed to let Noyce enroll when the second semester began in January 1945. As it was, his classes were unusually small, since nearly every physics major on the campus had been drafted.

In this introductory course, Gale focused on demonstrating the relevance of physics to daily life. He eschewed note taking—"that's what textbooks are for"—in favor of real-life demonstrations. With what force did the snowball he hurled against the side of the science building hit the bricks? Why did a skater spin faster when she pulled her arms in to her side? Why

could you fill a drinking straw with water, seal the top with your finger, and lift the straw without spilling the water? How could you prove your answers to these questions? His stock of homilies was legendary. "Have the courage of your convictions," he would urge a student hesitating to guess an answer. "Be brave." When a student with real promise began to ramble, Gale would gently admonish, "If you can't define it in one sentence, you probably don't understand it."[29]

Noyce was the only male in the class of 14, a position to which he did not object. While Gale lectured, Noyce would lean back in his chair, listening carefully and occasionally volunteering comments. "[Gale's] interest was infectious," Noyce later recalled. "I caught the disease." At the lab tables, Noyce was eager and thorough, despite being somewhat preoccupied with flirting with his lab partners, who despite his best efforts, treated him like a kid brother. At the semester's end, Noyce had earned the highest grade in the course. [30]

MUCH TO HIS RELIEF—"it's almost become a family tradition now," he explained—Bob Noyce was named valedictorian of his high school class. The honor surprised several of his friends, who knew Noyce was a good student, but not that good. They knew he took a class at the college, but not that he was the best student in the room; that he shoveled walks, but not that he had developed an elaborate contract system to entice clients. Noyce did not try or need to hide such facts from his friends. They simply never would have expected such things from him, the buddy one of them described as "bright but common."[31]

He spent the summer after graduation taking classes at Miami University of Ohio where Gaylord was undergoing his officer training. Noyce arrived at Miami a bit cocky from his end-of-year accomplishments. He told his math instructor that he was "getting a nice bit of review out of her course, even though [he] didn't attend classes."[32]

Alone with his brother, Noyce's world began telescoping far beyond rural Iowa. He saw his first opera, Verdi's *Aida*, and was transfixed. He stayed up late talking with Gaylord and his friends about the atomic bomb that had recently devastated Hiroshima and Nagasaki. He hitchhiked 200 miles to Gallipolis, Ohio, to visit Marianne Standing. He listened attentively to Gaylord's stories about his trip to New York City, and swamped with the admixture of envy and insecurity that was his typical response to any of his brothers' accomplishments, wrote to his parents: "So Gay has seen the Statue of Liberty, huh! Some day I may get to. I hope. I'd better stop dreaming."[33]

He began swimming for an hour every day and after watching three Miami divers flipping and twisting through the air, he decided he wanted to dive, too. "After landing flat on my back only twice, I perfected the

technique," he reported to his family. "Before I went home, I did both a half and a full gainer off the ten-foot board—Whoopee!" [34]

He met with similar academic success. At the end of the summer, the head of the Physics Department made him a job offer: if Noyce would enroll in the fall, the department would place him on the faculty payroll and employ him as a lab assistant, a position traditionally reserved for graduate students. He would be expected to grade papers, teach a few class sessions, and explain experiments to other students—all while he was a freshman. The invitation pierced Noyce's veneer of academic nonchalance. "My front teeth almost fell out," he proudly wrote to his parents, sounding like the 17-year-old he was.[35]

Noyce was slowly gathering experiences that would anchor his adult approach to life, which was not so much an approach as a headlong rush into any challenge with the unshakable assumption that he would emerge not only successful, but triumphant. If joining a college physics course as a high school senior meant finishing first in the class or getting an offer to teach, if dating meant snagging the most desirable girl in the school for your steady, and learning to dive meant turning full back flips off the platform's edge within hours of climbing the board for the first time—well, why wouldn't you come to think you could do almost anything?

Noyce was tempted by the offer to teach at Miami but worried he might be just "another insignificant student" on the large campus. If, on the other hand, he attended Grinnell College, he would face no possibility of insignificance. He had already won the same prestigious scholarship earlier awarded to his brother Don. The college president, Samuel Stevens, was a family friend who personally congratulated Bob on his acceptance to Grinnell with a note that inadvertently encapsulated the best and worst aspects of life as a Noyce boy: "Your brothers before you have performed in a distinguished manner. You seem to have the ability to perform equally well. We expect great things from you." At the end of the summer, Noyce decided to return to Grinnell for college.[36]

Once on the Grinnell campus, Noyce hurled himself into a frenzy of activity. In addition to a full course load, he stuffed his waking hours with nightly bridge games, chorus practice, yearbook staff meetings, play rehearsals, and attendance at dozens of lectures and musical performances. Noyce starred in a campus radio melodrama that his parents, to their great delight, could pick up on a neighbor's radio set. He approached dating with the same gusto that characterized everything he did. In his spare time, he plowed through the recently issued Smyth report on the atomic bomb, fascinated by the details of its technical development.[37]

The GI Bill and the end of the war meant that the campus now teemed with veterans, but Noyce drew most of his friends from a more traditional group of freshmen—boys and girls just graduated from high school, most

from churchgoing Iowa families that could afford to pay what was then one of the highest tuitions in the state. He immediately assumed a leadership role among this group, usually managing to convince even the most studious to take a break for a sandwich or a stroll past the girls' dorms. "He never pushed himself forward at all," recalled one of Noyce's college roommates. "But why not follow him?"[38]

Noyce's father once wrote that in the same way toddlers thrive on juice and milk, Bob thrived on "adrenaline and gasoline."[39]

THE INTENSITY THAT NOYCE BROUGHT to his extracurricular activities extended to the classroom. He challenged himself to derive every formula he used in physics class rather than simply accepting the formulas written on the board as accurate. This was not easy work, even for Noyce, who declared himself "elated" after deriving the formula for determining the viscosity of a liquid. His electronics professor had him write his own exam and requested his help designing the circuits for his airplane models. His calculus professor asked him to teach a class based on the independent investigations Noyce had conducted into De Moivre's theorem for calculating complex numbers. These academic accomplishments earned Noyce an invitation to join the campus honorary society and inspired a heartfelt note from his father, who wrote, "You won't know till you have a son in college doing as good and grand work there as you are in Grinnell[,] how much satisfaction we are getting from reports of your good work."[40]

Such praise did not lessen Noyce's constant comparison of himself to his brothers. When Gaylord was named to Phi Beta Kappa after only five semesters of college, Bob's congratulations were tempered with doubt. "I'm just sorry that I've got such brothers to follow," he wrote. "When and if I get the same, it will just be another key in the family." As if to prove his own worth, he proceeded to describe in great detail how Grant Gale had asked him to help build an apparatus to study expansion and compression of metals.[41]

Money was always an issue. "$5 in the bank, $4 in my pocket" was the state of his finances soon after his arrival at Grinnell. Noyce worked several jobs—go-fer in the campus post office (until a returning vet asked for the work), lifeguard during Sunday afternoon free swims, assistant in Grant Gale's lab—but pleas for cash, accompanied by detailed accounts of where his last installment went, dominated many of his letters to his parents. Harriet Noyce, who never forgot that Bob once used his $19 savings to buy a pair of saddle shoes and a sweater rather than a bond during the war, thought him a spendthrift, particularly when it came to clothes and girls. She asked repeatedly about expenditures she found suspicious, including a check to an unnamed woman, whom Noyce, in great frustration, explained was simply the bank clerk who cashed the check, not a cause for worry.[42]

In the second semester of his freshman year, Noyce decided he wanted a varsity letter from Grinnell. His small stature and lack of experience would handicap him in most sports, but he thought he had a shot in diving. The Grinnell College pool was primitive, a wood-frame building over a concrete hole and a wooden deck. The roof was so low that divers would have undoubtedly hit their heads on it had a ten-foot by twelve-foot hole not been cut into the area directly over the diving board and the roof raised some eight feet in this one spot. From the outside, this "diving well" looked a bit like a widow's walk eight feet above the main roofline. Inside, a diver looking up from the board would have had the sense of peering up a short, broad chimney. When the team practiced, people in the pool or on the deck would see the diver leave the board, disappear into the chimney (where he would twist, flip, and turn) and then reappear shortly before he hit the water. The diving well was nerve wracking, but it gave an advantage to Grinnell divers. If they could dive up a chimney, everything else was pretty simple.[43]

Every night before he fell asleep, Noyce would mentally rehearse each of his dives in slow motion until he could see himself executing them perfectly. He called this habit "envisioning myself at the next level," and he carried it with him throughout his life. In his mind's eye, he could always see himself achieving something more.[44]

Two years after joining the diving team, Noyce won the 1948 Midwest Conference Diving Championship in Rockford, Illinois, defeating divers from Beloit, Carleton, Knox, and Monmouth colleges. He proceeded undefeated through the next season, when he lost the conference championship by two points. His parents were in the audience for this 1949 championship, and he worried that they were disappointed by his performance.[45]

LIKE OTHER UNMARRIED STUDENTS at Grinnell, Noyce had been assigned to a residence hall in which he was to live for all four years of school. The halls functioned much like fraternities, complete with internal house governments and athletic, academic, and social competition with other houses. Every spring and fall, each hall hosted a party. In their zeal to create the most spectacular party—the better the celebration, the larger the pool of potential dates—residents often enhanced the décor with a few bales of hay or a stack of lumber "borrowed" from unsuspecting farmers or townfolk.

Noyce lived in Clark Hall, which decided upon a Hawaiian luau theme for its spring house party a few weeks before the end of his junior year. Since Noyce knew the town of Grinnell especially well, he was assigned the task of liberating a young pig to be roasted upon a realistic looking spit.[46]

Noyce accepted the assignment but most likely gave it little thought. He was contending with the direst news of his young life. His girlfriend was pregnant. He was the father. She was going to have an abortion.

Whether Noyce encouraged her to have the operation, whether he offered to marry the young woman, how they paid for the procedure—these are all mysteries. What is known, however, is that Noyce was in an extremely agitated state the night he and a partner in crime downed a few drinks and set off to steal the pig for the luau.[47]

They walked across the golf course behind campus, grabbed a suckling pig, and ran with it back to Clark Hall. His housemates decided to butcher the piglet in a third-floor shower. A frantically squealing animal, intoxicated young men with knives—the ruckus was such that students all over campus immediately knew something untoward was happening in Clark Hall. The administration, however, did not hear about it until the next day, when Noyce and his housemate repented and returned to the farm with an offer to pay for the pig, whose absence had not yet been noticed.

It quickly became apparent that Noyce had not chosen a good farm to target. The farmer was the mayor of Grinnell, a no-nonsense man given to motivating his constituents through mild intimidation. He wanted to press charges. The college's dean of personnel, a recently retired army colonel, was also inclined towards the harshest punishment possible; a few months later, he would expel another of Gale's advisees for swearing at his housemother. Since the farm was outside the city limits, the county sheriff was called in.[48]

Noyce's previous exploits—tipping outhouses, lighting illegal fireworks—had been dismissed as boys-will-be-boys tomfoolery. Stealing a pig was a different matter entirely. It crossed the line Noyce had skirted throughout his high school years, for as the letter the dean sent home to Ralph and Harriet Noyce explained, "In the agricultural state of Iowa, stealing a domestic animal is a felony which carries a minimum penalty of a year in prison and a fine of one thousand dollars." A prize pig could easily sell for $1,000, nearly three times Noyce's annual college tuition.[49]

Grant Gale and Grinnell College president Stevens were in a frenzy. Even without a criminal conviction, expulsion alone would have meant the end of the boys' education. In 1948 no school would have accepted a student expelled from another, and Gale in particular could not bear the prospect of "losing Bob." The two college representatives, both longtime residents of Grinnell and friends of the Noyces, brokered a compromise in which the college would compensate the farmer for his pig, and no charges would be pressed. The boys would be allowed to finish the few remaining days of their junior year but were suspended for the first semester of their senior year—exiled not only from the college, but from the town of Grinnell as well.

After his sentence was handed down, Noyce fled. He hitchhiked to Sandwich, Illinois, where his parents and youngest brother had moved after Reverend Noyce had been asked to leave his job at the Congregational Conference. Bob Noyce returned to his parents a chastened soul, con-

vinced he had brought disgrace on himself and his family. It must have come as a relief to discover that Harriet and Ralph Noyce were angrier at the farmer than at him. Reverend Noyce decried those "who are more concerned with hogs than they are with the problems of adolescence and youth's efforts to find it[s] place in this terribly uncertain world that we adults are presenting to them." He wrote an angry letter to the dean of men that pointedly concluded: "the rest of us will have to be the more ready to accept youth's offer of repentance and desire for forgiveness even if Iowa hog farmers do not see it that way." Bob urged his father not to mail the letter, which he thought criticized college's handling of his case, but his father sent it anyway.[50]

NOYCE DECIDED to spend his semester's expulsion working as a clerk in the actuarial department of the Equitable Life Insurance Company in Manhattan, where his math professor helped him secure a position. Noyce could imagine himself as an actuary after college: the days immersed in numbers and the paycheck steady and generous enough to permit some fun in the evenings. To become an actuary, however, he would need to pass the five-part actuarial exam before he returned to Grinnell and his frantic pace of life there. The exam was notoriously difficult and assumed several graduate-level math courses that Noyce had not taken. He nonetheless signed up to take the exam.

As soon as Noyce left for Manhattan, his mother, whose inchoate fears about Bob had been confirmed by the pig heist, began worrying about him with fresh vigor. She criticized his choice of roommate (whom she knew vaguely and thought drank too much), reminded him to visit his brother Don, who was completing a PhD in chemistry at Columbia, and carefully scrutinized his every letter for any mention of church, which he appeared to have attended with some regularity for several weeks as he was settling in.

Noyce reported to work in a ten-dollar suit he had bought from a friend and spent hours at his desk, one of scores of young men with a penchant for numbers and a need for cash. "I have been working on settlement option mortality," he wrote his parents. "From the looks of things, the annuitant table which is being used is now quite outdated. . . ." He soon found the work unceasingly, unbearably dull, the tedium relieved only by the fact that female clerks outnumbered male by a ratio of ten to one. Noyce lived for the nights and weekends, when he spent nearly every cent he earned on plays, films, museum exhibits, and evenings with young women he met at the office. He befriended flat-broke producers, playwrights, and artists—the kind of folks that people in Grinnell might have called unsavory. He was busy but not particularly happy, suffering, he said, from "the loneliness which often overtakes you here in the middle of the largest city on earth."[51]

The suspension gave Noyce time to think about his future. He had taken sufficient extra credits in his first three years that he could return to Grinnell and graduate with his class in the spring of 1949. Noyce tried to join the air force, but when he learned he could not serve as a fighter pilot because he was color blind, he swore to avoid military service all together. He then considered that if he passed the actuarial exam—his math professor had suggested a few textbooks to read in preparation—he might try to find a job in California, where he had always wanted to live. Grant Gale wrote to suggest he apply to the doctoral program in physics at MIT. Noyce did.

When he returned to Grinnell in February 1949, Noyce immediately resumed the back-to-back schedule of working, diving, studying, singing, acting, and dating that had filled his earlier college days. A few weeks into the semester, he received a letter notifying him that he had passed the actuarial exam. His family's relief was almost palpable. "Congratulations high dive brain child!" read a Western Union telegram from a family friend. "Make no small plans." The Equitable offered him a permanent job at more than $80 per week, a sum tempting enough that Noyce thought it might overcome his dislike of actuarial work.[52]

Meanwhile, in his physics class, Grant Gale had begun talking about a device so unusual and potentially revolutionary that Gale's description of it struck Noyce "like an atom bomb." Noyce later explained, "I couldn't grasp how it worked—or why it worked—immediately, but that it worked . . ." His voice trailed off.[53]

It was called a transistor. A mere half-inch long, it could amplify electrical signals, a feat that had previously been accomplished only by much larger, and very fragile, vacuum tubes. These vacuum tubes were everywhere in postwar America, amplifying small currents to pull in radio and television stations, transmit telephone signals, operate hearing aids, and vibrate the cones of loudspeakers to produce sound. Vacuum tubes also enabled Noyce to control his model airplanes.[54]

The transistor promised to accomplish the same tasks—but with one essential difference. It amplified signals through a solid crystal of germanium, not through a vacuum. For years, scientists had theorized that it would be possible to amplify current through solids, thereby avoiding the high power consumption and heat generated by vacuum tubes. But no one had been able to do it until the transistor. "It was really a rather astonishing revelation that could get amplification without a vacuum," Noyce recalled. He decided the transistor was "a phenomenally new and wonderful thing, [a glimpse] as to what might happen in electronics in the future."[55]

The transistor was invented at Bell Labs, in Murray Hill, New Jersey, in 1947. Bell Labs was the research arm of AT&T and the nation's premier electronics research laboratory. Its scientists, several of whom would

go on to win the Nobel Prize, were probably the best electronics researchers in the world.

Bell Labs was normally a somewhat staid place, but when the transistor's inventors Walter Brattain and John Bardeen first demonstrated their device to the lab's senior management at the end of 1947, the researchers were almost giddy. One history of the event explains, "They hooked up a microphone to one end of their invention and a loudspeaker to the other. One by one, the men picked up the microphone and whispered 'hello'; the loudspeaker at the other end of the circuit shouted 'HELLO!'" William Shockley, a physicist who supervised Brattain and Bardeen and whom Bell Labs quickly named a co-inventor of the transistor, later used the occasion to recall another auspicious moment in Bell Labs history: "Hearing speech amplified by the transistor," he said, "was in the tradition of Alexander Graham Bell's famous, 'Mr. Watson, come here, I want you.'"[56]

Six months after this dramatic demonstration, Bell Labs announced the transistor's invention not in the pages of a technical journal, but at a press conference in downtown Manhattan, not far from where Noyce was then calculating annuities at the Equitable.

Noyce, however, did not learn about the transistor's invention while he was in New York. With automatic transmissions, frozen foods, the electric clothes dryer, and the Polaroid camera just coming on the market, Americans had little interest in the esoteric transistor, which had no obvious consumer application. In most American homes, vacuum-tube-powered radios encased in wooden cabinets occupied places of honor. The *New York Times*, the only paper in which Noyce might have read of the transistor's invention, buried the story on page 46, allotting it four paragraphs at the end of a "News of the Radio" column headlined with the promise, "New Shows on CBS Will Replace 'Radio Theatre' During the Summer."[57]

Military researchers, who had witnessed a demonstration of the device a week before the public press conference, had a very different reaction. A military press release declared that the device "could take a great load off the ground soldier's back." The statement was literal. Historians estimate that the heavy batteries used to power the vacuum tubes in standard-issue "walkie-talkie" radio telephone sets accounted for almost 40 percent of a set's weight. After considering and rejecting a plan to classify the transistor, representatives from the armed services were the first to request samples from Bell Labs.[58]

Among those next requesting "a couple of transistors" was Grant Gale, who had read and understood the significance of the short *Times* story, which he immediately posted on the bulletin board outside the physics classroom at Grinnell. Gale felt almost personally connected to the transistor. One of the inventors, John Bardeen, had attended the University of

Wisconsin with Gale and grown up with Gale's wife. The head of research at Bell Labs, Oliver Buckley, was a Grinnell graduate and the father of two current students. Buckley regularly sent Gale castoff equipment and spare copies of technical reports from Bell Labs, and it was to him that Gale mailed his request for transistors.[59]

Buckley did not have any devices to spare, but he did send Gale copies of several technical monographs that Bell Labs had written on the transistor. These monographs formed the basis of Noyce's initial exposure to the device. No textbooks addressed transistors, and (although prevailing mythology claims otherwise) Bell Labs did not ship Gale a transistor until after Noyce graduated. Together Gale and Noyce, who was far more interested in the transistor than any other student, pored over the Bell Labs monographs: "The Transistor and Related Experiments," "Positive Holes and the Transistor," "Physical Principles Involved in Transistor Action," "Some Contributions to Transistor Electronics."[60]

Through these monographs, Noyce learned that the secret to the transistor lay in the unusual properties of elements called semiconductors. The conductivity of semiconductors falls in between that of metals (which conduct electricity freely) and insulators (which do not conduct electricity at all). Moreover, a semiconductor's conductivity can be changed. Apply a certain stimulus to a semiconductor—light, voltage, or temperature—and it becomes a conductor. Change the stimulus, and the semiconductor can be made into an insulator. In electrical terms, it is equivalent to turning copper into glass instantaneously.[61]

Semiconductors can be doped or modified to come in two varieties. N-type semiconductors have an electron (negative charge) that is only loosely bound to its atom and is thus free to move around, thereby conducting electricity. P-type semiconductors have the positive virtual-equivalent of the electron, called a hole, that is only loosely bound to its atom and thus free to move around. If P- and N-type semiconductors make contact—at a point called a junction—something remarkable happens: a few electrons flow from the N-type area, across the junction, and into the P-type area. A voltage applied to the junction will accelerate the trickle of electrons into a rush. But reverse the voltage and essentially no electrons at all can flow across the junction. Bell Labs hoped to use these properties of semiconductors to create a device that would serve as an electrical switch.

At Bell Labs, Walter Brattain and John Bardeen built their transistor from a strip of an N-type semiconductor called germanium. They suspended a plastic triangle, point-down, above the germanium strip. A thin gold contact ran down each side of the triangle, with less than two-thousandths of an inch between the contacts at the point. The scientists carefully positioned the triangle so that the gold contacts just touched the surface of the germanium. Then they introduced a tiny current into the germanium via a thin

wire. If they "wriggled [the wire] just right," the device could amplify current 100-fold.[62]

It is impressive that Noyce, at 21, was able to understand the Bell Labs transistor monographs describing these events. The reports had been written by PhD scientists for senior electronics researchers, not for undergraduates. Yet Gale insists that when it came to transistors, "it would be a gross overstatement to suggest that I taught Bob much. . . . We learned about them together."[63]

The information that Noyce absorbed about the transistor in his last months at Grinnell inspired him. When he was accepted at MIT with a partial scholarship, he told Gale that he hoped to focus his studies on the movement of electrons through solids. [64]

Noyce graduated from Grinnell College with a double major in math and physics and a Phi Beta Kappa key. He also received a signal honor from his classmates: the Brown Derby Prize, which recognized "the senior man who earned the best grades with the least amount of work"—or as Noyce preferred to explain to his parents, the recipient was the "man who gets the best returns on the time spent studying."[65]

2

Rapid Robert

The decision to attend MIT was an enormous gamble for Noyce. He could not afford it. The $400-per-semester scholarship he received from the Physics Department was enough to cover tuition, but provided nothing toward the remaining $735 the university estimated would be needed for books and room and board. Noyce's parents were unable to be of much assistance, and Bob did not want to ask his maternal grandmother, who had loaned him money in college, for more. He needed to earn as much as he could in the summer before leaving for graduate school. This meant living with his parents in Sandwich and working long, sweaty days at a construction site, where he was badly burned on his back and hands after carrying wood that had been treated with the volatile preservative creosote. Even before this injury, Noyce had always hated this sort of labor. Most of his high school and college classmates worked every summer baling hay or detasseling corn, but Noyce and a close friend had spent the summers after their first and second years of college tending bar and waiting tables at the Century Country Club north of New York City. There Noyce had been shocked and more than a little impressed to learn that his customers regularly paid $25 for a dinner and $2,000 to rent a tiny home on the water.[1]

The contrast between those country club summers and the blazing toil of the summer of 1949 left Noyce cursing a world in which a Phi Beta Kappa physics major could earn more with his muscles than with his mind. It also led him to a decision. He would not do this again. He would so impress the Physics Department powers-that-be that within a year they would give him the graduate-school equivalent of a free ride: a research fellowship that not only covered tuition but also paid $122.50 every month.[2]

When Noyce parked his beat-up Ford in Cambridge in September 1949, he encountered a world dramatically different from Grinnell College. Where Grinnell had been a self-contained red-brick universe safely tucked in the middle of cornfields, in the middle of a state, in the middle of the country,

MIT was an urban campus—three miles from downtown Boston, a short train ride to New York—run by men eager to extend its reach beyond the traditional limits of the academy. MIT professors helped develop the radar technology that saved American planes, and they helped build the atomic bomb that devastated Japan. MIT faculty served on presidential commissions and in the boardrooms of the nation's most powerful corporations.

The "military-industrial complex" would not be named until a dozen years after Noyce entered graduate school, but it was well under construction at MIT in the fall of 1949. During the Second World War, MIT received $117 million in federal research contracts from the Office of Scientific Research and Development—by far the most money awarded to any American university during the war. A few weeks after Noyce started classes, the Soviets exploded their first atomic bomb, and the monumental threat this implied would help ensure a steady flow of federal defense dollars to MIT researchers throughout the Cold War.

The MIT physics building sat near the middle of campus. In its basement were multiple subterranean corridors, some of which branched off into dimly lit classrooms, all part of the vast network of tunnels that linked MIT buildings to each other. This underground universe was a place apart, filled with miles of exposed overhead pipes, thousands of tools to build all sorts of scientific equipment, giant machines that occupied entire rooms, and clusters of young men working together over tables covered with instruments. This part of the Physics Department, in other words, resembled the world's greatest basement workshop—and what, Noyce might have asked himself, could be better than that?[3]

The Physics Department had undergone dramatic changes during the past two decades. Before 1930, the department had focused on teaching physics to engineers. Then in 1930, MIT's president Karl Compton recruited a young professor named John Clarke Slater to build a research program in physics that would rival any in the world. Slater was an impressive man: a leading proponent of quantum theory, a top student of a Nobel Prize winner, a pioneer in the electromagnetic theory behind radar, and a prolific author who churned out dozens of articles while also writing a textbook or other weighty tome roughly every three years. (Such accomplishments led to his election to the National Academy of Sciences at the age of 31.) His youthful, almost prissy, appearance—his face full-cheeked, his brown hair thick and parted carefully at the side—led more than one person to mistake him for an undergraduate, but no one made that mistake more than once. Slater had a glare that could petrify and an overall presence that one student called "remote and austere, with all the warmth of an emotional iceberg."[4]

Armed with a generous grant from the MIT president, Slater spent the decades of the 1930s and 1940s tightening graduation standards, raising

faculty salaries, and loosening departmental controls over faculty research. The wartime combination of increased federal funds and a pool of top-notch European physicists eager to emigrate worked to Slater's advantage. By the time Noyce came to campus, some of the best-known physicists in the world—nuclear physicists Herman Feshbach and Victor Weisskopf, microwave physicist Nathaniel Frank, acoustics and operations research pioneer Philip Morse—were members of the faculty. The department was also home to the most famous graduate student in America, Murray Gell-Mann, who had arrived a year before Noyce. A prodigy who taught himself calculus at age seven and began studying physics at Yale just a few weeks shy of his fifteenth birthday, Gell-Mann would emerge with his PhD in quantum theory after only two years in the program. He was one of two students in graduate school with Noyce who would one day win the Nobel Prize for Physics.

It was an intimidating place by any standard, and presumably even more so for a student from a two-man Physics Department led by someone who did not even have a PhD. "I had come from a protected home and sort of sailed through college, never worrying too much about getting the work done," recalled one of the few students in Noyce's cohort who arrived with a similar background. "Then I got to MIT and bam! I was with the best of the bunch, 800 miles from home.... It was incredibly difficult." Grant Gale certainly worried whether he had adequately prepared Noyce for the academic rigors of the nation's premier scientific university. He wrote to the head of the department, asking for periodic updates on MIT's "reaction to Mr. Noyce and to the training which he has had."[5]

If Noyce, who soon learned that most of his classmates came to MIT with teaching fellowships in hand, had begun to wonder whether he belonged in Cambridge, his first months on campus could not have helped matters. Most students lived in the Graduate House at the corner of Massachusetts Avenue and the Charles River—a five-minute walk from the physics building and the center of graduate student social life—but the monthly $78 room-and-board fee was too dear for Noyce, who instead shared an apartment in a slightly seedy part of Cambridge with a friend from his semester as an actuary. A month into the school year, Noyce took the first set of required exams, which were designed to assess a student's knowledge of physics and determine in which subjects, if any, he needed to do remedial coursework. He did so badly on the first test that he refused to tell his parents his grade and even asked his current girlfriend to stay away for the weekend, presumably because he needed to study.[6]

At the end of the exam period, Philip Morse, who oversaw registration in the department, marked Noyce's background "deficient" in several areas and required him to take the two-semester undergraduate introduction to theoretical physics as well as advanced undergraduate courses in elec-